Water Quality of North Carolina Streams

United States
Geological
Survey
Water-Supply
Paper 2185–F

Prepared in cooperation
with the North Carolina
Department of Natural
Resources and
Community Development

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Water Quality of North Carolina Streams—Water-Quality Characteristics for Selected Sites on the Cape Fear River, North Carolina, 1955–80—Variability, Loads, and Trends of Selected Constituents

By J. KENT CRAWFORD

Prepared in cooperation
with the North Carolina
Department of Natural
Resources and
Community Development

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2185–F

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE: 1985

For sale by the Distribution Branch, U.S. Geological Survey,
604 South Pickett Street, Alexandria, VA 22304

Library of Congress Cataloging in Publication Data
(Revised for volume F)
Main entry under title:

Water quality of North Carolina streams.

(Geological Survey water-supply paper ; 2185 A,)
Vol. E. by Douglas Harned and Dann Meyer.
Vol. F. by J. Kent Crawford.
Includes bibliographies.
Supt. of Docs. no.: I 19.4/2:764
1. Water quality--North Carolina--Addresses, essays, lectures. 2. Water--Pollution--North Carolina--Addresses, essays, lectures. 3. Rivers--North Carolina--Addresses, essays, lectures. I. Harned, Douglas. II. Meyer, Dann. III. Crawford, J. Kent. IV. Title: North Carolina. Dept. of Natural and Economic Resources. V. Series.(Revised for volume F)
TC801.U2 no. 2185,etc. 363.7'3942'09756 81-607988
[TD224.N8]

PREFACE

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

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

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

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

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

CONTENTS

FIGURES

TABLES

Water Quality of North Carolina Streams--Water-Quality Characteristics for Selected Sites on the Cape Fear River, North Carolina, 1955-80--Variability, Loads, and Trends of Selected Constituents

By J. Kent Crawford

Abstract

Water-quality data for selected sites in the Cape Fear River basin collected by the U.S. Geological Survey, the North Carolina Department of Natural Resources and Community Development, and the University of North Carolina at Chapel Hill are analyzed and interpreted in this report. Emphasis is given to the Cape Fear River at Lock 1 near Kelly, where data are most complete. Other data included in the report were collected from the Cape Fear River at Lillington, the Haw River near the Jordan Dam, and the Deep River at Moncure.

Available data indicate that concentrations of dissolved oxygen at study sites are almost always within U.S. Environmental Protection Agency criteria; however, on two sampling dates, the concentration of dissolved oxygen in the Cape Fear at Lock 1 fell slightly below the 5.0 mg/L recommended for fish populations. Measurements of pH from all stations were frequently below the lower limit of 6.5 pH units recommended for protection of freshwater aquatic life.

Major dissolved ions detected are sodium and bicarbonate. Sodium concentration averages 8.6 mg/L and bicarbonate averages 17.5 mg/L at Lock 1. Concentrations of dissolved substances and suspended sediment decrease in the downstream direction, presumably because the more heavily populated part of the basin is near the headwaters of the system.

Heavy metals, with the exception of mercury, rarely exceed Environmental Protection Agency criteria for the protection of aquatic life. Concentrations of mercury in the Haw River exceeding the recommended 0.20 µg/L needed to protect aquatic life have frequently been reported by other authors. Several of the most toxic metals, arsenic, cadmium, and cobalt, are about five times more concentrated in water from the Haw River site than from other study sites in the basin. Iron and manganese frequently exceed North Carolina water-quality standards.

Available nitrogen averages 1.21 mg/L and available phosphorus averages 0.21 mg/L at Lock 1. Nuisance algal growths have not been identified as a problem in the river.

Comparisons of water-quality data for baseline (natural) and present conditions indicate that more than 50 percent of most dissolved substances and over 80 percent of certain forms of nitrogen and phosphorus result from development.

Over the past 25 years, increases in concentrations of specific conductance, dissolved magnesium, dissolved sodium, dissolved potassium, dissolved sulfate, dissolved solids, and total nitrite plus nitrate nitrogen were detected in the Cape Fear River at Lock 1. Values for pH and dissolved silica are decreasing. Concentrations of most dissolved constituents at Lock 1 are increasing. These increases are statistically related to increases in population and manufacturing employment in the basin but are unrelated to agricultural activity.

INTRODUCTION

Water quality is a critical factor in the well-being of any area. Health, recreation, and aesthetic appeal depend on good water quality. Industry, municipalities, and individuals require it.

To characterize the water quality of North Carolina streams, the North Carolina Department of Natural Resources and Community Development (NRCD) and the U.S. Geological Survey have undertaken a joint statewide water-quality monitoring study. The U.S. Geological Survey evaluates water-quality conditions at key locations, and the NRCD identifies and monitors specific sources of pollution. Details and objectives of the entire program are outlined in U.S. Geological Survey Circular 764, "Program for Evaluating Stream Quality in North Carolina" (Wilder and Simmons, 1978).

This report characterizes the water quality of the Cape Fear River and represents a portion of the U.S. Geological Survey's responsibility to the overall program. Other interpretive reports published as part of the program address water quality in the French Broad River (Daniel, Wilder and Weiner, 1979), in forested and rural streams of North Carolina (Simmons and Heath, 1979), in the Neuse River (Harned, 1982), and in the Yadkin-Pee Dee River System (Harned and Meyer, 1983).

Purpose and Scope

The purpose of this report is to describe water-quality characteristics of the part of the Cape Fear River basin upstream from Lock 1 near Kelly (fig. 1). Existing conditions, natural and development-induced loads, and long-term trends of selected chemical constituents are evaluated.

Basin characteristics that affect water quality, including climate, topography, geology, population, and streamflow, are presented as background. Descriptions of existing water-quality conditions are based on an evaluation of concentrations of the major dissolved ions, including calcium, sodium, potassium, magnesium, chloride, sulfate, silicate, bicarbonate, and fluoride. Dissolved solids and specific conductance are also examined, as are concentrations of arsenic, cadmium, cobalt, copper, iron, lead, manganese, mercury, selenium, and zinc. Nutrients and biological data are also described. Mean concentrations, high and low measured values, and contraventions of water-quality criteria are used in the evaluation. Loads are calculated for each of the major dissolved substances, and the impact of development in the basin on loads is assessed. Predevelopment loads are estimated from existing water quality in undeveloped areas. Trends in concentrations of the major dissolved substances are assessed. The trend analyses include data from a 25-year record and employ residual analysis to remove the effects of discharge prior to testing for trends.

Because data for the Cape Fear River are limited, the scope of this report is limited. Only one station, the Cape Fear River at Lock 1 near Kelly, has enough data available to allow a determination of water-quality trends or to calculate the influence of basin development on loads. With sparse data, conclusions are limited to the specific location where the data were collected, and generalizations of water quality throughout the basin are impossible.

Previous Investigations

A number of reports on the Cape Fear River have been published. Reports pertinent to this study can be grouped into water-quality reports of statewide scope, regional water-quality reports, water-supply reports, and planning reports.

The North Carolina Water Quality Inventory (North Carolina Department of Natural and Economic Resources, 1976; North Carolina Department of Natural Resources and Community Development, 1977a, 1978, 1980a) is a report of statewide scope required annually by Section 305(b) of the Federal Water Pollution Control Act Amendments of 1972 (U.S. Congress, 1973). The Clean Water Act of 1977 (U.S. Congress, 1978) changed the 1972 law to require the inventory biannually. The report summarizes the "pollution abatement program achievements, activities, and objectives, and the existing and anticipated quality of waters of the State." Point discharges and the monitoring results from these point sources are the primary concern of the inventories. So far, four inventories have been published, covering 1975, 1976, 1977, and 1978-79.

The U.S. Geological Survey publishes statewide water-quality data annually in "Water Resources Data for North Carolina." Data for the period 1943-67 are summarized by Wilder and Slack (1971) in "Summary of Data on Chemical Quality of Streams of North Carolina, 1943-67."

Reports of a more limited geographical scope include several publications from the Water Resources Research Institute of the University of North Carolina. Three reports specifically address water quality in the New Hope and lower Haw Rivers. The New Hope River is a tributary to the Haw River which, in turn, joins the Deep River to form the Cape Fear River (fig. 1). These three documents (Weiss, 1971, 1974; Weiss and others, 1972) present a picture of water quality in the Durham-Chapel Hill-Pittsboro-Saxapahaw area (fig. 1) for the late 1960's and early 1970's. Another study of the Haw and New Hope Rivers, that of Shuman and others (1977), presents an analysis of existing concentrations of metal in the water, sediments, and macroinvertebrates in these streams. Another study of metals in water, by Pfaender and others (1977), included samples from a wider geographic area, covering the length of the Cape Fear and Haw Rivers. Weiss (1970) also examined waters of the Haw and New Hope Rivers to determine the relative importance of nitrogen and phophorus as algal nutrients.

Extensive studies have been conducted relating to three major projects in the Cape Fear River basin, the nuclear-fueled Brunswick Steam Electric Plant, the Shearon Harris Nuclear Power Plant, and the B. Everett Jordan Dam and Reservoir (fig. 1). The Brunswick plant, a Carolina Power and Light Company facility located near the mouth of the Cape Fear River, is downstream of the study area. Studies accompanying the construction of the plant include chemical, hydrological, and biological assessments of waters near the plant site

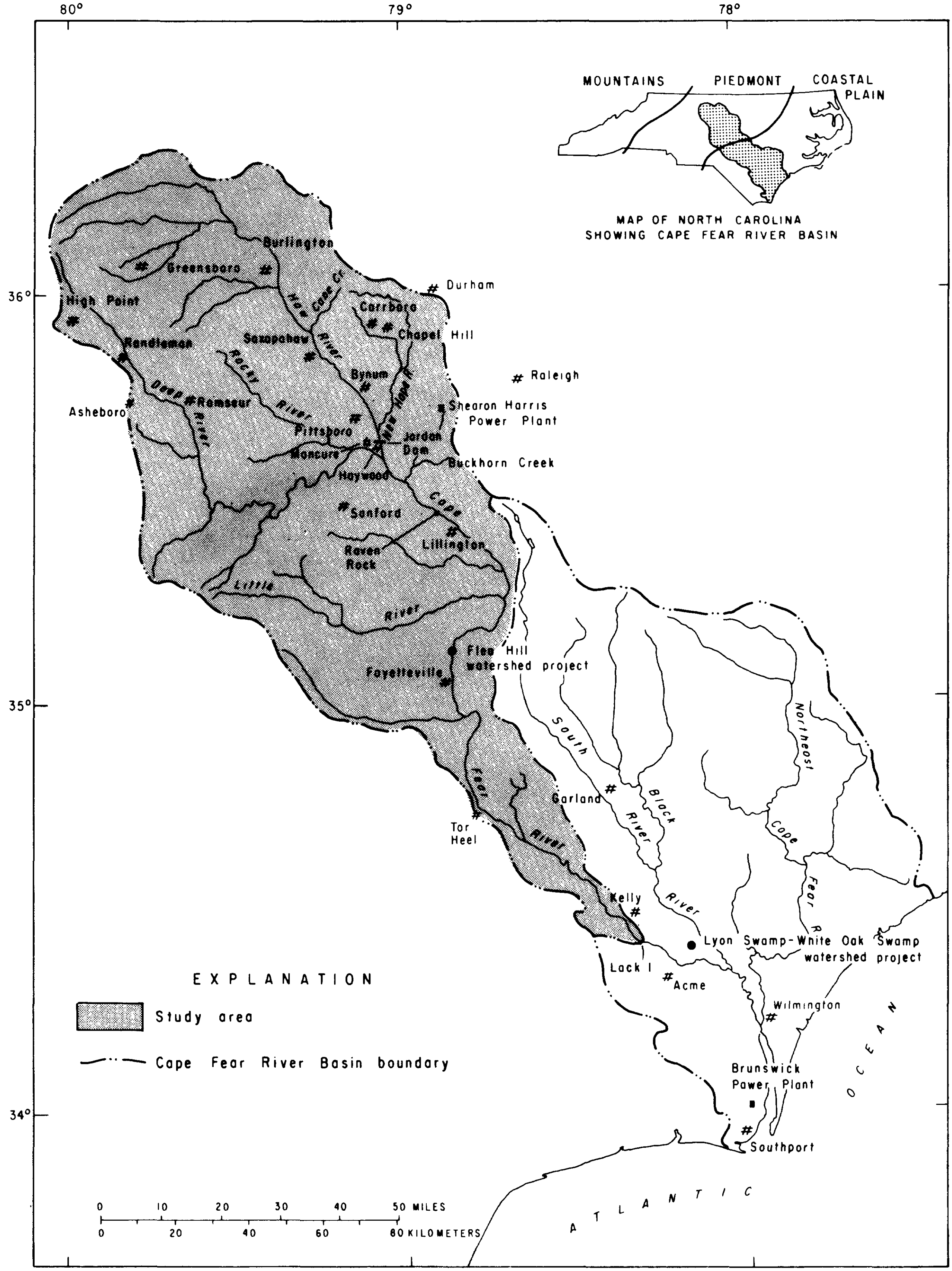

Figure 1. Geographic features of the Cape Fear River Basin.

(Carolina Power and Light Company, no date; U.S. Atomic Energy Commission, 1974a).

The Shearon Harris plant, a nuclear facility of the Carolina Power and Light Company, is presently under construction in the Buckhorn Creek watershed in southeastern Wake County (fig. 1). Descriptions of water quality in the project area have been prepared (Anderson and others, 1978; Cullen, Hobbs, and Sager, 1978; Cullen, Hobbs, Sager, and Panek, 1978). In addition, the Atomic Energy Commission prepared an environmental impact statement for the Harris plant (U.S. Atomic Energy Commission, 1974b). An environmental report prepared by Carolina Power and Light Company (1980) contains water-quality data, hydrologic information, and an assessment of the aquatic ecology of the area to be affected by the powerplant and its cooling lake.

The B. Everett Jordan Dam and Reservoir is a multipurpose project on the Haw River for flood control, water supply, recreation, water-quality control, and fish and wildlife enhancement. An environmental impact statement by the U.S. Army Corps of Engineers (1971a, 1971b, 1975) includes an exhaustive examination of the potential for eutrophication in the lake.

Another special study was conducted by Aquatic Control (1973) to determine baseline biological conditions and other background information on the South River in the vicinity of Garland, N.C., for possible development of a nuclear powerplant and accompanying reservoir (fig. 1).

Two statewide water-supply studies have included comprehensive treatment of the Cape Fear River basin. A five-volume compilation of data on water use, sources of water, water quality, water treatment, capacity, and problems of 224 public water-supply systems was prepared by the U.S. Geological Survey (Jackson, 1972, 1973, 1974; Robison, 1977; Robison and Mann, 1977). Parts 1, 2, and 5 include data from the Cape Fear River basin. The entire series was summarized by Mann (1978).

Another statewide water-supply survey (Boney-Wiggins-Rimer & Associates, 1977) contains 13 volumes of data and an executive summary on the type of system and the quality of water delivered for 494 water-supply systems in the State.

The North Carolina Department of Natural Resources and Community Development (1977b) examined the various potential water-supply sources in the upper part of the Cape Fear River basin. The study focuses on the Greensboro, N.C., area and includes Guilford, Rockingham, and Randolph Counties. The report examines population projections, development of new sources, and nontraditional alternatives for water supply in the three-county area.

Flow data for streams in the State compiled by Goddard (1963) include information on streamflow variation, flow duration, low-flow frequency, drainage area, discharge per unit area, and other water-supply characteristics.

Several significant planning documents have been published which address water-quality concerns of the Cape Fear River basin. The North Carolina Department of Natural and Economic Resources (1975) produced a four-volume water-quality management plan for the Cape Fear River basin. The plan, mandated by the Water Pollution Control Act Amendments of 1972 (Public Law 92-500), is intended to develop and monitor a pollution abatement program for the basin. The four-volume report presents existing conditions and programs for pollution control.

In 1977, the North Carolina Water Resources Framework Study (North Carolina Department of Natural and Economic Resources, 1977) was published. This document addresses existing conditions and presents plans of action for a variety of water-related concerns, including water supply, electric power, water quality, flood management, sedimentation, wildlife resources, and recreation.

The Triangle J Council of Governments has been delegated water-planning responsibility for the northeast part of the Cape Fear River basin. Several documents relating to water quality have been released by the Triangle J Council of Governments, all part of the 208 planning function of the agency as authorized by the Water Pollution Control Act Amendments of 1972 (U.S. Congress, 1973). These include a Pollution Source Analysis (1976a), a Pollution Source Analysis Summary (1976b), an Inventory of Existing Resources (1976c), and a Water Quality Management Plan (1977).

Acknowledgments

This report was prepared in cooperation with the North Carolina NRCD. Additional data were provided by the Department of Environmental Sciences and Engineering at the University of North Carolina at Chapel Hill. Others from the U.S. Army Corps of Engineers, the North Carolina Department of Human Resources, and other U.S. Geological Survey offices also assisted in various aspects of the study. However, most significant of

all were the contributions of my colleagues in the North Carolina District of the U.S. Geological Survey.

BASIN DESCRIPTION

The Cape Fear River and its tributaries drain 9,010 mi^2 of the Piedmont and Coastal Plain provinces of North Carolina. Headwaters of the Cape Fear River originate in the northern Piedmont, and drainage is generally to the south and east. The basin lies entirely within North Carolina and is the largest of all the river basins in the State (fig. 1). It includes part or all of 29 counties. The Cape Fear River itself is formed by the confluence of the Haw and Deep Rivers near Moncure. The river then flows southeastward to Wilmington and then south to the Atlantic Ocean at Southport, about 200 linear miles from its origin and some 300 stream miles downstream from the headwaters of the basin.

Major tributaries to the Cape Fear River are the Haw River and its tributary, the New Hope River, the Deep River and its tributary, the Rocky River, the Black River and its tributary, the South River, and the Northeast Cape Fear River. Table 1 shows drainage areas and average discharge of the major tributaries and the percentage of the total basin area and discharge contributed by each. Table 1 also gives data for the Cape Fear River at Lock 1 near Kelly, since that point in the basin is the focus of much of this report.

Table 1. Drainage areas and average annual discharge for selected sites on the Cape Fear River and major tributaries

River	Drainage area		Average annual discharge	
	mi^2	Percent of total basin area	ft^3/s	Percent of total basin discharge
Cape Fear River at mouth	9,010	100	[1]10,354	100
Northeast Cape Fear River at mouth	1,645	18	[1]2,034	20
Black River at mouth	1,534	17	[1]1,836	18
South River at mouth	498	6	[1]567	5
Cape Fear River at Lock 1 near Kelly	5,255	58	[2]5740	55
Little River at mouth	479	5	[1]584	6
Deep River at mouth	1,436	16	[1]1,460	14
Rocky River at mouth	248	3	[3]252	2
Haw River at mouth	1,666	18	[1]1,558	15
New Hope River at mouth	345	4	[1]338	3

[1] Estimated from the ratio of drainage area to discharge at gaged stations.

[2] Measured value.

[3] Estimated from discharge per unit area data.

Climate

The Cape Fear River basin is characterized by hot, humid summers, mild winters, and long growing seasons. Generally, temperatures are warmest in the southeastern part of the basin and coolest in the northwestern part. However, the moderating influence of the Atlantic Ocean affects this pattern and keeps summer maximum temperatures down in the near-coastal regions.

Mean maximum July temperatures range from approximately 29°C to 33°C. In January, mean minimum temperatures fall within a range from about -1°C to 4.5°C. The freeze-free season lasts for about 200 days in the northwestern part of the basin and for more than 270 days in the southeastern part (Kopec and Clay, 1975).

Precipitation in the basin is greatest in coastal areas, averaging around 55 inches per year. Inland areas receive an average of about 50 inches per year. Rainfall is highest in summer and winter months and lowest in the fall. Snowfall averages less than 10 inches per year throughout the basin (Kopec and Clay, 1975).

Hurricanes occasionally hit the North Carolina coast and can radically affect the hydrology of the Cape Fear River. The sporadic nature of hurricanes thwarts attempts to characterize them, but since 1900 "North Carolina has experienced 12 especially disastrous hurricanes" (Kopec and Clay, 1975).

Topography

The Cape Fear River basin is divided into upper (Piedmont) and lower (Coastal Plain) basins at Raven Rock, about 7 miles upstream from Lillington (fig. 1). The upper basin has gently rolling hills with local relief. Maximum land-surface elevations in the upper basin are slightly more than 1,000 feet above sea level. The hilly topography imparts moderate slopes and velocities to streams. Typical slopes for streams in the upper basin range from about 5 to 20 feet per mile. Maximum land-surface elevations in the lower basin are less than 500 feet. Typical slopes for streams in the lower basin are less than 5 feet per mile.

Geology

North Carolina's Coastal Plain is the youngest geologic area of the State. The underlying rocks are of sedimentary origin deposited during the Cenozoic and Mesozoic Eras. These materials include surficial sands and clays, marine deposits of shell beds and marls, limestones, sandstones, shale, and conglomerates. Parent material in the Piedmont includes mostly metamorphosed rocks from the late Precambrian to early Paleozoic Eras. This parent material is covered by a layer of weathered saprolite that varies in thickness up to 50 feet. Piedmont rock types include conglomerates, sandstones, siltstones, and shales. Conrad and others (1975) present a more detailed account of the geology of North Carolina.

Geochemical Zones

Surface-water quality, to varying degrees, is dependent on geology. Surface waters are mixtures of ground water, overland runoff, and effluent discharges. The chemical makeup of ground water, in the absence of contamination, is affected by the minerals contained in underground rocks, the solubility of those rocks, and the time that water has been in contact with them. Therefore, geology is one determining factor of surface-water quality.

Simmons and Heath (1979), recognizing the connection between geology and surface water, have divided the State of North Carolina into five geochemical zones. Each geochemical zone has similar ground-water chemistry throughout but different chemistry from the other geochemical zones of the State. Similar rock types generally produce ground water of similar quality, so the geochemical zones of Simmons and Heath correspond closely to geological zones. The geochemical zones of North Carolina and the boundaries of the Cape Fear River drainage basin are outlined in figure 2. All five geochemical zones are represented in the Cape Fear River basin.

In the Cape Fear part of Zone I, rocks are primarily gneiss and schist. These rocks are quite insoluble and, therefore, water draining from them is low in dissolved solids (less than 20 mg/L).

Geochemical Zone II is underlain by metamorphosed volcanic and metamorphosed sedimentary rocks. These rocks are more soluble than the material in Zone I and, consequently, the water in Zone II is more highly mineralized than in Zone I, with typical dissolved solids concentrations ranging from 20 to 60 mg/L.

Zone III corresponds to the Sandhills region of south-central North Carolina. This area is characterized by a very permeable but relatively insoluble quartz sand. Thus, water draining from this zone is low in dissolved minerals, with typical dissolved solids concentrations less than 15 mg/L.

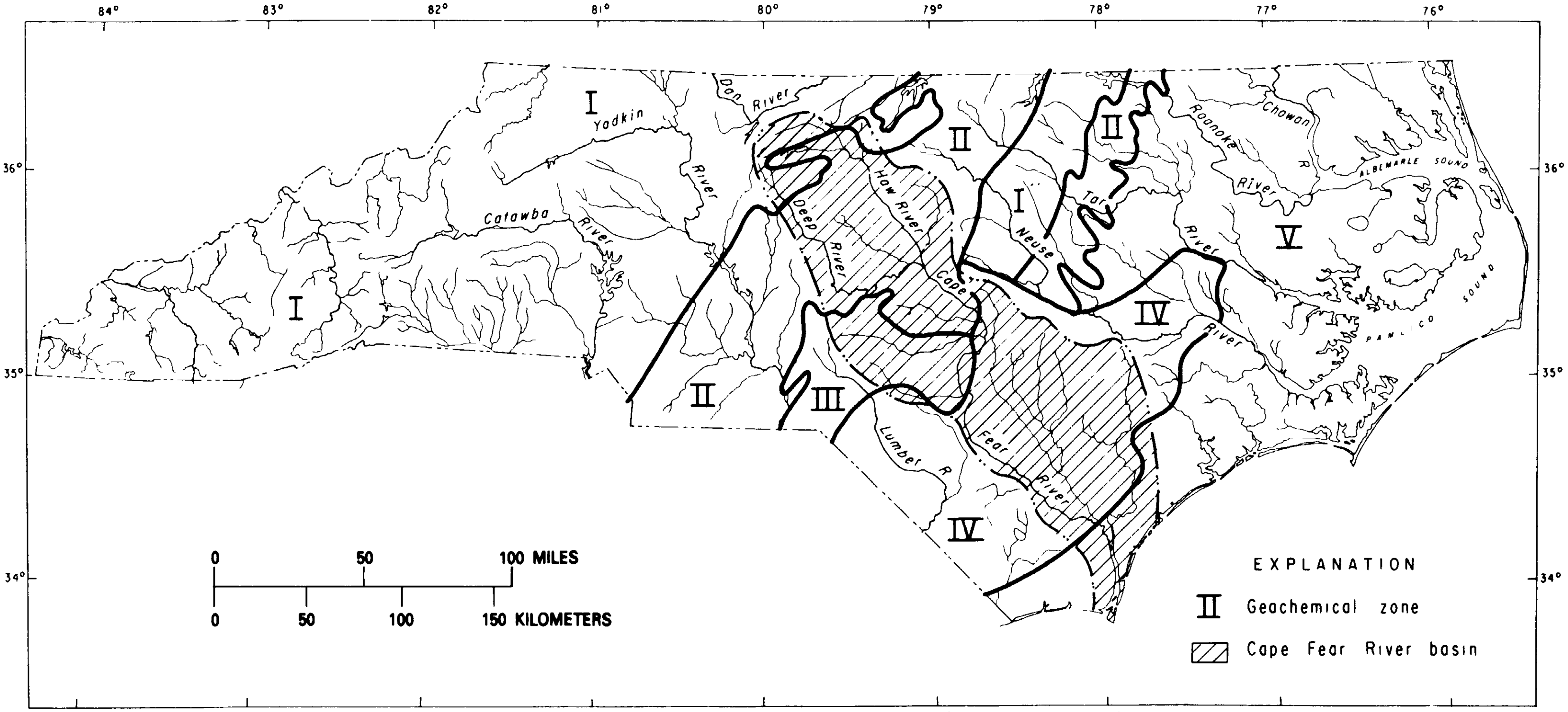

Figure 2. The Cape Fear River basin and geochemical zones of North Carolina (from Simmons and Heath, 1979).

Zone IV contains layers of sand, clay, and marl, underlain by quartz sand. The insoluble nature of the sand makes water draining from this zone low in dissolved minerals. Dissolved solids concentrations in surface waters of Zone IV would be expected to range between 20 and 25 mg/L.

In Zone V, limestone, sand, shell beds, and clays are the predominant geologic materials. The limestone and shell beds are quite soluble, but the sands are not. Thus, ground water from Zone V has variable amounts of dissolved minerals, depending on local geologic conditions. Averaged over the entire zone, the water of Zone V is moderately high in dissolved substances, with dissolved solids concentrations in the neighborhood of 30 mg/L.

In the "Development Impacts" section, quantitative water-quality data for each of the five geochemical zones are presented and those data are used to calculate the effect of human-related activities on the water quality of the Cape Fear River.

Streamflow

Streamflow is important for allocating water use, for maintaining aquatic habitats, and for handling wastes. Effluent standards rely to a large extent on the ability of receiving waters to dilute and purify the effluents. The quality of streamflow also affects water quality. At high flow, a given amount of a pollutant may result in concentrations that are within water- quality guidelines, when the stream returns to low flow and much of the diluting effect is lost, that same amount of a pollutant may produce concentrations that exceed guidelines. For this report, streamflow is a significant factor in assessing water-quality data.

Streamflow varies throughout the year, in response to changes in a number of factors, including precipitation, surface runoff, and the contribution from ground water. Ground-water storage, evaporation, transpiration, and physical characteristics of the watershed such as the porosity of soils, the slope of the terrain, and the amount of storage in reservoirs, swamps, and wetlands all affect contributions from surface runoff and ground water. Seasonal influences are important. In North Carolina, rainfall is usually heaviest during summer and winter months, whereas evapotranspiration is highest during summer months and lowest during winter months. Maximum flows in North Carolina streams usually occur in the winter months. Minimum flows generally occur in the summer and fall months.

Population

In 1970, 1,122,034 people lived in the Cape Fear River basin (North Carolina Department of Water and Air Resources, 1972). This represents 22 percent of the 5,082,059 people of the State at that time. In the 1980 census, Greensboro had a population of 155,642, making it the largest city in the basin. Populations of other cities in the basin are as follows: Fayetteville, 59,507; Wilmington, 44,000; Burlington, 37,266; Chapel Hill, 32,421; and Sanford, 14,773. Three other cities with populations greater than 10,000 lie on the boundary of the basin: Durham, 100,831; High Point, 63,380; and Asheboro, 15,252 (North Carolina Office of the Governor, 1982) (fig. 1). The population of the basin, particularly upstream from the confluence of the Haw and Deep Rivers (fig. 1), is increasing.

Population density averages 122 persons/mi^2 for the entire basin (1970 data). However, population density is much greater in the upper basin than in the lower basin. For example, in Guilford County (upper basin), the population density in 1970 was 442 persons/mi^2 (483 persons/mi^2 in 1980) while in Sampson County (lower basin), the density was only 48 persons/mi^2 (53 persons/mi^2 in 1980). Approximately 80 percent of the population of the basin is included in the study area upstream from the Cape Fear River at Lock 1 near Kelly (fig. 1).

Water Use and Waste Disposal

In the Cape Fear River basin, 85 municipal public water supply systems currently provide more than 120 Mgal/d for almost 1 million people (North Carolina Department of Human Resources, 1980). These figures do not include all public systems. Many others which serve at least 15 service connections or at least 25 individuals are considered public. These would include churches, trailer parks, and other nonmunicipal public categories. Another 25.4 Mgal/d are required by nonpublic domestic water users. In addition, industrial water users are using 97 Mgal/d, livestock use accounts for another 10.6 Mgal/d, and irrigation uses 14.6 Mgal/d (North Carolina Department of Natural and Economic Resources, 1977).

The Cape Fear River receives large amounts of waste effluents. Approximately 262 Mgal of wastes (estimated on the basis of design flow of treatment facilities) are discharged daily into the

Cape Fear River and its tributaries. These wastes come from 387 sources, as identified by the North Carolina Department of Natural Resources and Community Development (1980b). Sixty percent of these wastes by volume, or 156 Mgal/d (241 ft^3/s), enter the river upstream from Lock 1 (fig. 1). The long-term mean discharge for the Cape Fear River at Lock 1 near Kelly is 5,740 ft^3/s. Therefore, for average flow conditions, about 4 percent of the water that passes Lock 1 was at one time effluent water. The 7-day, 10-year minimum low flow at Lock 1 is 390 ft^3/s. Under this flow condition, water releases of 241 ft^3/s amount to 62 percent of the discharge at Lock 1. However, most of the waste effluent released upstream may be assimilated before reaching Lock 1. Because of the guaranteed minimum flow of 600 ft^3/s at Lillington from the operation of Jordan Dam (U.S. Army Corps of Engineers, 1961), extreme low flows at Lock 1 will be rare.

Hydrologic Modifications

Two types of hydrologic modifications, channelization and impoundments, affect the hydrology and water quality of the Cape Fear River.

Channelization

Channel modification projects in the Cape Fear River basin have been carried out by two agencies, the U.S. Soil Conservation Service and the U.S. Army Corps of Engineers. Two Soil Conservation Service watershed projects have been completed, three others have approved applications, and another is authorized for planning. Of the two completed projects, the Flea Hill project in Cumberland County includes 43.9 miles of channels and the Lyon Swamp-White Oak Swamp project in Bladen and Pender Counties includes 37.4 miles of channels (fig. 1). None of these channels is on the main stem of the Cape Fear River (U.S. Soil Conservation Service, 1979).

As the result of channel work by the U.S. Army Corps of Engineers, the Cape Fear River itself is navigable from its mouth at Southport upstream to Fayetteville (fig. 1), a distance of about 145 miles (U.S. Army Corps of Engineers, 1979).

Channelization and the vessels that use the navigation channels directly influence water quality. In the Cape Fear River basin, these influences have not been quantified, but increases in suspended sediment and turbidity are certain to occur, especially during construction. Water velocities and rates of land drainage may be increased by channelization. Sediment-carrying capacity increases with increased rate of flow. Channelization promotes rapid land drainage and reduces surface ponding, resulting in earlier and higher discharge peaks during floods. Alteration of the channel usually results in reduced habitat diversity and impairment of a stream's ability to support abundant aquatic life. Many of the hydrologic effects of channelization are discussed by Daniel (1981). Water-quality changes resulting from channelization in the Black River near Dunn, N.C., have been evaluated by Simmons (1980) and Simmons and Watkins (1982). Both hydrologic and water-quality changes associated with the channelization of Chicod Creek in Pitt County, N.C., are described by Simmons and Aldridge (1980).

Impoundments

The Cape Fear River basin includes 33 natural or manmade lakes of 100 acres or more (Fish, 1968). In addition, two large impoundments have recently been completed in the basin, and three others are in the planning stages. One impoundment, the B. Everett Jordan Dam and Reservoir (fig. 1), is a Corps of Engineers project completed in 1982. This 14,300-acre lake is intended "for flood control, water supply, water-quality control, general recreation, and fish and wildlife enhancement" (U.S. Army Corps of Engineers, 1971a). The dam is on the Haw River about 4 miles (7 km) above the mouth. The lake is more than seven times larger than any previously existing impoundment in the basin.

The second completed impoundment is a 4,000-acre lake that supplies cooling water to the Shearon Harris Nuclear Power Plant. This lake is in the Buckhorn Creek (fig. 1) watershed and is the second largest body of water in the basin. The three proposed impoundments are large water-supply reservoirs, two on the Deep River and one on Cane Creek (fig. 1).

DATA AVAILABLE

Data used for this report were obtained from three sources: the U.S. Geological Survey, NRCD, and the University of North Carolina at Chapel Hill. The principal source was the historical water-quality file of the U.S. Geological Survey. Data from the University of North Carolina were collected by Dr. Charles Weiss and his students in the Department of Environmental Sciences and Engineering as part of a long-term evaluation of water quality in the Haw and New Hope Rivers (Weiss, 1971, 1974; Weiss and others, 1972).

Data from the three sources were combined to form a broader and more consistent data base for evaluating water quality. Using data from three sources, however, increases the risk of introducing error into the analysis and the results because of differences in sampling techniques, laboratory analyses, procedures, equipment, and quality-assurance practices.

Statistical tests indicate that the NRCD and U.S. Geological Survey data are not statistically different for most of the commonly measured constituents (table 2). Data provided by the University of North Carolina could not be compared because sampling periods and some stations did not correspond to those of the NRCD and the Geological Survey.

The Geological Survey data include water-quality or water-quantity information for 84 stations in the Cape Fear River basin. Data for most of these stations are sparse; however, there are 42 stations with daily discharge records over 5 years in length. Daily discharges are important in evaluating annual loads and trends for selected constituents in subsequent sections of this report. Stations having the most data are identified in figure 3 along with the source and type of data available for each station. The location of each of these stations is shown in figure 4.

Table 2. Comparisons of water-quality data collected by the U.S. Geological Survey and by the North Carolina Department of Natural Resources and Community Development

[Based on water years when samples were collected by both agencies at the same station]

Location Parameter	USGS Mean	USGS Number of samples	NRCD Mean	NRCD Number of samples	Results of *t*-test
Haw River below Jordan Dam					
Dissolved oxygen	9.0	64	9.3	102	[1]Not significant.
5-day biochemical oxygen demand	[2]-	-	2.4	103	-
pH	7.0	65	7.1	92	Not significant.
Specific conductance (µmho/cm)	172	36	143	45	Not significant.
Discharge (ft^3/s)	3252	73	2863	27	Not significant.
Total ammonia nitrogen	.09	17	.10	13	Not significant.
Total nitrite plus nitrate nitrogen	1.10	18	1.04	13	Not significant.
Total Kjeldahl nitrogen	.98	19	1.26	14	Not significant.
Total phosphorus	.69	19	.72	13	Not significant.
Dissolved orthophosphate	.30	16	.58	6	Not significant.
Cape Fear River, Lillington					
Dissolved oxygen	9.7	46	9.3	71	Not significant.
5-day biochemical oxygen demand	-	-	1.9	52	Not significant.
pH	6.95	62	6.73	67	[3]Significant.
Specific conductance (µmho/cm)	119	58	86	43	[4]Significant.
Discharge (ft^3/s)	10638	93	8819	14	Not significant.
Total ammonia nitrogen	.07	16	.06	2	Not significant.
Total nitrite plus nitrate nitrogen	.46	16	.58	3	Not significant.
Total Kjeldahl nitrogen	.92	16	.50	2	-
Total phosphorus	.27	19	.48	3	[3]Significant.
Dissolved orthophosphate	.09	16	-	-	-
Cape Fear River, Lock 1					
Dissolved oxygen	8.4	139	8.2	146	Not significant.
5-day biochemical oxygen demand	-	-	1.4	145	-
pH	6.5	123	6.6	134	[3]Significant.
Specific conductance (µmho/cm)	86	101	78	108	Not significant.
Discharge (ft^3/s)	6201	148	8879	32	Not significant.
Total ammonia nitrogen	.12	47	.15	36	Not significant.
Total nitrite plus nitrate nitrogen	.59	86	.61	37	Not significant.
Total Kjeldahl nitrogen	.65	81	.56	37	[4]Significant.
Total phosphorus	.20	85	.22	32	Not significant.
Dissolved orthophosphate	.11	11	.08	17	Not significant.

[1] No statistically significant difference at the 0.05 level of probability.

[2] No data or not enough data for statistical comparison.

[3] Statistically significant difference at the 0.05 level of probability.

[4] Statistically significant difference at the 0.01 level of probability.

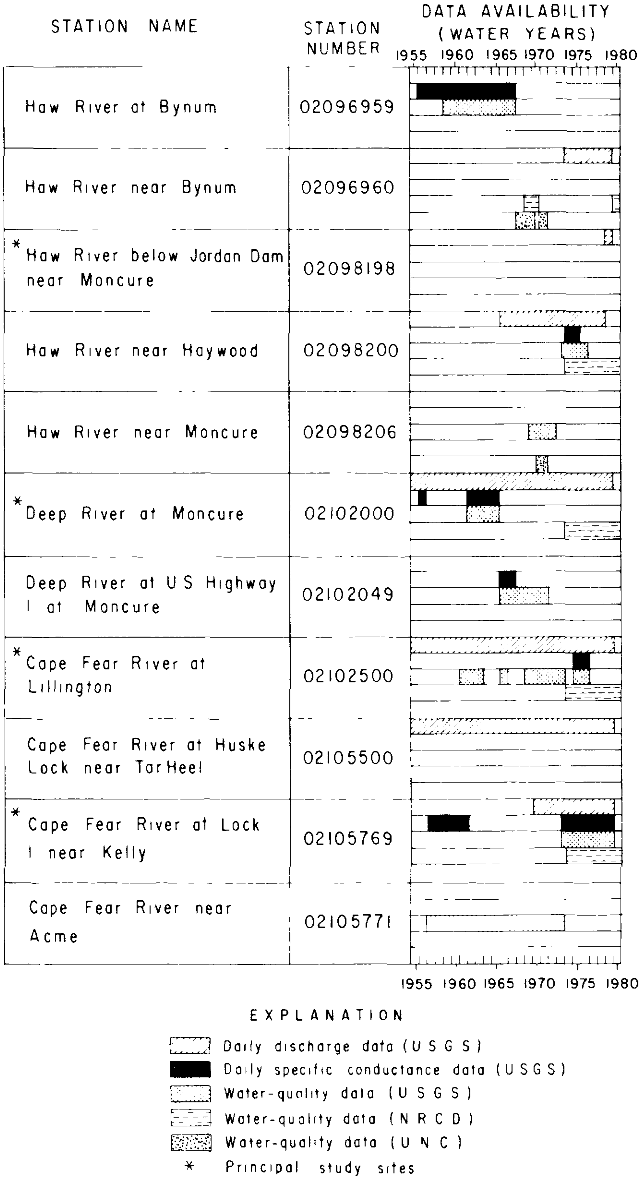

Figure 3. Streamflow and water-quality data used in this study.

Data records for several adjacent stations on the Cape Fear River were combined, providing the distance beween them was small and no major tributaries or point-source effluents entered between them. Records for the Haw River at Bynum (station 02096959) were combined with records for the Haw River near Bynum (station 02096960) (fig. 4). Records were also combined for three stations near the mouth of the Haw River (stations 02098198, 02098200, and 02098206), for two stations near the mouth of the Deep River (stations 02102000 and 02102049), and for the stations on the Cape Fear River at Lock 1 and near Acme (stations 02105769 and 02105771) (fig. 4).

Missing discharge data for the Cape Fear River at Lock 1 near Kelly for the 1955-68 water years were estimated by correlation with the station at Huske Lock near Tar Heel (station 02105500) (fig. 4). The regression equation for calculating daily mean discharges, y, at Lock 1 is

$$y = 1.79X^{0.95}, \qquad (1)$$

where X = mean daily discharge at Huske Lock on the preceding day, in ft^3/sec.

The relation given by equation 1 has a correlation coefficient of 0.97.

Available data for combined data sets are outlined in figure 5. Of the five stations listed in figure 5, the station at Bynum has only 2 years of recent water-quality data. Data for the other four stations are adequate for evaluating existing conditions and water-quality variations. Only the data for the Cape Fear River at Lock 1 are sufficient for evaluating constituent loads and historical changes.

The Cape Fear River at Lock 1 is a pivotal station because it is located downstream from the most populated and most industrialized sections of the basin. Lock 1 marks the upstream limit of tidal influences and is only a few miles upstream of the most inland point of saltwater intrusion (Giese and others, 1979). The station is upstream from the Black River, the South River, and the Northeast Cape Fear River.

The data record for Lock 1, including discharge estimated from records for Huske Lock, includes daily discharge values from the 1955 water year to 1980, daily specific conductance values for water years 1957-1961 and 1974-1980, with a half year of conductance data in water year 1973. Data for several constituents are available for Lock 1. Thus, this report focuses on data from the Cape Fear River at Lock 1, with additional information presented for upstream stations at Lillington, Moncure, below Jordan Dam, and Bynum where available.

Conclusions in this report are based primarily on data from study sites as follows: Haw River below Jordan Dam near Moncure, Deep River at Moncure, Cape Fear River at Lillington, and Cape Fear River at Lock 1 near Kelly. For convenience, the stations are referred to as "study sites" in following sections of the report; specific references to each respective site are "below Jordan Dam," "Moncure," "Lillington," and "Lock 1." For some constituents, particularly metals, there are few observations. Thus, characterizations of water

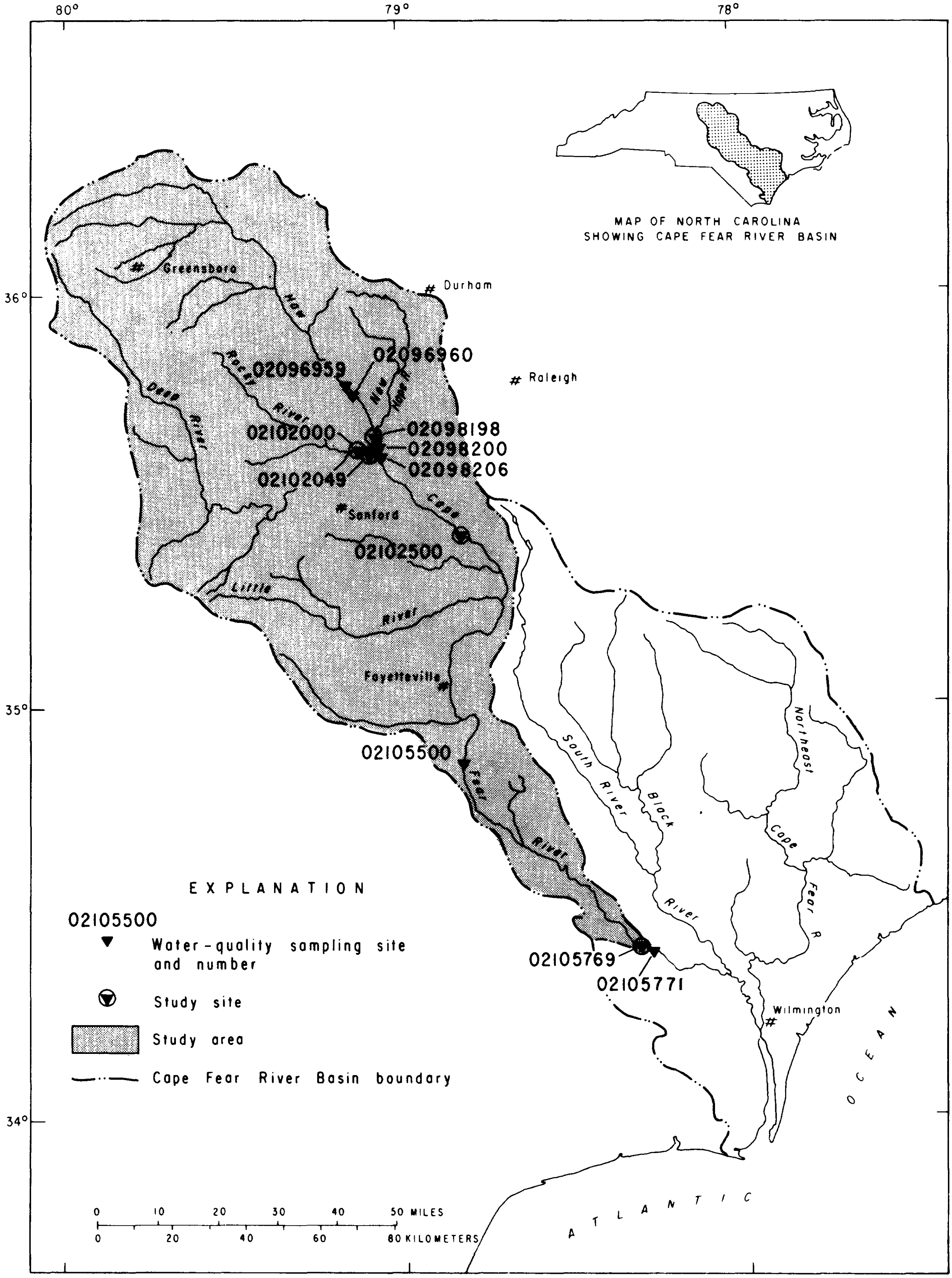

Figure 4. The Cape Fear River basin, major cities, drainage patterns, and important sampling stations.

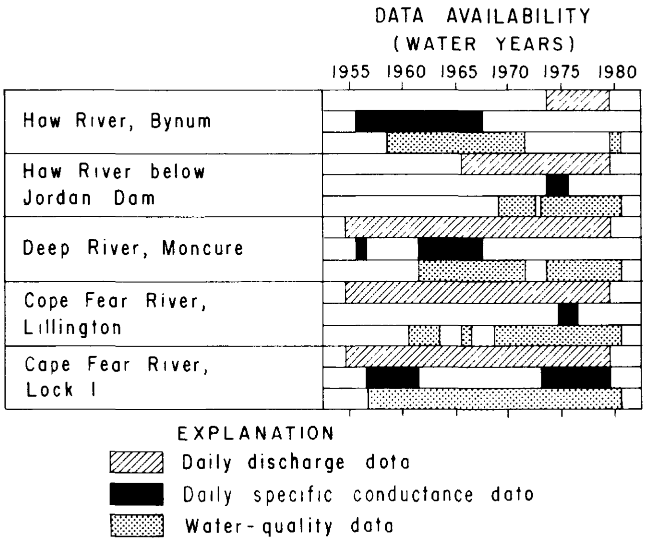

Figure 5. Data available for combined Cape Fear River stations.

quality for the entire basin based on this limited data base are not possible.

WATER-QUALITY VARIATION

The quality of water in a river system varies greatly. This is a consequence of variable precipitation, physical conditions, waste inputs, and biological activity within the stream. Small changes in water-quality conditions may reflect proper functioning of the stream ecosystem, whereas large variations may limit overall suitability of the stream for some uses.

This section evaluates the existing water-quality conditions at selected sites in the Cape Fear River. Only recent data (October 1975-June 1980) are considered. Particular attention is given to extreme short-term variations in water quality that could imperil the use of the stream for water supply, industrial use, recreation, or aquatic life. A later section of the report addresses long-term, systematic variations, or trends, in water quality.

Where appropriate, concentrations of various constituents are compared with concentration levels recommended as safe by the Environmental Protection Agency (U.S. Environmental Protection Agency, 1977). For most constituents, North Carolina water-quality standards are identical to Environmental Protection Agency criteria. Where differences exist, the standards are cited and measured concentrations are compared with them.

Physical Characteristics

The physical characteristics of water contribute to the overall water quality of a stream by controlling rates of chemical and biological activity. In the sections that follow, dissolved oxygen, temperature, pH, and suspended sediment and their impacts on the water quality of the Cape Fear River are considered.

Dissolved Oxygen

Oxygen dissolved in water is essential for aquatic life. Oxygen is also necessary for chemical oxidation, which is important in the breakdown of waterborne wastes and in the self-purification of streams.

Because dissolved oxygen is important in stream self-purification and because it is required for aquatic life, the U.S. Environmental Protection Agency has established the criterion level of 5.0 mg/L in water (U.S. Environmental Protection Agency, 1977). This criterion level accounts for the needs of different stages of the life cycle of fish, including embryonic, larval, juvenile, and adult stages. It is also adequate for protecting other aquatic organisms, some of which are food for fish. North Carolina's standards for Class A-II (water supply), B (primary recreation), and C (fishing) waters call for no instantaneous concentration of dissolved oxygen of less than 4.0 mg/L and a daily average of not less than 5.0 mg/L (North Carolina Environmental Management Commission, 1979).

Water temperature, plant photosynthesis, chemical reactions, biological activity, waste loads, and the physical character of the stream all affect dissolved oxygen concentrations in water. The sum of all these forces determines the existing oxygen concentration in a stream.

Oxygen solubility decreases with increasing water temperature, a relation shown in figure 6 for the Cape Fear River at Lock 1. This inverse relation indicates that low oxygen concentrations and violations of the Environmental Protection Agency dissolved-oxygen criterion are most likely to occur in summer when water temperatures are high.

Dissolved-oxygen concentrations at the study sites are almost always above the Environmental Protection Agency criterion of 5.0 mg/L. On two occasions since 1975, samples were taken at study sites when oxygen levels were below 5.0 mg/L. Both samples were from the Cape Fear River at Lock 1, and both had between 4 and 5 mg/L of oxygen (fig. 6). These data may be misleading

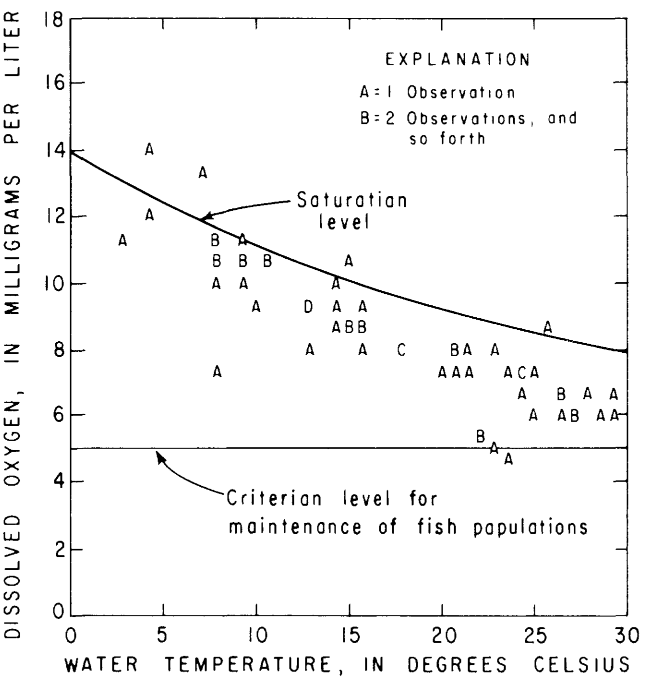

Figure 6. Variation of dissolved-oxygen concentrations with water temperature for the Cape Fear River at Lock 1 near Kelly, 1975-80 water years.

because all the water samples were taken in daylight hours, usually late in the morning or early in the afternoon. Therefore, the diurnal oxygen minimum, which normally occurs just before daybreak (Odum, 1956), was not sampled and the oxygen concentrations reported for the Cape Fear River are probably biased toward high values.

Average oxygen concentrations show abundant oxygen supplies throughout the basin (table 3). Average concentrations for study sites are from 8.4 to 10.0 mg/L. Concentrations cited in this report do not violate the North Carolina water-quality standard.

Water Temperature

The rates of most chemical reactions increase at higher temperatures. Therefore, the temperature of streams is a contributing factor in their rate of self-cleaning. Rates of biological processes, which are in part chemical reactions, also increase with increasing temperature. Biological processes have upper and lower temperature limits within which aquatic organisms can survive. Therefore, temperature also plays a role in determining the biological community in a stream.

Temperatures for study sites average about 17°C (table 3). Maximum temperature is the most stressful to aquatic organisms as it limits the type of community that will exist in an aquatic environment. Piedmont and Coastal Plain streams of North Carolina are classified as warmwater, able to support game fish such as largemouth bass, bluegill and pumpkinseed. The U.S. Environmental Protection Agency (1977) lists 32°C as the maximum weekly average water temperature that can support growth of largemouth bass. North Carolina water-quality standards (North Carolina Environmental Management Commission, 1979) call for a maximum temperature of 32°C in lower Piedmont and Coastal Plain streams.

Observed daily temperatures have reached or exceeded 32°C at only one study site since 1975, the Haw River below Jordan Dam. During August of 1980, a temperature of 32°C occurred five times at the station. Air temperatures during August 1980 were high and flows were low, possibly explaining high water temperatures.

pH

Low or high pH causes corrosion in water-supply lines and household plumbing fixtures. For this reason, the Environmental Protection Agency cites a range of pH values of 5 to 9 units as acceptable for domestic water supply. The Environmental Protection Agency criterion for the protection of aquatic life is a pH range of 6.5 to 9 units. Fish can survive in water having a pH as low as 5.0 units or even lower; however, when pH falls to less than 6.0 units, heavy metals become more soluble and, therefore, more toxic (Wright and Gjessing, 1976). A lower pH limit of 6.0 units has been established for North Carolina Class C waters, which are designated as best used for fishing, secondary recreation, and agriculture. Values of pH lower than 6.0 are acceptable if normal for waters of the area (North Carolina Environmental Management Commission, 1979).

Acid precipitation is a common phenomenon in North Carolina (National Atmospheric Deposition Program, 1981). This problem arises when sulfur and nitrogen compounds are released in the burning of fossil fuels. The sulfur and nitrogen in the air combine with water to form sulfuric acid and nitric acid in rainfall. The result is large inputs of acid into terrestrial and aquatic ecosystems. Some North Carolina streams had lower pH levels in 1979 than in the early 1960's, perhaps as a result of acid rain (Hendry and others, 1980; Burns and others, 1981).

Table 3. Summary statistics for physical characteristics of water from key locations in the Cape Fear River basin, 1975-80 water years

Character-istics	Statistic	Location				Criteria (U.S. Environmental Protection Agency, 1977)
		Haw River, Jordan Dam	Deep River, Moncure	Cape Fear River, Lillington	Cape Fear River, Lock 1	
Discharge (ft^3/s)	Mean	2047	1584	3350	3924	
	Number of samples	1616	1671	2923	4384	
	Standard deviation	2706	2987	5229	5794	
	Minimum-maximum	60 - 14,300	34 - 31,300	106 - 46,600	44 - 57,100	
Temperature (°C)	Mean	18.0	16.7	17.5	17.4	
	Number of samples	1506	1671	2813	4164	
	Standard deviation	8.51	8.34	7.99	8.26	
	Minimum-maximum	1.0 - 33.0	1.0 - 31.5	1.0 - 31.5	1.0 - 31.5	
Dissolved Oxygen (mg/L)	Mean	[1]9.5	[1]10.0	[1]9.3	[1]8.4	5 mg/L for fish population.
	Number of samples	105	68	111	166	
	Standard deviation	2.39	2.34	1.78	1.93	
	Minimum-maximum	5.5 - 18.5	5.9 - 17.5	6.1 - 14.1	4.7 - 14.0	
pH (pH units)	Geometric mean	[1]6.6	[1]6.2	[1]6.5	[1]6.3	5-9 for domestic water supplies. 6.5 - 9.0 for freshwater aquatic life.
	Number of samples	91	54	110	16	
	Standard deviation	0.60	0.69	0.63	0.42	
	Minimum-maximum	5.7 - 8.9	4.7 - 8.8	5.7 - 9.3	5.3 - 7.6	
Suspended Sediment (mg/L)	Mean	99	12	111	37	Not reduce compensation point for photosynthesis by more than 10 percent.
	Number of samples	18	7	27	64	
	Standard deviation	104	9	142	39	
	Minimum-maximum	10 - 438	2 - 27	2 - 558	7 - 186	

[1] Includes data from North Carolina Department of Natural Resources and Community Development.

Present pH levels at study sites are very close to the lower limit for protection of freshwater aquatic life. Geometric mean pH values of samples for study sites range from 6.2 units at Moncure to 6.6 units below Jordan Dam. Individual measurements fell below the 6.5 units criterion limit in 35 percent of the samples since the 1975 water year. During the 1975-80 sampling, the lowest pH value measured at any of the four sites was 4.7 units in the Deep River at Moncure.

Suspended Sediment

Sediment has been labeled the most widespread water-quality problem in North Carolina (North Carolina Department of Natural Resources and Community Development, 1979). Streams and lakes are unsightly and less productive because of sediment. Biologic productivity declines as sediment increases because less light can penetrate the water column and, therefore, less photosynthesis occurs. Over a period of time, sediment may change the stream bottom from rock or gravel to mud or silt, may cover fish spawning beds, and may fill stream channels and lakes. Covering gravel bottoms of streams removes productive habitats for aquatic organisms Covering spawning beds can block efficient exchange of oxygen and suffocate fish eggs.Filling channels and lakes with sediment results in the need for channelization of streams and dredging of lakes to restore their former depth.

Sediment problems in the Piedmont province of North Carolina are particularly severe because of the nature of the soils. Soils of this region are predominantly clays. These clays are highly erodable and, once eroded, the fine clay particles remain in suspension for long periods of time.

Statistics on suspended sediment data for the study sites are given in table 3. Average suspended sediment concentrations are higher for the Haw River than for the Deep River. The average concentration for Lillington is 111 mg/L, while downstream at Lock 1 the average value is 37 mg/L. Reduction of suspended sediment between these two stations is expected because three navigation locks in this section of the river impound water, thereby slowing the flow of the river and allowing sedimentation to occur.

The variation of suspended sediment with stream discharge at Lillington and Lock 1 is illustrated by the exponential relation shown in figure 7. High, positive correlation coefficients for these relations ($r=0.88$ for Lillington and $r=0.72$ for Lock 1) indicate a close association between suspended sediment and discharge. The data shown in figure 7 also indicate that high discharges at Lock 1 do not transport as much sediment as do comparable discharges at Lillington. Reduction in sediment transport is attributed to lower streamflow velocities at Lock 1 than at Lillington and sedimentation, enhanced by lock operation, between the two stations.

Suspended sediment standards have not been established for North Carolina. The Environmental Protection Agency criterion for suspended sediment states that "settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life" (U.S. Environmental Protection Agency, 1977).

Major Dissolved Substances

The average chemical composition of river waters in the world has been characterized by Livingstone (1963) and summarized by Hem (1970). On the whole, concentrations of major dissolved substances are lower at selected sites in the Cape Fear River basin (table 4) than in Livingstone's average U.S. river. Dissolved solids, a gross measure of all the substances dissolved in the water, range from an average of 76 mg/L in the Haw River below Jordan Dam to an average of 67 mg/L in the Cape Fear River at Lock 1 (table 4). The average concentration for rivers worldwide is 90 mg/L (Hem, 1970). Sodium concentrations are consistently higher at the study sites listed in table 4 than the 6.3 mg/L cited by Livingstone (1963) as the world average. Average values of potassium, sulfate, and chloride are higher than Livingstone's world average values at some stations, but are not higher in the watershed as a whole.

In general, concentrations of dissolved substances listed in table 4 for selected study sites decrease downstream. This trend is to be expected, because major sources of waste effluent from municipal and industrial centers are concentrated in the headwaters of the basin and the waste effluents have greater concentrations of dissolved substances than do the natural water entering downstream.

One method of illustrating the proportions of each ionic species contained in water is use of cation-anion diagrams (Stiff, 1951). Cation-anion diagrams for Lillington and at Lock 1 are similar (fig. 8). At both stations, sodium is the dominant cation and bicarbonate is the dominant anion.

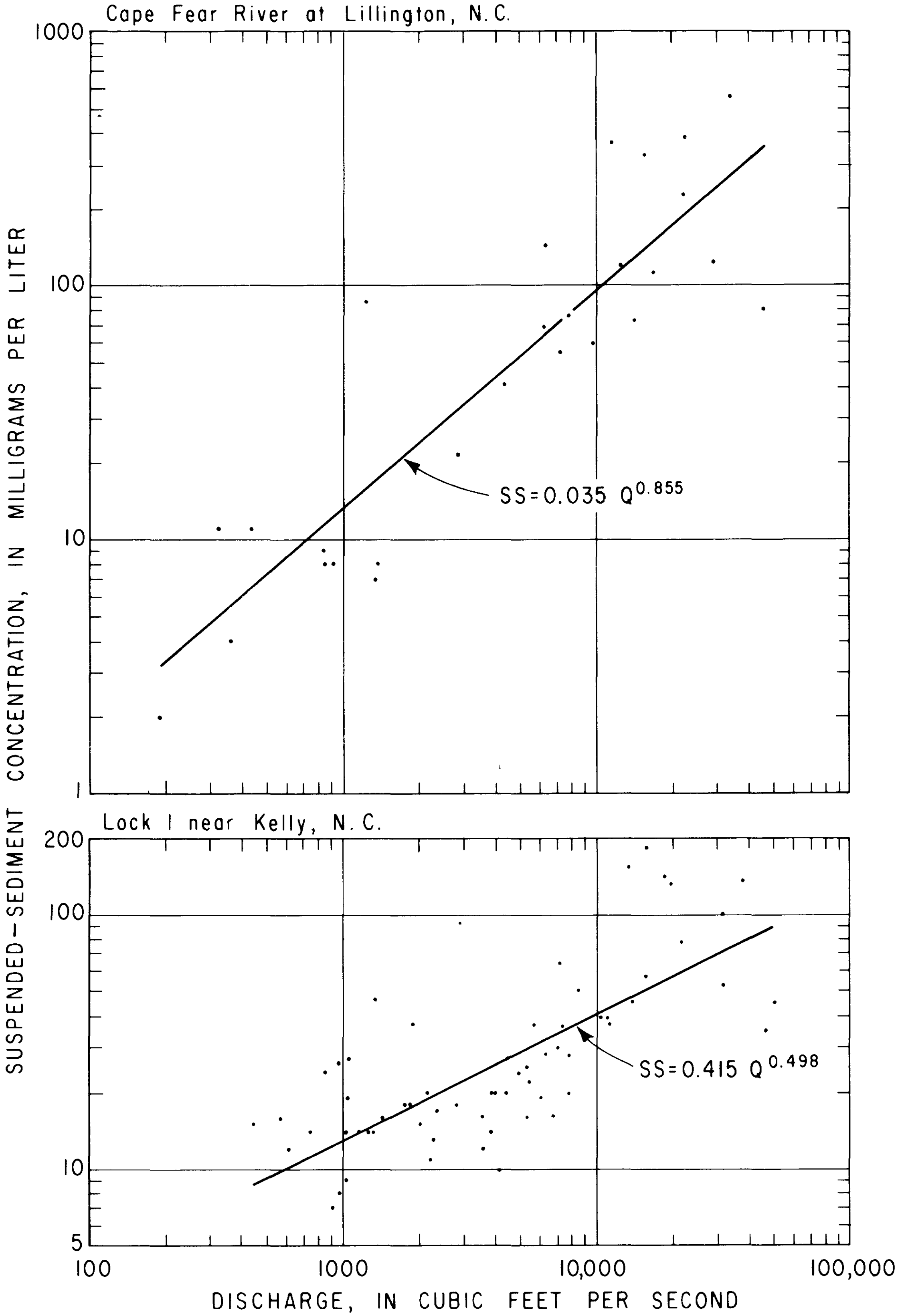

Figure 7. Variations of suspended sediment concentrations (SS) with discharge (Q) for the Cape Fear River at Lillington and at Lock 1 near Kelly, 1975-80 water years.

Table 4. Summary statistics for major dissolved substances in water from key locations in the Cape Fear River basin, 1975-80 water years

Constituent	Statistic	Location			Criteria (U.S. Environmental Protection Agency, 1977)
		Haw River, Jordan Dam	Cape Fear River, Lillington	Cape Fear River, Lock 1	
Silica (mg/L as SiO_2)	Mean	9.7	8.8	8.1	
	Number of samples	12	28	66	
	Standard deviation	3.10	2.54	1.54	
	Minimum-maximum	4.3 - 15.0	1.4 - 13.0	4.6 - 12.0	
Calcium (mg/L)	Mean	6.7	5.4	3.7	
	Number of samples	12	28	66	
	Standard deviation	2.14	1.72	1.12	
	Minimum-maximum	4.4 - 10.0	3.1 - 10.0	0.1 - 7.1	
Magnesium (mg/L)	Mean	2.5	2.1	1.7	
	Number of samples	12	28	66	
	Standard deviation	0.80	0.65	0.31	
	Minimum-maximum	1.7 - 4.0	1.1 - 3.7	0.8 - 2.8	
Sodium (mg/L)	Mean	10.7	8.8	8.6	No criterion. Annual monitoring required. ≤20 mg/L optimal.
	Number of samples	12	28	66	
	Standard deviation	11.48	5.85	4.37	
	Minimum-maximum	2.0 - 40.0	2.6 - 21.0	2.8 - 21.0	
Potassium (mg/L)	Mean	2.5	2.4	2.0	
	Number of samples	12	28	66	
	Standard deviation	0.60	0.50	0.57	
	Minimum-maximum	1.7 - 4.0	1.5 - 3.5	0.1 - 3.5	
Bicarbonate (mg/L as HCO_3)	Mean	31.2	24.9	17.5	
	Number of samples	12	28	66	
	Standard deviation	21.19	12.74	6.08	
	Minimum-maximum	14.0 - 75.0	8.0 - 55.0	7.0 - 39.0	
Sulfate (mg/L as SO_4)	Mean	11.8	9.3	9.7	Upper limit for domestic use: 250 mg/L.
	Number of samples	12	28	66	
	Standard deviation	5.30	2.54	2.88	
	Minimum-maximum	6.5 - 26.0	5.4 - 15.0	5.5 - 18.0	
Chloride (mg/L)	Mean	8.4	7.1	7.9	Upper limit for domestic use: 250 mg/L.
	Number of samples	12	28	66	
	Standard deviation	7.59	3.70	3.14	
	Minimum-maximum	2.4 - 29.0	2.3 - 15.0	2.8 - 17.0	
Fluoride (mg/L)	Mean	0.3	0.3	0.1	Upper limit for domestic use: 1.8 mg/L in North Carolina.
	Number of samples	12	28	66	
	Standard deviation	0.14	0.14	0.08	
	Minimum-maximum	0.0 - 0.5	0.0 - 0.7	0.0 - 0.4	
Dissolved solids (Residue at 180°C)	Mean	76	71	67	Upper limit for domestic use: 500 mg/L.
	Number of samples	12	28	66	
	Standard deviation	41.4	23.1	13.8	
	Minimum-maximum	35 - 167	27 - 124	29 - 112	
Hardness (mg/L as $CaCO_3$)	Mean	27	22	16	
	Number of samples	12	28	66	
	Standard deviation	8.4	6.5	3.5	
	Minimum-maximum	19 - 41	12 - 39	6 - 29	
Specific conductance (µmho/cm)	Mean	135	95	81	
	Number of samples	21	29	67	
	Standard deviation	97.2	38.9	24.1	
	Minimum-maximum	53 - 450	42 - 170	40 - 170	

Specific conductance measures the ability of a cubic centimeter of water at 25°C to conduct electricity. As such, it is a measure of the ionic strength of water and is useful as an indicator of the total amount of mineral matter dissolved in a sample. Specific conductance values average 135 µmho/cm in the Haw River below Jordan Dam, 95 µmho/cm at Lillington, and 81 µmho/cm at Lock 1. The pattern of decreasing conductance values in the downstream direction is consistent with concentrations of dissolved substances.

Histograms of specific conductance measurements taken at Lillington and at Lock 1 are shown in figure 9. Most specific conductance measurements for the two stations fall between 60 and 110 µmho/cm, with a few observations at each station greater than 200 µmho/cm. Shapes of histograms for the two stations are similar, but

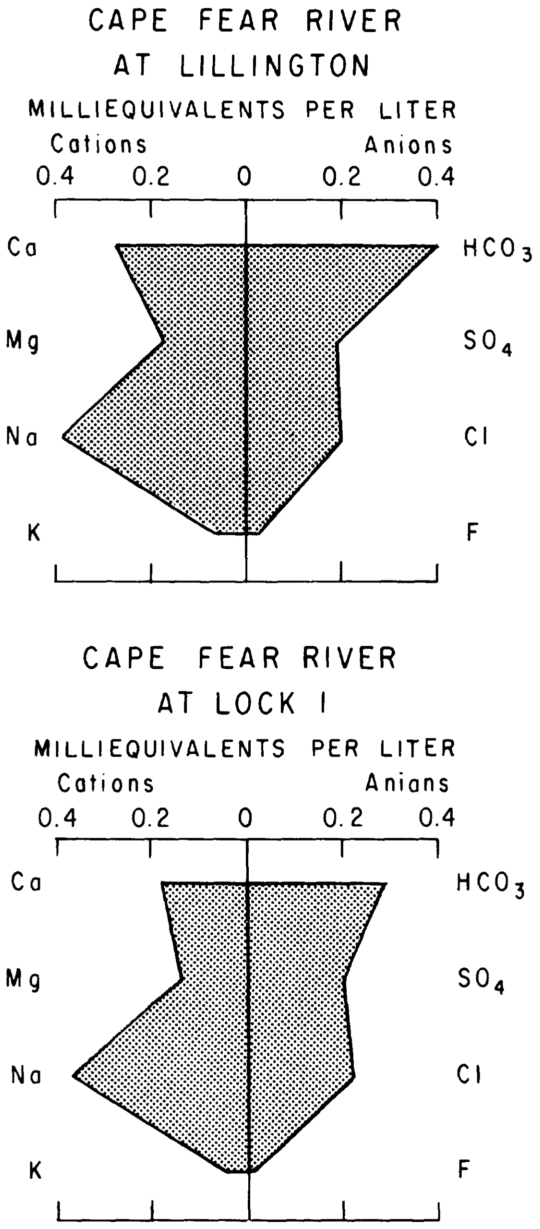

Figure 8. Cation-anion diagrams for the Cape Fear River at Lillington and at Lock 1 near Kelly.

more observations are recorded at Lock 1 and more high values are recorded at Lillington.

Specific conductance values and dissolved-constituent concentrations depend on streamflow. Generally, high discharges dilute concentrated waste inputs, so the relations between conductivity and discharge and between constituent concentrations and discharge are inverse. The inverse relations are closely approximated by exponential curves of the form:

$$C=aQ^{b}$$

or

$$\ln C=\ln a+b\ \ln(Q)$$

where C is the constituent concentration, ln a is the y-intercept, Q is the discharge, and b is the slope of the line. Dissolved solids, an approximate measure of all dissolved constituents, both ionic and nonionic, serve as an example of the relation and should reflect the general pattern of other dissolved materials. The relation between dissolved solids and discharge for the Cape Fear River at Lillington is shown in figure 10. The relation has a correlation coefficient of 0.81. The association between dissolved solids and discharge is not as close at Lock 1 (fig. 10); although it is statistically significant at the 1 percent level of confidence, the correlation coefficient is only 0.37. This poor relation between dissolved solids and discharge implies that something out of the ordinary is affecting the water quality at Lock 1. One possible explanation is the change in the normal flow patterns in the river caused by operation of the locks.

Specific conductance is easy and inexpensive to measure, whereas dissolved ions are not. If the association between specific conductance and a particular dissolved constituent is sufficiently close, specific conductance may be used to estimate the value of a dissolved constituent. This is particularly useful for stations for which there are daily records of specific conductance but only a few measurements of various dissolved constituents. Linear regression equations between specific conductance and various ions for Lillington and Lock 1 are summarized in table 5. Regression equations for chloride and sodium at both stations, and for bicarbonate and sulfate at Lillington, have correlation coefficients greater than 0.9. Statistically significant relations could not be determined, for any level of probability, for silica at both Lillington and Lock 1 and for calcium at Lock 1. Regression lines for various constituents are shown in figures 11 and 12. Relations listed in table 5 are used in a later section of this report to determine estimates for various dissolved constituents.

Trace Elements

Trace elements, many of which are essential for plant and animal life, occur in minute

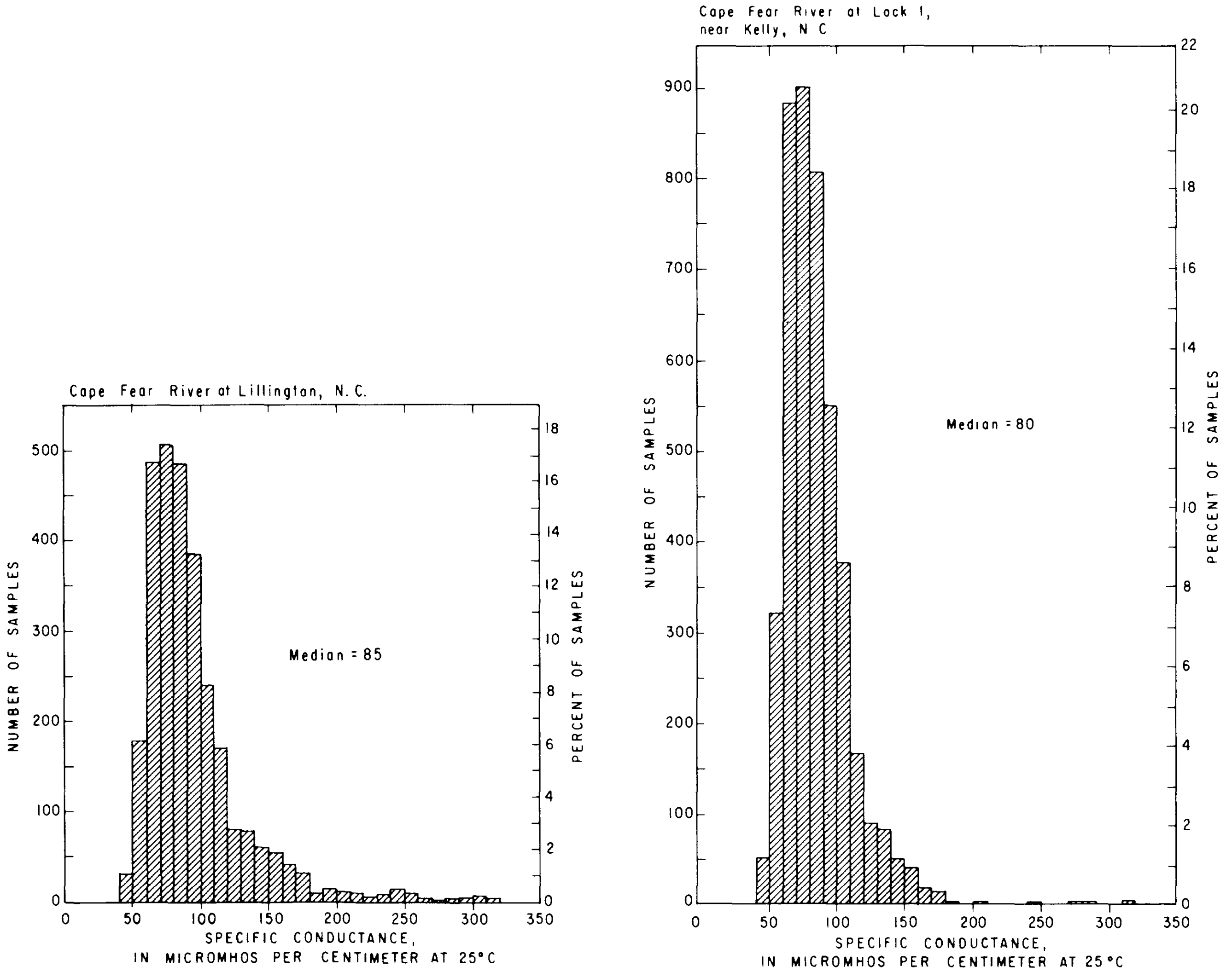

Figure 9. Frequency histograms for specific conductance measurements from the Cape Fear River at Lillington and at Lock 1 near Kelly.

concentrations in streamwater. Although they are essential in small quantities, some are frequently toxic at higher concentrations, often at concentrations only slightly higher than those that occur naturally. Therefore, close monitoring of trace elements may be warranted.

Trace elements considered in this study are arsenic, cadmium, cobalt, copper, iron, lead, manganese, mercury, selenium, and zinc; only total concentrations are evaluated. Weiss and others (1972), Pfaender and others (1977), and Shuman and others (1977) give additional information on metals in the Cape Fear River basin. For overviews of the effects of metals in aquatic systems and the potential hazards of metals to humans, reports by Gough and others (1979) and Callahan and others (1979) are recommended.

Except for mercury, statistical data for trace metals at selected study sites are summarized in table 6. These data indicate that iron, manganese, and, occasionally, lead are found in concentrations exceeding Environmental Protection Agency criteria for domestic water supply. Total iron concentrations for selected study sites listed in table 6 are almost always higher than the 300 µg/L recommended as the maximum for public water supplies. Since 1975, 98 percent of the iron samples for the selected study sites have exceeded this level.

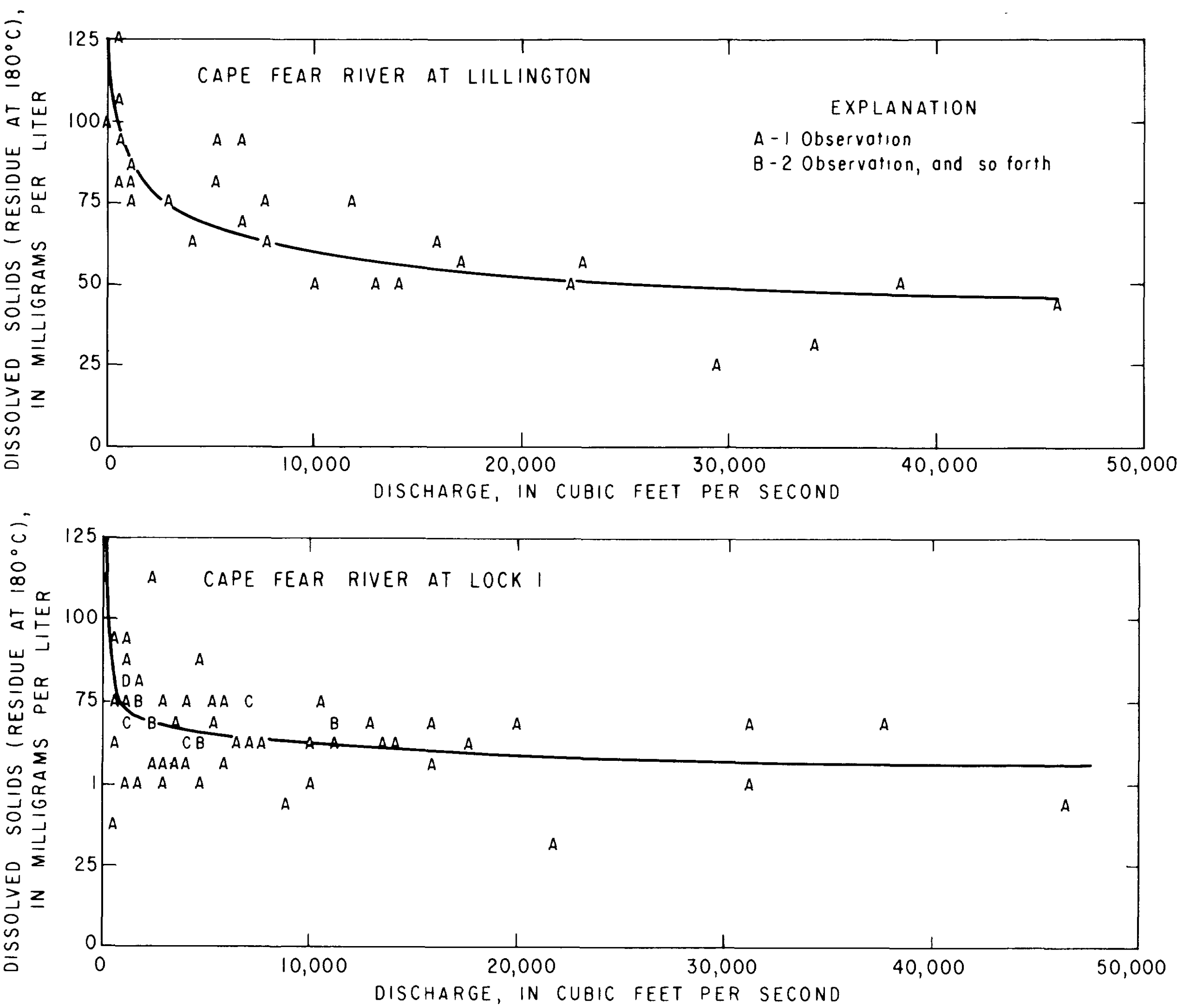

Figure 10. Variations of dissolved solids concentrations with discharge for the Cape Fear River at Lillington and at Lock 1 near Kelly.

The criterion for domestic water supplies is primarily intended to avoid the aesthetic problems of "bad taste in water, staining of plumbing fixtures, spotting of laundered clothes, and accumulation of deposits in distribution systems" (National Academy of Sciences, National Academy of Engineering, 1973). Also, 62 percent of the time, iron concentrations at the selected study sites were greater than the maximum 1 mg/L (1,000 µg/L) of total iron required to protect aquatic life. This level is identical to the North Carolina water-quality standard. Because most of the iron is suspended and little is dissolved, the toxic effects on aquatic life are probably moderated. Settling or filtration treatment may reduce the concentration of total iron.

Highest iron concentrations are found at Lillington, where 4 of 24 samples had concentrations greater than 10,000 µg/L. Limited data for the Deep River at Ramseur (fig. 1) indicate higher iron concentrations at Ramseur than at Lillington. Because most iron is suspended, and because maximum concentrations occur during periods of high discharge, soils appear to be the source of most iron.

Manganese concentrations exceed guidelines (U.S. Environmental Protection Agency, 1977) and standards (North Carolina Environmental

Table 5. Regression equations for dissolved constituents and specific conductance (SC) at selected stations on the Cape Fear River, 1975-80 water years

Dissolved constituent	Regression equation	Correlation coefficient
Cape Fear River at Lillington		
Calcium	Ca = 2.4 + 0.03 (SC)	0.70*
Magnesium	Mg = 0.8 + 0.01 (SC)	.82*
Potassium	K = 1.8 + 0.01 (SC)	.52*
Sodium	Na = -5.4 + 0.15 (SC)	.99*
Bicarbonate	HCO_3 = -5.4 + 0.33 (SC)	.96*
Chloride	Cl = -1.8 + 0.10 (SC)	.99*
Silica	SiO_2 = 9.3 - 0.01 (SC)	-.08
Sulfate	SO_4 = 3.6 + 0.06 (SC)	.91*
Dissolved solids	DS = 20.5 + 0.54 (SC)	.88*
Cape Fear River at Lock 1 near Kelly		
Calcium	Ca = 4.3 - 0.01 (SC)	-.15
Magnesium	Mg = 1.2 + 0.01 (SC)	.46*
Potassium	K = 0.9 + 0.01 (SC)	.55*
Sodium	Na = -5.4 + 0.18 (SC)	.96*
Bicarbonate	HCO_3 = 4.3 + 0.16 (SC)	.63*
Chloride	Cl = -2.6 + 0.13 (SC)	.96*
Silica	SiO_2 = 8.3 - 0.003(SC)	-.04
Sulfate	SO_4 = 1.8 + 0.10 (SC)	.79*
Dissolved solids	DS = 36.6 + 0.37 (SC)	.64*

*Statistically significant at the 0.05 level of probability.

Management Commission, 1979) for domestic water supplies in 85 percent of the samples collected at the sites listed in table 6. However, these guidelines are for aesthetic rather than health concerns. Toxicological effects are not expected from concentrations of manganese normally found in the Cape Fear River (U.S. Environmental Protection Agency, 1977).

Manganese concentrations are higher at Lillington than at Jordan Dam or Lock 1 (table 6), and concentrations for the Deep River at Ramseur (fig. 1) are higher than those at Lillington. Most of the manganese in samples from these stations is suspended. High concentrations generally occur during periods of high flow and therefore may originate from the soils of the watershed.

Lead concentrations in the Haw River below Jordan Dam and Cape Fear River at Lillington exceeded Environmental Protection Agency criteria (50 µg/L) for domestic water supplies and the North Carolina standard (30 µg/L) in two samples since 1975. The Lillington sample was taken during high-flow conditions. Lead can be introduced into waterways from manufacturing processes, urban runoff, or other sources. Lead concentrations in urban runoff are generally known to be high because of lead emissions from autos using leaded fuel.

The U.S. Environmental Protection Agency (1977) criterion for cadmium in domestic water supplies is 10 µg/L. Available data for the study sites indicate that this level has been exceeded only once since 1975. The concentration of cadmium exceeded the EPA criterion level in the Haw River below Jordan Dam on the same day high concentrations of lead were observed at the station. The standard for cadmium in North Carolina is 4.0 µg/L for non-trout waters.

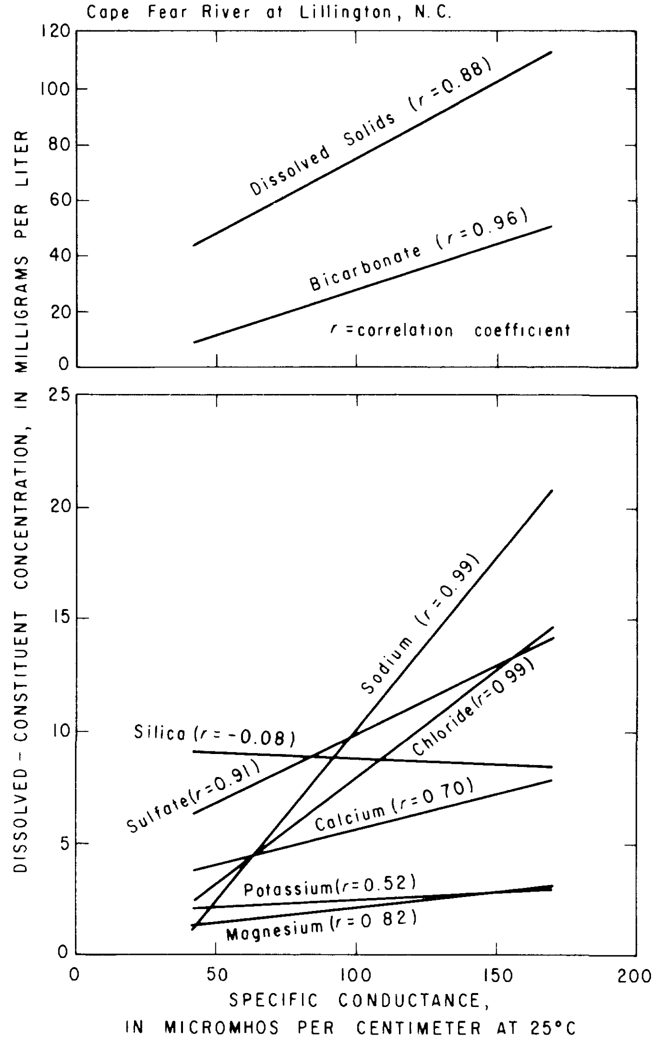

Figure 11. Relations between various dissolved constituents and specific conductance for the Cape Fear River at Lillington.

Statistics on mercury concentrations from several studies in the Haw River, in the vicinity of the B. Everett Jordan Dam, are listed in table 7. Average concentrations vary by an order of magnitude.

Mercury criteria for the protection of freshwater aquatic life are 0.20 µg/L as a 24-hour average and 4.1 µg/L as a maximum concentration at any time (U.S. Environmental Protection Agency, 1981). Results from the five studies listed in table 7 indicate only one measured instance of total mercury higher than the 4.1 µg/L criterion. However, average concentrations from four of the five studies exceed the level of 0.20 µg/L suggested as the maximum allowable for a 24-hour average. These data indicate possible sustained high concentrations of mercury in the Haw River in the vicinity of the B. Everett Jordan Dam.

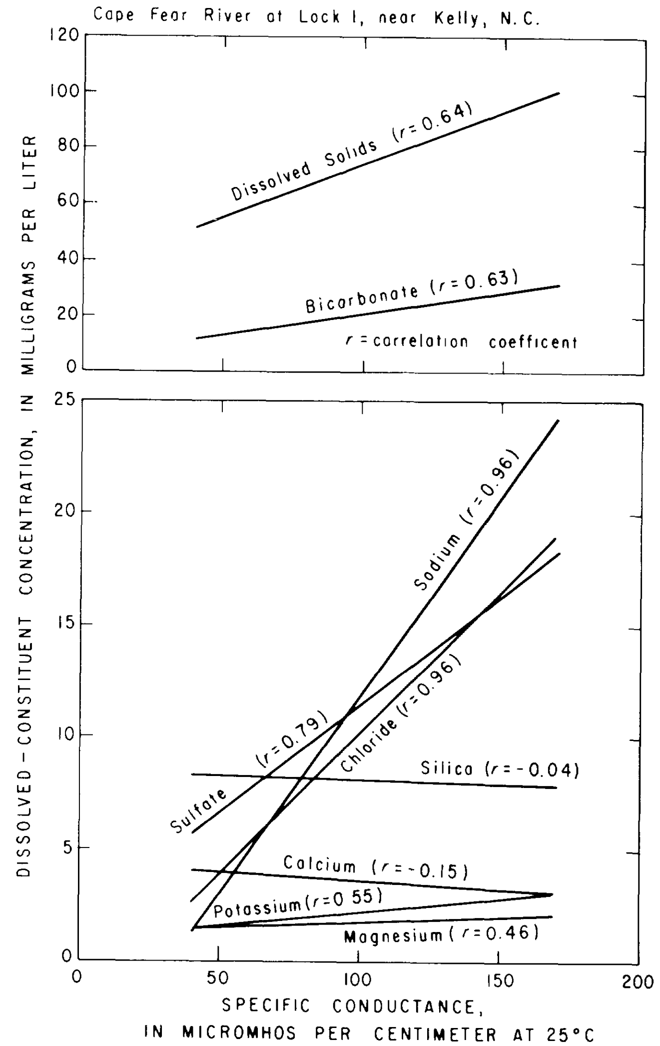

Figure 12. Relations between various dissolved constituents and specific conductance for the Cape Fear River at Lock 1 near Kelly.

No contraventions of water-quality standards or recommended criteria for arsenic, cobalt, copper, selenium, or zinc were observed in this study.

Nutrients

Twenty different elements have been identified as essential to plant growth (Mackenthum, 1969). Of these, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, magnesium, calcium, and sodium are required in the greatest quantities and are referred to as macronutrients. The others, iron, manganese, copper, zinc, molybdenum, vandium, boron, chloride, cobalt, and silicon, are required in lesser amounts and are called micronutrients. When in abundant supply relative to the needs, these 20 elements can trigger large growths of algae. However, if only one of these essential elements is in short supply, relative to the overall needs of the algae, then algal growth is limited by that one element.

Micronutrients are usually present in adequate supply in natural waters and seldom limit algal growth. Micronutrients commonly originate from natural sources (dissolution of rocks and soils by ground water and surface water). However, requirements for macronutrients often exceed available supplies, and a shortage of macronutrients commonly limits plant growth.

Control of nuisance algal growths usually involves reduction of nutrients. Macronutrients are capable of being controlled to a greater extent than micronutrients because much of their input is from human sources. Nutrient-control measures include advanced wastewater treatment, good agricultural practices, measures to reduce urban runoff and associated nutrients, and the use of laundry detergents with low phosphate content.

This section evaluates concentrations of the macronutrients carbon, nitrogen, and phosphorus at study sites under present conditions. Nutrient statistics for the study sites are presented in table 8 for water years 1975-80.

Carbon

Plants require more carbon for their growth than any other element. Carbon sources for algae are bicarbonate ions or carbon dioxide dissolved in

Table 6. Summary statistics for total trace element concentrations in water from key locations in the Cape Fear River basin, 1975-80 water years

[Results in micrograms per liter]

Constituent	Statistic	Location			Criteria (U.S. Environmental Protection Agency, 1977)
		Haw River, Jordan Dam	Cape Fear River, Lillington	Cape Fear River, Lock 1	
Arsenic	Mean	10.7	1.5	1.6	50 μg/L for domestic water supply.
	Number of samples	4	4	24	
	Standard deviation	13.45	0.58	0.72	
	Minimum-maximum	1 - 30	1 - 2	0 - 3	
Cadmium	Mean	16.7	0.3	0.5	10 μg/L for domestic water supply. 4 μg/L for most freshwater aquatic life.
	Number of samples	3	4	26	
	Standard deviation	28.87	0.50	1.07	
	Minimum-maximum	0 - 50	0 - 1	0 - 4	
Cobalt	Mean	36.3	5.5	1.5	
	Number of samples	3	4	26	
	Standard deviation	55.16	3.79	4.20	
	Minimum-maximum	3 - 100	3 - 11	0 - 20	
Copper	Mean	13.0	15.5	6.2	1000 μg/L for domestic water supply. (0.1)x(96-hour LC_{50}) for aquatic life.
	Number of samples	8	24	26	
	Standard deviation	15.14	35.51	6.53	
	Minimum-maximum	5 - 50	2 - 180	1 - 36	
Iron	Mean	2374	4388	1839	300 μg/L for domestic water supply. 1000 μg/L for freshwater aquatic life.
	Number of samples	8	24	26	
	Standard deviation	1721.7	5105.3	1765.8	
	Minimum-maximum	690 - 5900	220 - 18000	450 - 8600	
Lead	Mean	20.1	18.3	6.3	50 μg/L for domestic water supply. (0.01)x(96-hour LC_{50}) for aquatic life.
	Number of samples	8	24	24	
	Standard deviation	32.7	39.7	61	
	Minimum-maximum	2 - 100	2 - 200	0 - 22	
Manganese	Mean	82	199	109	50 μg/L for domestic water supply.
	Number of samples	3	4	26	
	Standard deviation	53.0	206.4	71.6	
	Minimum-maximum	36 - 140	35 - 500	30 - 390	
Selenium	Mean	[1]0.0	[1]0.0	[1]0.0	10 μg/L for domestic water supply. (0.01)x(96-hr LC_{50}) for aquatic life.
	Number of samples	2	4	24	
	Standard deviation	0.0	0.0	0.0	
	Minimum-maximum	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	
Zinc	Mean	26.1	27.4	28.8	5000 μg/L for domestic water supply. (0.01)x(96-hr LC_{50}) for aquatic life.
	Number of samples	8	24	26	
	Standard deviation	14.2	23.5	29.1	
	Minimum-maximum	9 - 50	0 - 100	0 - 120	

[1] Concentrations below detection limits are recorded as 0 μg/L. Detection limit for selenium is 1.0 μg/L.

water. Because carbon dioxide is readily exchanged between air and water, it is unusual that carbon would limit algal growth. Carbon limitation does occur in situations in which nutrients are in abundant supply, for example, in a sewage lagoon.

Important sources of organic carbon in water include algal cells and excretory products from algae, higher aquatic plants, sewage effluents, decaying leaf matter, and feedlot runoff. For the study sites, total organic carbon concentrations (table 8) are usually within the range of 5-15 mg/L identified by Weiss and others (1973) as characteristic of unpolluted streams in the region. Observed concentrations vary only slightly from station to station.

Average concentrations of dissolved organic carbon are greater than average concentrations of total organic carbon below Jordan Dam and at Lock 1 (table 8). This comparison is based on samples collected on different days--hence the impossible relation. Samples taken at the same time indicate that concentrations of dissolved organic carbon are about 10 percent less than concentrations of total organic carbon.

Table 7. Comparison of mercury concentrations for the Haw River at sampling sites within 2 miles of the B. Everett Jordan Dam

Sampling dates[1]	Statistic	Total mercury ($\mu g/L$)	Source
January, 1971- March, 1972	Mean Number of samples Minimum-maximum	0.12 5 0.03 - 0.30	Weiss, and others, 1972.
September, 1972- September, 1973	Mean Number of samples Minimum-maximum	0.29 23 0.01 - 0.81	Perkins and Yarborough, 1974.
April, 1974- March, 1975	Mean Number of samples Minimum-maximum	1.60 12 <1.0 - 9.0	U.S. Army Corps of Engineers, 1975.
April, 1975- March, 1976	Mean Number of samples Minimum-maximum	0.48 12 <0.2 - 1.0	U.S. Army Corps of Engineers, 1976.
October, 1975- June, 1980	Mean Number of samples Minimum-maximum	0.25 4 0.0 - 0.5	U.S. Geological Survey.

[1] Construction on Jordan Dam began in 1970 and the lake was filled in 1981.

Nitrogen

Inorganic nitrogen is a major factor in controlling algal growth. Although there are numerous cases in which phosphorus rather than nitrogen causes excessive algal populations (Wetzel, 1975), nitrogen can be regarded as a significant factor in many cases (Golterman, 1975). Table 9, modified from Wetzel (1975), shows that lake productivities correspond roughly to their nitrogen levels. Others studies suggest 0.3 mg/L as an approximate concentration of nitrogen below which algal growths do not occur in lakes (Sawyer, 1947; Sakamoto, 1966; Vollenweider, 1971). Although results of the above studies apply to lakes, nitrogen concentrations in streams greater than 0.3 mg/L may be roughly indicative of the level at which nuisance algal growths could occur, other controlling factors being favorable. Streams are different from lakes; they are continually being flushed, and algal growths may be washed downstream before nuisance populations have a chance to develop. In addition, other nutrients may be limiting, or, if all nutrients are available in adequate supply, some non-nutritional factor, such as light or temperature, may restrict algal productivity.

Algae are capable of using nitrogen dissolved in water in the form of organic nitrogen, ammonia, nitrite, and nitrate (Vollenweider, 1971). Therefore, a summation of these species offers the best estimate of nitrogen available to plants. At study sites, concentrations of available dissolved nitrogen are almost always greater than 0.3 mg/L (table 8). Specifically, the average concentration of available dissolved nitrogen is 1.02 mg/L at Lock 1, 0.99 mg/L at Lillington, and 1.31 mg/L at Jordan Dam. At each location, nitrogen is available in excess of the amount needed for abundant algal growth.

Nitrogen concentrations at the study sites generally decrease downstream. Average total nitrogen concentrations (suspended plus dissolved) are 1.94 mg/L in the Haw River below Jordan Dam, 1.33 mg/L in the Cape Fear River at Lillington, and 1.21 mg/L in the Cape Fear River at Lock 1 (table 8). Most of the nitrogen species follow the same general pattern. Highest concentrations of almost

Table 8. Summary statistics for nutrients in water from key locations in the Cape Fear River basin, 1975-80 water years

[Results in milligrams per liter]

Constituent	Statistic	Location			
		Haw River, Jordan Dam	Deep River, Moncure	Cape Fear River, Lillington	Cape Fear River, Lock 1
Total organic carbon	Mean	9.8	-	13	8.6
	Number of samples	3		20	29
	Standard deviation	1.9		7.5	2.7
	minimum-maximum	8.5 - 12		4.8 - 38	2.0 - 14
Dissolved organic carbon	Mean	12.8	-	12	11.2
	Number of samples	8		24	16
	Standard deviation	8.5		4.9	3.2
	Minimum-maximum	6.5 - 29		4.3 - 28	6.6 - 17
Total ammonia nitrogen	Mean	[1]0.36	[1]0.37	[1]0.08	[1]0.14
	Number of samples	25	16	51	69
	Standard deviation	1.06	1.21	0.08	0.07
	Minimum-maximum	0.01 - 5.2	0.03 - 4.9	0 - 0.38	0.02 - 0.35
Dissolved ammonia nitrogen	Mean	0.05	-	0.04	0.13
	Number of samples	8		24	11
	Standard deviation	0.04		0.04	0.09
	Minimum-maximum	0.01 - 0.11		0 - 0.16	0.02 - 0.28
Total organic nitrogen	Mean	0.72	-	0.77	0.54
	Number of samples	9		24	29
	Standard deviation	0.27		0.36	0.20
	Minimum-maximum	0.40 - 1.3		0.33 - 1.8	0.26 - 1.2
Dissolved organic nitrogen	Mean	0.49	-	0.49	0.34
	Number of samples	8		24	11
	Standard deviation	0.17		0.18	0.13
	Minimum-maximum	0.29 - 0.72		0.31 - 1.2	0.15 - 0.58
Total nitrate nitrogen	Mean	[1]1.00	[1]0.52	[1]0.65	[1]0.57
	Number of samples	32	23	58	101
	Standard deviation	0.67	0.23	0.36	0.20
	Minimum-maximum	0.23 - 2.7	0.03 - 0.97	0.02 - 1.5	0.04 - 1.2
Dissolved nitrite + nitrate nitrogen	Mean	0.77	-	0.46	0.55
	Number of samples	8		24	11
	Standard deviation	0.49		0.26	0.24
	Minimum-maximum	0.25 - 1.50		0.01 - 1.2	0.31 - 1.2
Total Kjeldahl nitrogen	Mean	[1]1.04	[1]0.57	[1]0.67	[1]0.63
	Number of samples	32	23	57	96
	Standard deviation	1.19	0.31	0.31	0.16
	Minimum-maximum	0.40 - 7.2	0.30 - 1.7	0.30 - 2.0	0.32 - 1.2
Total nitrogen	Mean	1.94	-	1.33	1.21
	Number of samples	9		24	61
	Standard deviation	0.96		0.54	0.31
	Minimum-maximum	0.96 - 3.6		0.43 - 2.6	0.36 - 2.1
Total orthophosphate	Mean	[1]0.16	[1]0.04	[1]0.07	[1]0.03
	Number of samples	4	3	2	3
	Standard deviation	0.04	0.01	0.05	0.01
	Minimum-maximum	0.11 - 0.19	0.04 - 0.05	0.03 - 0.10	0.02 - 0.04
Dissolved orthophosphate	Mean	[1]0.36	[1]0.19	[1]0.12	[1]0.09
	Number of samples	28	20	42	21
	Standard deviation	0.40	0.25	0.08	0.10
	Minimum-maximum	0.04 - 1.3	0.03 - 12	0.03 - 0.38	0.01 - 0.46
Total phosphorus	Mean	[1]0.51	[1]0.23	[1]0.28	[1]0.21
	Number of samples	31	22	52	95
	Standard deviation	0.36	0.07	0.12	0.08
	Minimum-maximum	0.06 - 1.5	0.14 - 0.37	0.13 - 0.62	0.02 - 0.46
Dissolved phosphorus	Mean	0.24	-	0.13	0.13
	Number of samples	8		24	34
	Standard deviation	0.25		0.07	0.10
	Minimum-maximum	0.05 - 0.71		0.06 - 0.25	0.01 - 0.51

[1] Includes data from North Carolina Department of Natural Resources and Community Development.

Table 9. The association between total inorganic nitrogen, total phosphorus, and algal productivities in lakes (modified from Wetzel, 1975; Vollenweider, 1971)

Total inorganic nitrogen (in mg/L)	Total phosphorus (in mg/L)	Algal productivity level
<0.2	<0.005	Very low.
0.2 - 0.4	0.005 - 0.010	Moderately low.
0.3 - 0.65	0.010 - 0.030	Moderately high.
0.5 - 1.5	0.030 - 0.100	High.
>1.5	>0.100	Very high.

all nitrogen species occur below Jordan Dam (table 8). High nitrogen levels below Jordan Dam are probably the result of wasteloads from upstream development. Nitrogen concentrations at all study sites are well below the 10.0 mg/L established as a North Carolina water-quality standard for drinking water.

Phosphorus

Phosphorus is the nutrient most frequently cited as limiting algal growth. It is a common element that is needed in fairly small amounts compared with other nutrients. The solubility of rocks containing phosphorus is low. Once dissolved, phosphorus is quickly taken up by living organisms or adsorbed onto iron and aluminum hydroxides and oxides. Therefore, the amount of phosphorus available for plant growth at any one time is usually low--and frequently is limiting. Contributions from human activities greatly affect the phosphorus supply of waters. Agriculture and laundry detergents are the development sources that supply the major portion of phosphorus to natural waters (Kramer and others, 1972).

As with nitrogen, specific concentrations of phosphorus have been associated with various degrees of algal production in lakes. Table 9 gives a generalized guide to the amount of algal growth to be expected in a lake with a certain concentration of phosphorus. Several authors (Sawyer, 1947; Sakamoto, 1966; Vollenweider, 1971) are in general agreement that concentrations of total phosphorus in lakes above 0.01 mg/L produce nuisance algal growths. However, Mackenthum (1969) indicates that total phosphorus should not exceed 0.1 mg/L if nuisance growths in streams are to be prevented. The National Technical Advisory Committee (1968) halves the value suggested by Mackenthum and lists 0.05 mg/L as the limit "for streams entering impoundments."

Average dissolved phosphorus concentrations (table 8) at all study sites exceed 0.05 mg/L. Average total phosphorus concentrations at Lock 1, Lillington, and Moncure range between 0.21 and 0.28 mg/L (table 8). Below Jordan Dam, the average concentration for total phosphorus is 0.51 mg/L, nearly double that at the other study sites (table 8). Even dissolved orthophosphate, that fraction considered available to algae, occurs in concentrations at study sites that exceed 0.05 mg/L (table 8). Thus, concentrations of phosphorus at study sites are more than adequate to support algal growths.

Nutrient Relations

One way to estimate whether nitrogen or phosphorus is the factor controlling algal growth is to compare their relative abundance in water with the relative needs of the plants growing in that water. Although there is a certain amount of variability in plant tissue compositions, Redfield and others (1963) have defined a typical alga as requiring 106 carbon atoms for every 16 nitrogen atoms for each phosphorus atom. This ratio of 106:16:1 is equivalent to a ratio of 41:7:1 by weight and is virtually the same as the ratio of 40:7:1 put forth by Vallentyne (1974) as typical of aquatic algae and higher aquatic plants. By comparing the ratio of nutrients at study sites with these generalized plant ratios, a determination can be made as to which nutrient is in short supply.

Ratios of carbon to nitrogen to phosphorus for study sites listed in table 10 indicate that available nitrogen is in short supply, relative to carbon and phosphorus. Nitrogen may be in shorter supply at study sites than phosphorus; however, implementation of controls on phosphorus inputs may be technically and economically more feasible than controls on nitrogen inputs. Because both nitrogen and phosphorus are in abundant supply at the study sites, some other factor may limit plant productivity.

Certain qualifications should accompany the statistics presented in table 10. Carbon concentrations cited in table 10 are a combination of average total organic carbon and average bicarbonate carbon because total carbon measurements are not available. Therefore, carbon concentrations given in table 10 probably underestimate the amount of carbon in a stream

Table 10. Ratios of nutrients for selected stations[1]

Location	Average C : N : P concentration	Average C : N : P ratio	Probable importance as limiting nutrient
Haw River, Jordan Dam	15.9 : 1.94 : 0.51	31 : 4 : 1	N > C > P
Cape Fear River, Lillington	17.9 : 1.33 : 0.28	64 : 5 : 1	N > P > C
Cape Fear River, Lock 1	12.0 : 1.21 : 0.21	57 : 6 : 1	N > P > C

[1] Carbon (C) values are calculated as the sum of total organic carbon and bicarbonate carbon. Nitrogen (N) and phosphorus (P) values are for total concentrations.

because other forms of inorganic carbon such as dissolved carbon dioxide are not included. Therefore, carbon is more abundant and is probably less likely to be a limiting factor than indicated.

In summary, nitrogen and phosphorus at study sites occur in concentrations capable of supporting nuisance algal growths, but nuisance populations were not observed during the study. Data on existing concentrations indicate that neither nitrogen nor phosphorus is limiting. Nitrogen concentrations are higher than phosphorus concentrations, but nitrogen is in shorter supply, relative to the needs of algal cells. An abundant nutrient supply occurs below Jordan Dam.

Organic Compounds

Except for organic carbon and organic nitrogen discussed in the section titled "Nutrients," this report does not address organic compounds in the Cape Fear River basin, because data are not available for study sites. Because of the potential importance of organics such as pesticides, polychlorinated biphenyls, and dyes in the basin, this lack of data is unfortunate. Pfaender and others (1977) examined concentrations of seven pesticides in the Cape Fear River from July 1974 through June 1975, and the reader is referred to their work for an examination of selected organics. More recent data on selected pesticides, trihalomethanes, and total organic carbon from the Cane Creek area of the basin (fig. 1) are published in the draft environmental statement for the proposed Cane Creek Reservoir (North Carolina Department of Natural Resources and Community Development, 1982).

Biological Characteristics

Of the wide range of biological measures available to characterize the health of a stream, only bacterial counts, biochemical oxygen demand, and phytoplankton community structure are evaluated for the study sites. Biological measures enhance water-quality evaluations because they reflect an integrated picture of conditions as evolved in the recent past.

Bacteria

Historically, one of the greatest human health concerns has been the transfer of disease through water. Although the problems of pathogenic contamination of water in the United States have been nearly eliminated by modern water treatment techniques, continued surveillance for contamination is necessary to protect public health.

To monitor bacteriological pathogens in water, fecal coliform bacterial counts are used as indicators of fecal contamination. For drinking water supplies, the maximum allowable count is 1 bacterium per 100 mL of water as an arithmetic average for any month (U.S. Environmental

Protection Agency, 1975b). (This standard is modified depending on the number of samples taken per month and the method of enumerating the bacteria.) For bathing, the established criterion is a geometric mean not to exceed 200 bacteria per 100 mL of water (U.S. Environmental Protection Agency, 1977).

It is inappropriate to judge raw water against the drinking water standard because drinking water receives treatment and the standard applies to the treated water. Bacteriological data for study sites (table 11) generally meet the standards for bathing. Geometric means for total coliform bacteria range from 54 colonies per 100 mL at Moncure to 132 colonies per 100 mL below Jordan Dam. The higer values in the Haw River may reflect the influence of upstream population centers.

Fecal streptococcus bacteria are also used to indicate fecal waste from warmblooded animals. The geometric mean of 36 samples for fecal streptococci at Lock 1 was 97 bacterial colonies per 100 mL of water (table 11), which is about the same as the number of fecal coliforms at that location. This indicates that fecal waste is the primary source of bacterial colonies in the water.

Biochemical Oxygen Demand

Biological processes, such as respiration and decay, and certain chemical processes, such as nitrification and oxidation, consume oxygen. A quantitative measure of the amount of the oxygen-consuming components in water is the 5-day biochemical oxygen demand. This measure is important for establishing discharge permits and as a general measure of the amount of organic material in water. Naturally, large quantities of oxygen-demanding material are undesirable in water because they consume oxygen vital to the health of a stream. Values of 1 to 8 mg/L for biochemical oxygen demand are common for moderately contaminated streams (Nemerow, 1974).

Five-day biochemical oxygen demand at study sites ranges from 1.2 mg/L at Lock 1 to 2.4 mg/L below Jordan Dam (table 11). These values are relatively low and are within the range of moderately contaminated water.

Algae

Algae are simple, nonvascular plants, usually small in size. The chief benefit of algae is their role as producers for aquatic ecosystems, providing the base for the food chain. They also produce oxygen in the process of photosynthesis, an aid in restoring oxygen to oxygen-depleted waters. On the harmful side, algae can sometimes build up to excessive populations. When this happens, algal respiration consumes more oxygen from the water than photosynthesis can restore, and oxygen-depleted water results. Certain species of algae, notably blue-green algae, are associated with taste and odor problems in water supplies. Algae can also restrict recreational uses of a water body, clog intake filters, and result in a general degradation of the aesthetic quality of a lake or stream.

Measured numbers of algal cells range from as low as 6 to as high as 53,000 cells/mL at study sites (table 11). Geometric means range from a low of 360 cells/mL at Lock 1 to a high of 6,647 cells/mL at Lillington (table 11). Interpretation of these data is difficult because cell counts are highly variable in time, and because they were collected during all seasons of the year. Furthermore, the significance of cell counts has been criticized because different species of phytoplankton are different sizes and, therefore, contribute differently to biomass and to production. Generally, phytoplankton counts greater than 5,000 cells/mL are indicative of overenrichment (U.S. Environmental Protection Agency, 1975a). Average phytoplankton counts below Jordan Dam (table 11) indicate that the site is near the borderline of having too many algal cells for a good, healthy ecosystem. Lock 1 has low average phytoplankton counts (table 11). Maximum counts at each of the study sites are well above the 5,000 cells/mL, and this suggests that eutrophic conditions exist at times.

Phytoplankton counts at Lock 1 have large year-to-year and moderate seasonal variations (fig. 13). Peaks in phytoplankton populations during 1975-80 occurred in early spring, generally in March. Low cell counts have occurred with regularity in fall, usually in October or November.

The species composition of the phytoplankton in a flowing-water community is a good indicator of the biological health of a waterway. Blue-green algae are undesirable, whereas diatoms are desirable. Diatoms are readily ingested by animals in higher orders of the food chain, and they seldom cause water-quality problems. The amount of blue-green algae in a population relative to the amount of diatoms and other algae is a measure of the health of the photoplankton of a stream. At Lock 1, the 7-year record indicates that on an annual basis, about 40 percent of the phytoplankton population is composed of blue-greens (fig. 14). Since 1974, no

Table 11. Summary statistics for biological parameters in water from key locations in the Cape Fear River basin, 1975-80

Parameter	Statistic	Location			
		Haw River, Jordan Dam	Deep River, Moncure	Cape Fear River, Lillington	Cape Fear River, Lock 1
Fecal coliform bacteria (colonies per 100 mL)	Geometric mean	[1]132	[1]54	[1]117	[1]94
	Number of samples	83	66	85	102
	Standard deviation	-	-	-	-
	Minimum-maximum	5 - 12,000	5 - 8,900	5 - 19,000	5 - 2,500
Fecal streptococcus bacteria (colonies per 100 mL)	Geometric mean	-	-	-	97
	Number of samples				36
	Standard deviation				-
	Minimum-maximum				8 - 2,500
Five-day biochemical oxygen demand (mg/L)	Arithmetic mean	[1]2.4	[1]1.7	[1]1.7	[1]1.2
	Number of samples	86	67	86	102
	Standard deviation	1.01	1.10	1.04	0.54
	Minimum-maximum	0.6 - 6.0	0.05 - 8.0	0.2 - 7.0	0.1 - 2.6
Phytoplankton count (cells/mL)	Geometric mean	4433	3146	6647	360
	Number of samples	4	7	4	54
	Standard deviation	-	-	-	-
	Minimum-maximum	916 - 53,000	200 - 40,100	2499 - 33,000	6 - 24,340

[1] Includes data from North Carolina Department of Natural Resources and Community Development.

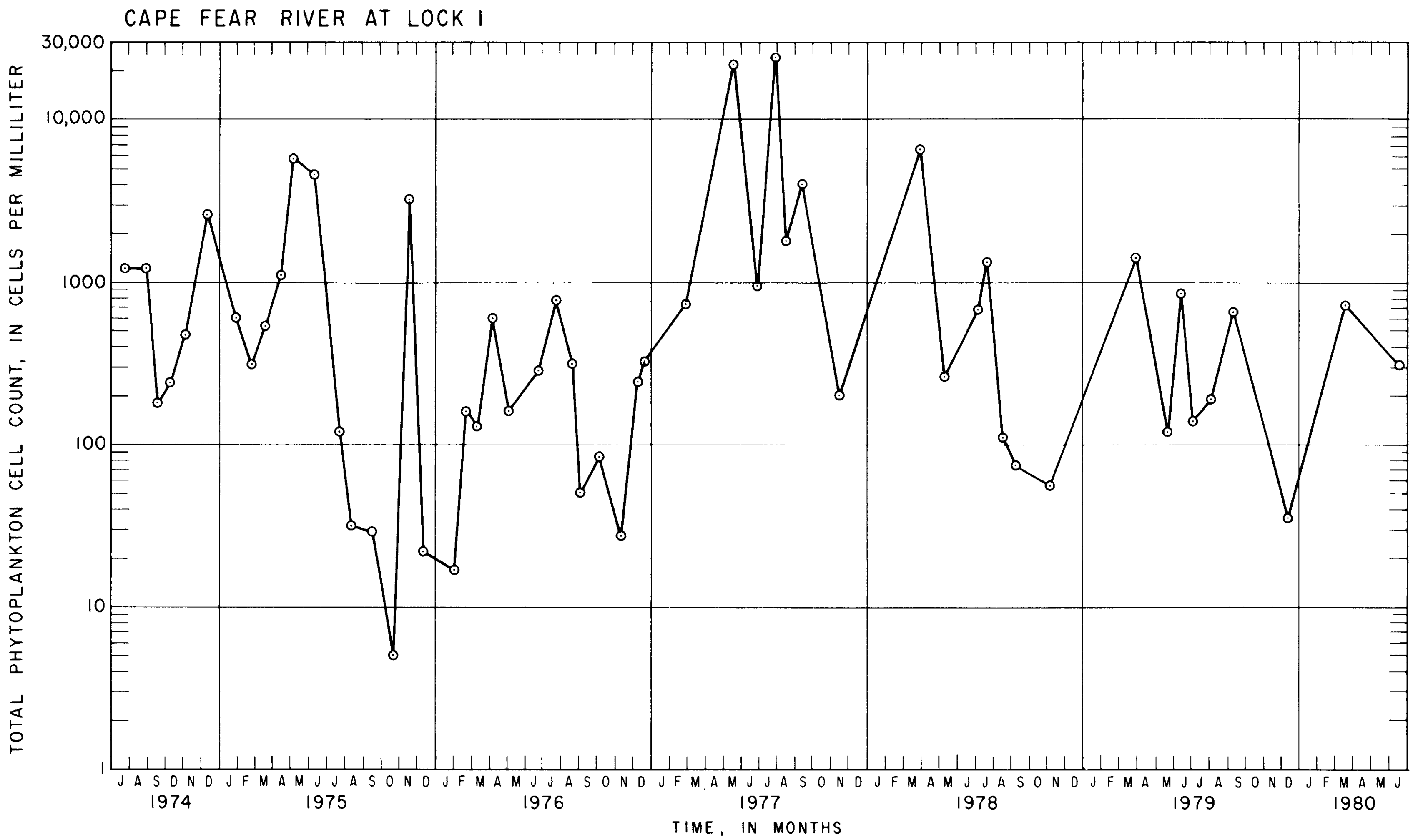

Figure 13. Total phytoplankton cell counts from the Cape Fear River at Lock 1 near Kelly.

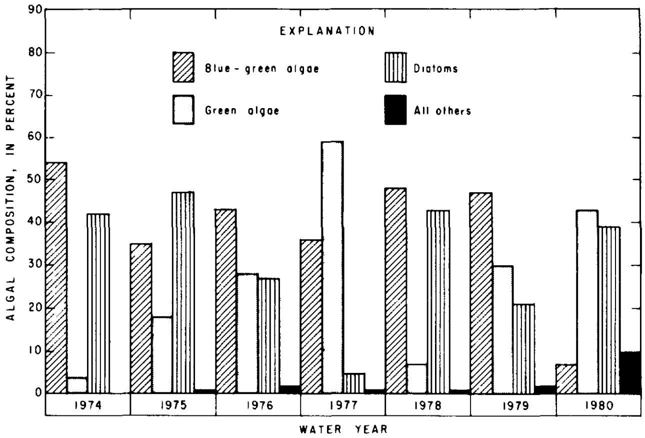

Figure 14. Percentage of various algal groups making up the phytoplankton community of the Cape Fear River at Lock 1 near Kelly.

appreciable increase or decrease in the percentage of blue-greens has occurred. However, figure 14 may be misleading because data are not available for the first half of 1974 or for the second half of 1974 or for the second half of 1980. Blue-green algae usually thrive in late summer. Therefore, the percentages of blue-greens are probably biased on the high side in the annual average for 1974 and biased on the low side for the 1980 annual average. Disregarding data for 1974 and 1980, there appears to be a slightly upward trend in the percentage of blue-greens for 1975-79. A trend may be indicative of a gradual decline in water quality at Lock 1.

This section has presented information about recent conditions at study sites based on data collected from October 1975 through June 1980. In the two following sections, "Development Impacts" and "Trends," water-quality characteristics for existing conditions are compared with conditions that existed previously.

DEVELOPMENT IMPACTS

One goal of this study is to evaluate the impact of development on the water-quality characteristics at study sites. The key to this analysis is determining water-quality characteristics under natural, or baseline, conditions. The impact of development is simply the difference between present and baseline water-quality conditions.

Baseline Water Quality

Simmons and Heath (1979) describe water-quality characteristics of North Carolina streams for nearly undeveloped conditions. They analyzed water-quality measurements at many sites, geographically dispersed across the State; individual watersheds were in near-natural conditions. For these conditions, watersheds of similar geology had similar chemical characteristics. Simmons and Heath identified five geochemical zones in North Carolina (fig. 2). Water-quality characteristics for high- and low-flow conditions are available for each geochemical zone.

Calculation of baseline (natural) water quality for study sites involves applying the methodology of Simmons and Heath. Baseline concentrations for various constituents were computed from the percentage of the subbasin, for each study site, lying within the various geochemical zones (fig. 2). The calculation requires three steps:

1. Determine the percentage of the basin lying within each geochemical zone (table 12),
2. Weight baseline concentrations from each geochemical zone according to the percentage of the drainage subbasin within that zone (table 13); and
3. Sum the weighted concentrations for a total subbasin average baseline concentration (table 13).

The calculations are made for both high flow, Q_H, and low flow, Q_L.

Once baseline concentrations are established, baseline loads, $LOAD_B$, can be calculated from:

$$LOAD_B = k\,(Q_H C_H + Q_L C_L), \qquad (4)$$

where k is a constant depending on the units used, C_H is the baseline water-quality concentration at high flow, and C_L is the baseline water-quality concentration at base flow (table 14). For purposes of this report, annual hydrographs were separated as described by Wilder and Simmons (1978) as modified from Rorabaugh (1964) and Daniel (1976), and the results of that hydrograph separation were used to estimate Q_H and Q_L.

Present Water Quality

Daily values are used to calculate the existing total annual load. This technique requires data on daily mean concentrations for constituents and daily mean discharges. Daily mean discharges are

Table 12. Distribution of land in the Cape Fear River basin among geochemical zones

Geochemical zone (fig. 2)	Area in total Cape Fear basin (mi^2)	Percent of total basin area (percent)	Area upstream from Lock 1 (mi^2)	Percent of area in Lock 1 subbasin (percent)
I	608	7	612	12
II	2834	31	2853	54
III	1124	12	1132	21
IV	3524	39	681	13
V	920	10	0	0
Totals	9010	99	5278	100

available for study sites, whereas daily concentrations of various chemical constituents are rarely available. However, daily concentrations for several constituents can be estimated from relations established with specific conductance. The relations are described in a previous section, "Major Dissolved Substances." Specific conductance is measured continuously at several sites, and, therefore, estimated daily mean concentrations for several constituents can be derived from the previously derived relations. Daily loads for various constituents are calculated by multiplying estimated concentrations by daily mean discharge. Daily loads are summed for each day of the year to obtain annual load. Baseline load is subtracted from annual load to obtain the load attributed to development.

Development-Induced Loads

Development-induced loads were determined for selected constituents at Lock 1. Data for the 1974-79 water years were used to define existing conditions. For those water years, hydrograph separations (Rorabaugh, 1964; Daniel, 1976; Wilder and Simmons, 1978) indicate that an

Table 13. Sample calculation of baseline concentrations for magensium in the Cape Fear River at Lock 1 near Kelly

Geochemical zone	Percentage of Lock 1 subbasin in zone	Baseline concentration, in milligrams per liter		Weighted concentration, in milligrams per liter	
		Low flow[1]	High flow	Low flow	High flow
I	12	0.6	0.4	0.07	0.05
II	54	2.4	1.0	1.30	.54
III	21	.4	.4	.08	.08
IV	13	.4	.4	.05	.05
V	0	.8	.6	0	0
Baseline concentrations for entire Lock 1 Subbasin				1.50	0.72

[1] From Simmons and Heath (1979)

Table 14. Sample calculation of baseline load for magnesium in the Cape Fear River at Lock 1 near Kelly for the 1974 water year

LOW-FLOW CONCENTRATION	x	LOW-FLOW DISCHARGE	x	CONSTANT[1]	=	LOW-FLOW LOAD
1.50 mg/L		763,618 ft /s		0.0027		3100 tons/yr
HIGH-FLOW CONCENTRATION	x	HIGH-FLOW DISCHARGE	x	CONSTANT	=	HIGH-FLOW LOAD
0.72 mg/L		1,145,428 ft /s		0.0027		2200 tons/yr
				TOTAL BASELINE LOAD		5300 tons/yr

[1] Constant converts units to tons/yr.

average of 40 percent of the annual discharge at Lock 1 came from ground water and that 60 percent came from overland runoff. Individual yearly percentages vary slightly from these averages and were taken for year-by-year computation of total baseline water-quality loads.

Development loads for several constituents were calculated using data from Lock 1 in 1974-79 water years. In the few cases in which specific conductance data were missing, specific conductance values were estimated from the exponential relation between specific conductance and discharge. Results of the analysis (table 15) indicate that 50 percent or more of the constituent loads is from development. The one exception is sulfate, with an average contribution from development of 47 percent.

Development loads listed in table 15 indicate little change from year to year and no discernable pattern of increasing or decreasing trends. Variation of baseline and development-induced loads for dissolved solids, 1974-79 water years, is illustrated in figure 15. A considerable amount of waste effluent enters the stream, but loads shown in figure 15 do not indicate significant changes. Development in the basin has been nearly constant during the 1974-79 water years.

TRENDS

The final question to be answered in this report is whether water quality is getting better or worse. Water quality is affected by an increasing population and by increasing manufacturing activities in the Cape Fear River basin. These factors obviously contribute waste effluent to the stream system, and, therefore, water quality may be deteriorating. On the other hand, new and more effective water-quality laws (U.S. Congress, 1973; North Carolina Environmental Management Commission, 1979) have been enacted in recent years. As these laws are implemented, at least some aspects of water quality may be improving.

Water-quality trends are important because they may indicate future water-quality problems. Also, they can help in evaluating the adequacy of existing and new wastewater treatment facilities. Finally, trends can aid in planning for future treatment needs.

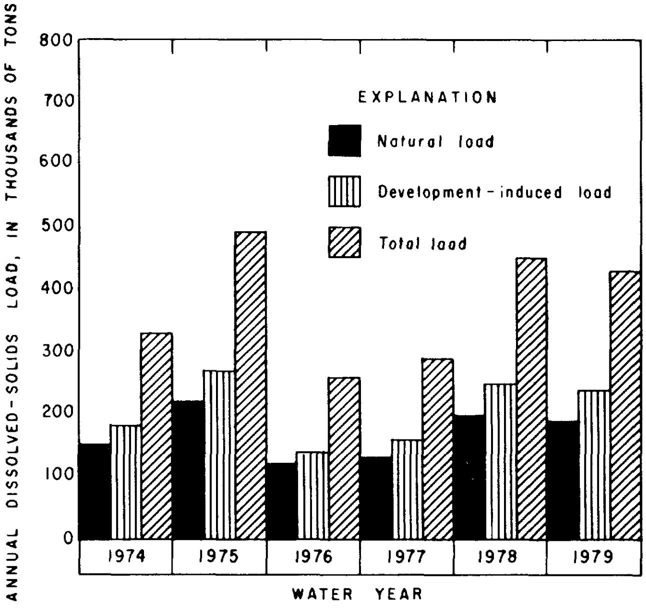

Figure 15. Variations in annual loads of dissolved solids in the Cape Fear River at Lock 1 near Kelly.

Table 15. Annual loads of selected constituents for the Cape Fear River at Lock 1 near Kelly

Constituent	Water year	Existing annual load (tons/yr)	Baseline load (tons/yr)	Load from development (tons/yr)	Percentage of annual load due to development (percent)
Magnesium	1974	11,000	5,300	5,700	52
	1975	16,000	8,000	8,000	50
	1976	8,300	4,300	4,000	48
	1977	9,200	4,500	4,700	51
	1978	15,000	7,000	8,000	53
	1979	14,000	7,000	7,000	50
Potassium	1974	9,600	4,100	5,500	57
	1975	14,000	6,500	7,500	54
	1976	7,600	3,100	4,500	59
	1977	8,600	3,500	5,100	59
	1978	13,000	5,800	7,200	55
	1979	13,000	5,500	7,500	58
Sodium	1974	36,000	13,000	23,000	64
	1975	41,000	20,000	21,000	51
	1976	31,000	11,000	20,000	65
	1977	37,000	11,000	26,000	70
	1978	43,000	17,000	26,000	60
	1979	45,000	17,000	28,000	62
Bicarbonate	1974	82,000	18,000	64,000	78
	1975	120,000	27,000	93,000	78
	1976	66,000	14,000	52,000	79
	1977	75,000	15,000	60,000	80
	1978	110,000	24,000	86,000	78
	1979	110,000	23,000	87,000	79
Chloride	1974	61,000	15,000	46,000	75
	1975	85,000	22,000	63,000	74
	1976	49,000	12,000	37,000	76
	1977	56,000	12,000	44,000	79
	1978	81,000	20,000	61,000	75
	1979	79,000	19,000	60,000	76
Sulfate	1974	46,000	24,000	22,000	48
	1975	63,000	37,000	26,000	41
	1976	37,000	17,000	20,000	54
	1977	42,000	20,000	22,000	52
	1978	60,000	35,000	25,000	42
	1979	59,000	32,000	27,000	46
Dissolved solids	1974	330,000	150,000	180,000	55
	1975	490,000	220,000	270,000	55
	1976	260,000	120,000	140,000	54
	1977	290,000	130,000	160,000	55
	1978	450,000	200,000	250,000	56
	1979	430,000	190,000	240,000	56

For the Cape Fear River at Lock 1, slight upward trends were found for several dissolved major ions included in this study. Slight downward trends were identified for pH and silica. Methodology used to arrive at these conclusions and the results on which the conclusions are based are described in this section.

Trend Analysis Techniques

Detection of water-quality trends in streams is complicated by the effects of stream discharge. A series of drier than normal years or wetter than normal years can create the appearance of a change in water quality that may be only a consequence of variations in flow. Thus, trend-detection efforts should adjust for the influence of discharge before evaluating trends.

Techniques adapted from Hirsch and others (1982) are used to analyze the Cape Fear River data for trends. This methodology uses regression techniques to account for the effects of discharge on water quality. First, a line is fitted to the concentration-versus-discharge data. Five different functions (linear, inverse, hyperbolic, logarithmic, and log-log) are fitted to the data by least squares regression, and the residuals are squared and summed for each function. The function with the smallest sum of squared residuals is chosen as the best fit. Residuals from this line are considered to have the effects of discharge removed. Next, residuals are adjusted to the long-term period-of-record average concentration by adding the residuals to the period-of-record average. This keeps the residual in positive space. Adjusted residuals are then tested with linear regression to identify trends.

Combined data from Lock 1 and from Acme were used in the trend analysis. These two stations are approximately 2 miles apart, and there are no significant inputs between them. Water-quality data are available from the Acme station for 1957 through 1973; however, discharge data are not available. Water-quality data are available for Lock 1 from 1973 through 1980; daily discharges are available since July 1969. For 1957 through 1961, samples from the Acme station were taken daily and composited at varying intervals for analysis.

Although the station at Acme is below the uppermost point of tidal influence on the stage of the Cape Fear River, no actual encroachment of saltwater has ever been observed this far up the river. The low chloride concentrations observed in the data for this report confirm this. This observation is reinforced by Giese and others (1979). Their report places the maximum upstream intrusion of saltwater at a point in Brunswick County, approximately 4 miles downstream from the Acme station.

Because discharge data before 1969 are not available for Lock 1, discharges prior to that date were estimated from the measured discharge at Huske Lock. (Details of this estimation are presented in the "Data Collection" part of the "Introduction" section of this report.) Discharge at the Acme station is assumed to be the same as the discharge at Lock 1. For composite water-quality samples at Acme, daily discharges for each of the days represented in the composite were averaged to give a corresponding composite discharge. Only data collected and analyzed by the Geological Survey are used in the trend analysis.

Trend Analysis Results

Results of trend analyses for all the constituents considered in this report are presented in table 16. Both dissolved solids and specific conductance, which are gross measures of several chemical species combined, show statistically significant upward trends.

Potassium, sodium, and magnesium show statistically significant positive trends. Calcium is the only major cation that shows no significant trend. Since sodium is the dominant cation in the system, it makes up a significant portion of the concentration of total dissolved solids and strongly affects specific conductance. The increase in sodium probably accounts for much of the increase in these two overall measures of water quality.

Sulfate and chloride are the only major anions to show a statistically significant upward trend. Increased sulfate concentrations are not, in themselves, particularly disturbing because the 10-mg/L concentration found in the Cape Fear River is much less than the approximately 250-mg/L concentration that can cause laxative effects in humans (U.S. Environmental Protection Agency, 1977). Likewise, 250 mg/L is recommended as the maximum concentration of chloride for domestic water supplies (U.S. Environmental Protection Agency, 1977). Since current average chloride concentrations at study sites are less than 10 mg/L, the slight upward trend in chloride concentrations is probably of little consequence.

Of the nutrients, only total nitrite plus nitrate nitrogen is increasing at Lock 1 (table 16); available data for other forms of nitrogen show no statistically significant trend. Neither total

Table 16. Results of trend analyses for various chemical constituents from the Cape Fear River at Lock 1 near Kelly, 1957-80

Constituent	Regression equation	Correlation coefficient	Slope statistically different from zero?[2]	Number of observations
Specific conductance	SC = -1274 + 0.69 (Date)	0.23	Yes	310
pH	pH = 25.5 - 0.01 (Date)	-.17	Yes	344
Hardness	Hard = -40 + 0.03 (Date)	.07	No	284
Dissolved calcium	Ca = 23.3 - 0.01 (Date)	.08	No	281
Dissolved magnesium	Mg = -22 + 0.01 (Date)	.23	Yes	281
Dissolved sodium	Na = -183 + 0.10 (Date)	.25	Yes	279
Dissolved potassium	K = -70 + 0.04 (Date)	.53	Yes	279
Bicarbonate ion	HCO_3 = 120 - 0.05 (Date)	.07	No	292
Total alkalinity	Alk = 30 - 0.01 (Date)	.01	No	258
Dissolved sulfate	SO_4 = -470 + 0.24 (Date)	.66	Yes	282
Dissolved chloride	Cl = -136 + 0.07 (Date)	.21	Yes	284
Dissolved fluoride	Fl = 1.0 - 0.0005 (Date)	.04	No	277
Dissolved silica	Si = 93 - 0.04 (Date)	-.18	Yes	278
Dissolved solids	DS = -1170 + 0.63 (Date)	.40	Yes	278
Total nitrite + nitrate nitrogen	NO_3 = -22 + 0.01 (Date)	.24	Yes	230
Total ammonia nitrogen	NH_3 = -0.4 + 0.0003 (Date)	.01	No	50
Total nitrogen	N = 20 - 0.010 (Date)	.03	No	84
Total phosphorus	P = -7 + 0.004 (Date)	.11	No	95
Dissolved phosphorus	DissP = 4.5 - 0.002 (Date)	.06	No	44

[1] Includes data from Cape Fear River station near Acme.

[2] Statistically significant at the 0.01 level of probability.

phosphorus nor dissolved phosphorus shows a trend. Except for nitrite plus nitrate nitrogen, nutrients were not monitored for more than a 9-year period. Therefore, the data record may be too short to detect slight trends.

Dissolved silica and pH show significant decreasing trends. In general, dissolved substances are gradually increasing at Lock 1. This is shown by statistically significant upward trends in specific conductance and total dissolved solids. Although other ions, specifically magnesium, potassium, and choloride, are increasing, it is sodium and sulfate that appear to be the primary individual constituents contributing to the overall upward trend.

Basin Influences on Water-Quality Trends

Identification of the causes of water-quality trends at Lock 1 is appropriate. Many development factors may contribute to changes in water-quality conditions over time, including increasing population, larger volumes of industrial sewage effluent, more automobiles, and changing agricultural practices such as the increasing use of fertilizers.

For this study, data on population, agriculture, and manufacturing were pooled from available sources. Population data were taken from official census counts (U.S. Department of

Commerce, 1971, 1981). These data are available county-by-county at 10-year intervals. Linear interpolation was used to calculate populations for years between official census counts. County totals were adjusted to include only that portion of the county that actually lies within the Cape Fear River basin. This adjustment was based on subbasin population (North Carolina Department of Water and Air Resources, 1972) calculated from detailed census maps for 1970 census data. Adjusted county populations were summed to obtain a total basin population.

Harvested cropland was used as an indicator of agricultural activity. The number of acres of cropland harvested annually from 1953 through 1976 for each county was available from the U.S. Department of Agriculture (1978). Countywide cropland figures were adjusted to include only the amount of cropland in the Cape Fear River basin. The adjustment was done on the basis of the percentage of total land area of a county that is in the basin. Harvested cropland data for 1977 through 1980 were not available.

The number of people employed in manufacturing was used as an indicator of industrial activity. Manufacturing employment data available from the Employment Security Commission of North Carolina (1973-1980) were compiled annually beginning in 1962, by county. Again, population distribution data were used to adjust countywide manufacturing employment data to values representative of the portion of the county actually within the basin boundaries. County data were summed to give an overall value representing the entire Lock 1 subbasin. Manufacturing employment data are not available from 1957 to 1961.

To assess the impact of population, agriculture, and industry on water quality, correlations were calculated between each of the indicator measures and various water-quality constituents. Annual averages of adjusted residual values were used as the most representative measure of the various constituents. Results for the more important constituents are presented in table 17.

Specific conductance and dissolved solids are indicative of the broad response of water quality. Both are significantly correlated with population and with manufacturing employment in the basin. Both are also *negatively* correlated with the amount of cropland harvested. These relations are depicted graphically for specific conductance in figure 16. The positive correlations of specific conductance and dissolved solids with population and industrial activity are not surprising. Increases in population and manufacturing bring predictable deterioration in water quality.

The negative correlation between agricultural activity and water quality is unexpected. Normally, decreasing cropland acreage would be accompanied by lower concentrations of water-quality constituents. The reverse effect is occurring in the Cape Fear River basin. Cropland acreage is declining, but water quality continues to deteriorate.

At least four points are relevant to this apparent anomaly. First, the impact of population, or industrial activity or other contributing factors, may be so great as to overshadow any water-quality improvements resulting from reductions in agricultural activity. Second, the measure used to assess the impact of agriculture, acres of cropland harvested, is of limited scope and may not reflect changes in other types of agricultural activity. For

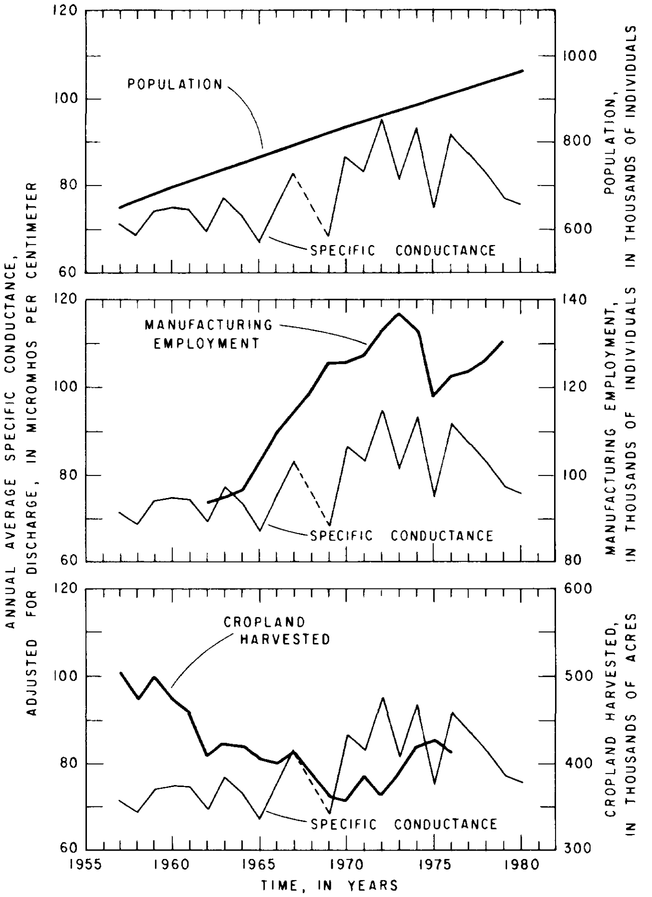

Figure 16. Annual variations of specific conductance, adjusted for discharge, for the Cape Fear River at Lock 1 near Kelly, with population, manufacturing employment, and cropland harvested in the basin.

Table 17. Correlation coefficients for concentrations of selected chemical constituents for the Cape Fear River at Lock 1 near Kelly, adjusted for discharge, and population, agriculture, and industry in the Lock 1 near Kelly subbasin, 1957-80

Constituent	Correlation coefficient[1]		
	Subbasin population	Subbasin Cropland harvested	Subbasin manufacturing employment
Specific conductance	0.51* (24)	-0.45* (20)	0.58* (18)
Dissolved solids	0.72* (24)	-0.58* (20)	0.77* (18)
Dissolved calcium	-0.17 (24)	-0.28 (20)	0.27 (18)
Dissolved magnesium	0.49* (24)	-0.41 (20)	0.65* (18)
Dissolved sodium	0.41* (24)	-0.54* (20)	0.35 (18)
Dissolved potassium	0.86* (24)	-0.61* (20)	0.77* (18)
Dissolved sulfate	0.85* (24)	-0.79* (20)	0.74* (18)
Dissolved chloride	0.30 (24)	-0.66* (20)	0.29 (18)
Dissolved nitrite plus nitrate nitrogen	0.61* (22)	-0.14 (18)	0.80* (18)
Bicarbonate	-0.27 (24)	0.07 (20)	0.01 (18)
Total alkalinity	-0.21 (20)	-0.08 (16)	0.08 (17)
pH	-0.30 (24)	0.34 (20)	0.55* (18)
Dissolved silica	-0.13 (24)	0.22 (20)	0.55* (18)
Total hardness	0.14 (24)	-0.41 (20)	0.54* (18)

[1] Number of years of data used in analysis shown in parentheses.

*Statistically significant at the 0.05 level of probability.

example, possible increases in dairy or poultry farming may offset water-quality improvements due to the reduction in harvested cropland. Third, as the amount of harvested cropland in the basin declines, other land uses (urban development, pastureland) increase. If these new land uses contribute to water-quality deterioration, then there may be little or no overall effect on water quality when land is taken out of agricultural production. Fourth, agricultural cultivation contributes heavily to the amounts of materials in suspension. All the water-quality measures examined in this correlation analysis are for dissolved constituents and therefore may not be strongly affected by changes in harvested cropland (Holt, 1973).

Significant positive correlations were also found for dissolved magnesium, dissolved potassium, dissolved sulfate, and dissolved nitrite plus nitrate nitrogen, with both population and manufacturing employment (table 17). Dissolved sodium was significantly correlated with population, but not with manufacturing employment. Significant negative correlations were found between harvested cropland and dissolved sodium, dissolved potassium, dissolved sulfate, and dissolved chloride (table 17). Significant correlations could not be found for dissolved calcium with either population, industrial activity, or cropland.

Dissolved silica, total hardness, and pH were all positively correlated with manufacturing employment.

In sum, dissolved water-quality consitiuents at Lock 1 generally vary positively with population and industrial activity and inversely with the acres of cropland harvested; however, causation cannot be assumed from correlation. Population and manufacturing employment are strongly correlated with each other ($r=0.81$, $p=0.001$), making it difficult to evaluate the relative impact of these individual measures of development on water quality.

SUMMARY

This study was undertaken to identify variability, loads, and long-term trends in selected chemical constituents for selected sites on the Cape Fear River basin upstream from Lock 1 near Kelly. Study sites included the Haw River below Jordan Dam, the Deep River at Moncure, the Cape Fear River at Lillington, and the Cape Fear River at Lock 1 near Kelly. Data indicate that, overall, water quality at the study sites is suitable for most purposes. High concentrations of nitrogen and phosphorus (plant nutrients) and mercury occurred at the Haw River below Jordan Dam, and on two occasions dissolved-oxygen concentrations in the Cape Fear River at Lock 1 fell below the 5.0 mg/L recommended for the maintenance of fish populations.

Values of pH were frequently below the 6.5 pH units recommended for the protection of freshwater aquatic life. The lowest measured pH, 4.7 units in the Deep River at Moncure, is below the minimum criterion level for domestic water supplies.

Suspended sediment concentrations average 111 mg/L at Lillington and 37 mg/L at Lock 1. At both stations, the concentration of suspended sediment varies closely with discharge.

Concentrations of major dissolved consitiuents at study sites are well within water-quality criteria. Dissolved-solids concentations, which average around 70-75 mg/L, and specific conductance concentrations, which average around 100 µmho/cm, are indicative of unpolluted water. Concentrations of most constituents decrease in the downstream direction, away from population centers near the headwaters of the basin. Bicarbonate, averaging 17.5 mg/L at Lock 1, is the dominant anion and sodium, averaging 8.6 mg/L at Lock 1, is the major cation.

Trace elements are usually within safe concentration limits. However, data from several sources show mercury concentrations exceeding the recommended level of 0.20 µg/L for the protection of freshwater aquatic life. The highest metal concentrations among the study sites are invariably found in the Haw River below Jordan Dam.

Nutrients are in abundant supply at study sites. Both nitrogen and phosphorus are frequently found at levels that support problem algal growths in lakes. Dissolved nitrite plus nitrate nitrogen averages 0.55 mg/L at Lock 1. This is well above the 0.30 mg/L normally cited as the level below which nuisance algal growths do not normally occur in lakes. Total phosphorus, averaging 0.21 mg/L at Lock 1, is also much higher than the 0.01 mg/L below which nuisance algal growths do not normally occur. Nitrogen and phosphorus are not limiting to algal growth in the Cape Fear River; therefore the potential exists for algae to grow abundantly.

As of 1980, phytoplankton populations at study sites are low and composed mostly of beneficial types (diatoms and green algae). There is a hint of increasing proportions of undesirable blue-green algae, but the evidence for this trend is not conclusive.

When 1980 water-quality conditions at study sites are compared with the estimated natural water quality, increased concentrations are found for most constituents. More than 50 percent of the 1980 load of dissolved potassium, dissolved bicarbonate, dissolved sulfate, dissolved chloride, and total dissolved solids is attributable to inputs from development. More than 80 percent of the nitrite plus nitrate nitrogen, ammonia nitrogen, and total phosphorus presently in the stream originates from development activity.

Concentrations of several constituents, dissolved magnesium, dissolved sodium, dissolved potassium, dissolved sulfate, total nitrite plus nitrate nitrogen, and dissolved chloride, show increasing trends with time at Lock 1. The overall measures of chemical quality, total dissolved solids and specific conductance, are increasing also. Two consitiuents, dissolved silica and pH are decreasing.

Finally, the changes in water-quality conditions at Lock 1 are statistically related to changes in the population, agriculture, and amount of industrial activity in the basin. Concentrations of dissolved magnesium, sodium, potassium, sulfate, nitrite plus nitrate nitrogen, dissolved solids, and specific conductance are all positively correlated with the population. Magnesium, potassium, sulfate, nitrite plus nitrate nitrogen, dissolved solids, specific conductance, pH, dissolved silica, and total hardness are positively correlated with manufacturing employment. Sodium, potassium, sulfate, chloride, specific conductance, and dissolved solids are all negatively correlated with the amount of cropland harvested.

REFERENCES CITED

Anderson, Carolyn, Schiller, D. H., and Yates, R. C.; Heard, J. L., ed., 1978, Preconstruction monitoring report, Shearon Harris Nuclear Power Plant, terrestrial biology, June 1974-January 1978, water chemistry, 1972-1977: Carolina Power and Light Company, 129 p.

Aquatic Control, 1973, Exploratory baseline biota survey of the E-16 site, South River, North Carolina: Carolina Power and Light Company, 232 p.

Boney-Wiggins-Rimer & Associates, 1977, A survey of municipal water supplies of North Carolina: North Carolina Department of Human Resources, 13 vol., exec. summ.

Burns, D. A., Galloway, J. N., and Hendry, G. R., 1981, Acidification of surface waters in two areas of the eastern United States: Water, Air, and Soil Pollution, v. 16, p. 277-285.

Callahan, M. A., and others, 1979, Water-related environmental fate of 129 priority pollutants, Volume I: Introduction and technical background, metals and inorganics, pesticides and PCBs: Environmental Protection Agency EPA-440/4-79-029a, 514p.

Carolina Power and Light Company, no date, Environmental report, Brunswick Steam Electric Plant, units 1 and 2, v. 1 and 2: p. 1.1-1--10.1-1, 7 amendments.

————1980, Shearon Harris Nuclear Power Plant, units 1, 2, 3, and 4, environmental report, operating license stage, v. 1, 2, and 3: p. 1.1-1--13.0-1, 3 app.

Conrad, S. G., Carpenter, P. A., III, and Wilson, W. F., 1975, Physiography, geology, and mineral resources, *in* Clay, J. W., Orr, D. M., Jr., and Stuart, A. W., eds., North Carolina atlas, portrait of a changing southern state: Chapel Hill, The University of North Carolina Press, p. 112-127.

Cullen, Maureen, Hobbs, Ron, and Sager, Dave, 1978, Annual report, Shearon Harris Nuclear Power Plant, baseline monitoring program, aquatic biology unit, 1977: Carolina Power and Light Company, 91 p.

Cullen, Maureen, Hobbs, Ron, Sager, Dave, and Panek, Frank, 1978, Annual report, Shearon Harris Nuclear Power Plant, baseline monitoring program, aquatic biology unit, 1976: Carolina Power and Light Company, 126 p.

Daniel, C. C., III, 1981, Hydrology, geology, and soils of pocosins: A comparison of natural and altered systems, *in* Richardson, C. J., ed., Pocosin wetlands--an integrated analysis of Coastal Plain freshwater bogs in North Carolina: Stroudsburg, Pa., Hutchinson Ross Publishing Company, p. 69-108.

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

Daniel, J. F., 1976, Estimating evapotranspiration from streamflow records: Water Resources Research, v. 12, no. 3, p. 360-364.

Employment Security Commission of North Carolina, 1973, North Carolina labor force estimates by county, area, and state: Bureau of Employment Security Research, Raleigh, 274 p.

————1980, North Carolina labor force estimates by county, area, and state: Bureau of Employment Security Research, Raleigh, 274 p.

Fish, F. F., 1968, A catalog of the inland fishing waters in North Carolina: North Carolina Wildlife Resources Commission, Project F-14-R, 312 p.

Giese, G. L., Wilder, H. B., and Parker, G. G., Jr., 1979, Hydrology of major estuaries and sounds of North Carolina: U.S. Geological Survey Water-Resources Investigations 79-46, 175 p.

Goddard, G. C., 1963, Water-supply characteristics of North Carolina streams: U.S. Geological Survey Water-Supply Paper 1761, 223 p.

Golterman, H. L., 1975, Physiological limnology, an approach to the physiology of lake ecosystems: Amsterdam, Elsevier, 489 p.

Gough, L. P., Shacklette, H. T., and Case, A. A., 1979, Element concentrations toxic to plants, animals, and man: U.S. Geological Survey Bulletin 1466, 80 p.

Harned, D. A., 1982, Water quality of the Neuse River, North Carolina; variability pollution loads, and long-term trends: U.S. Geological Survey Water-Supply Paper 2185-D, 44 p.

Harned, D. A., and Meyer, D., 1983, Water quality of the Yadkin-Pee Dee River System, North Carolina--variability, pollution loads and long-term trends: U.S. Geological Survey Water-Supply Paper 2185-E, 71 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2nd ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hendry, G. R., and others, 1980, Geological and hydrochemical sensitivity of the eastern United States to acid precipitation: U.S. Environmental Protection Agency EPA-600/3-80-024, 100 p.

Hirsch, R. M., Slack, J. R., and Smith, R. A., 1982, Techniques of trend analysis for monthly water quality data: Water Resources Research, v. 18, no. 1, p. 107-121.

Holt, R. F., 1973, Fate of fertilizers and pesticides applied to crop land, *in* Wiebe, J. D., ed., Proceedings of a workshop on water quality and land use activities: Windsor, Canada, International Joint Commission, p. 3-16.

Jackson, N. M., Jr., 1972, Public water supplies of North Carolina, Pt. 1, northern Piedmont: North Carolina Department of Natural and Economic Resources, 277 p.

————1973, Public water supplies of North Carolina, Pt. 2, southern Piedmont: North Carolina Department of Natural and Economic Resources, 255 p.

————1974, Public water supplies of North Carolina, Pt. 3, Mountains and western Piedmont: North Carolina Department of Natural and Economic Resources, 232 p.

Kopec, R. J., and Clay, J. W., 1975, Climate and air quality, *in* Clay, J. W., Orr, D. M., Jr., and Stuart, A. W., eds., North Carolina atlas, portrait of a changing southern state: Chapel Hill, The University of North Carolina Press, p. 92-111.

Kramer, J. R., Herbes, S. E., and Allen, H. E., 1972, Phosphorus: analysis of water biomass and sediment, *in* Allen, H. E., and Kramer, J. R., eds., Nutrients in natural waters: New York, John Wiley, p. 51-100.

Livingstone, D. A., 1963, Chemical composition of rivers and lakes, *in* Data of geochemistry (6th ed.): U.S. Geological Survey Professional Paper 440-G, p. G1-G64.

Mackenthum, K. M., 1969, The practice of water pollution biology: Washington, D.C., Federal Water Pollution Control Administration, 281 p.

Mann, L. T., Jr., 1978, Public water supplies of North Carolina, a summary of water sources, use, treatment, and capacity of water supply systems: U.S. Geological Survey Water-Resources Investigations 78-16, 61 p.

National Academy of Sciences, National Academy of Engineering, 1973, Water quality criteria, 1972: Ecological Research Series EPA.R3.73.033, U.S. Government Printing Office, Washington, D.C., 594 p.

National Atmospheric Deposition Program, 1981, NADP data report--precipitation chemistry: National Resources Ecology Laboratory, Colorado State University, Fort Collins, Colo., v. 3, no. 2, 281 p.

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

Nemerow, N. L., 1974, Scientific stream pollution analysis: New York, McGraw Hill, 358 p.

North Carolina Department of Human Resources, 1980, Water supply data: Water Supply Branch, unpublished.

North Carolina Department of Natural and Economic Resources, 1975, Water quality management plan, Cape Fear River Basin, Parts I, II, III, and IV: Division of Environmental Management, p. CPF-1-CPF-PH75-75.

————1976, North Carolina water quality inventory, 305(b) report, calendar year 1975: Division of Environmental Management, p. I-1-XVI-B-44.

————1977, North Carolina water resources framework study: Division of Environmental Management, p. 1-1--5-12.

North Carolina Department of Natural Resources and Community Development, 1977a, North Carolina water quality inventory, 305(b) report, calendar year 1976: Division of Environmental Management, p. 1-XVI-B-4.

————1977b, Upper Cape Fear water supply alternatives: Division of Environmental Management, 44 p., 6 app., p. 1-F.1.

————1978, North Carolina water quality inventory, 305(b) report, calendar year 1977: Division of Environmental Management, p. 1-XVI-B-40.

————1979, Water quality management plan, executive summary: Division of Environmental Management, 27 p.

————1980a, North Carolina water quality inventory, 305(b) report, calendar years 1978 and 1979: Division of Environmental Management, 291 p.

————1980b, Waste load allocations, 303 E, phase I update: Division of Environmental Management, unpublished.

————1982, Draft Cane Creek eis: Division of Environmental Management, 85 p., 7 app.

North Carolina Department of Water and Air Resources, 1972, Basin population by sub-basin and county: Water Resources Planning Section, 10 p., unpublished data.

North Carolina Environmental Management Commission, 1979, Classification and water quality standards applicable to surface waters of North Carolina: North Carolina Administrative Code, Title 15, Chapter 2, pp. 2-23--2-30.

North Carolina Office of the Governor, 1982, North Carolina municipal population 1980: Office of State Budget and Management, 10 p.

Odum, H. T., 1956, Primary production in flowing waters: Limnology and Oceanography, v. 1, p. 103-117.

Perkins, R. L., and Yarborough, C. G., 1974, An analysis of physical, chemical, and biological aspects of water quality in the upper Cape Fear River basin: Campbell College unpublished report, 226 p.

Pfaender, F. K., Shuman, M. S., Dempsey, H., and Harden, C. W., 1977, Monitoring heavy metals and pesticides in the Cape Fear River basin of North Carolina: Water Resources Research Institute of North Carolina Report 126, 151 p.

Redfield, A. C., Ketchum, B. H., and Richards, F. A., 1963, The influence of organisms on the composition of sea water, *in* Hill, M. N., ed., The sea (v. 2): New York, John Wiley, p. 26-77.

Robison, T. M., 1977, Public water supplies of North Carolina, Pt. 4, northern Coastal Plain: North Carolina Department of Natural and Economic Resources, 218 p.

Robison, T..M., and Mann, L. T., Jr., 1977, Public water supplies of North Carolina, Pt. 5, southern Coastal Plain: North Carolina Department of Natural and Economic Resources, 333 p.

Rorabaugh, M. I., 1964, Estimating changes in bank storage and groundwater contribution to streamflow: International Association of Scientific Hydrology Publication 63, p. 432-441.

Sakamoto, M., 1966, Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth: Arch. Hydrobiol., v. 62, p. 1-28.

Sawyer, C. N., 1947, Fertilization of lakes by agricultural and urban drainage: Journal, New England Water Works Association, v. 61, no. 2, p. 109-127.

Shuman, M. S., Smock, L. A., and Haynie, C. L., 1977, Metals in the water, sediments and biota of the Haw and New

Hope Rivers, North Carolina: Water Resources Research Institute of the University of North Carolina Report 124, 127 p.

Simmons, C. E., 1980, Quality of water in the Black River near Dunn, North Carolina, and ground-water levels adjacent to the river prior to channel excavation in 1976-79: U.S. Geological Survey Open-File Report 80-425, Raleigh, N.C., 18 p.

Simmons, C. E., and Aldridge, M. C., 1980, Hydrology of the Chicod Creek basin, North Carolina, prior to channel improvements: U.S. Geological Survey Open-File Report 80-680, Raleigh, N.C., 27 p.

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

Simmons, C. E., and Watkins, S. A., 1982, The effects of channel excavation on water-quality characteristics of the Black River and on ground-water levels near Dunn, North Carolina: U.S. Geological Survey Water-Resources Investigations 82-4083, 28 p.

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

Triangle J Council of Governments, 1976a, Areawide water quality management plan, 208 pollution source analysis: p. I.A.1-VIII. E.12., app.

————1976b, Areawide water quality management plan, 208 pollution source analysis, summ., 32 p.

————1976c, Areawide water quality management plan, 208 project inventory of existing resources: p. I.A.1-VI.B.45.

————1977, 208 Areawide water quality management plan: p. I.1-XI.8 and 9 supp. reports.

U.S. Army Corps of Engineers, 1961, Comprehensive report on Cape Fear River basin, North Carolina, v. I: Wilmington District, 73 p.

————1971a, New Hope Lake, North Carolina, environmental impact statement, v. I: Wilmington District, 230 p.

————1971b, New Hope Lake, North Carolina, environmental impact statement, v. II: Wilmington District, 110 p.

————1975, Supplement to the final environmental statement, v. II, supplemental studies, B. Everett Jordan Dam and Lake, Cape Fear River Basin, North Carolina: Wilmington District, 527 p.

————1976, B. Everett Jordan Project water quality surveillance: Wilmington District, unpublished report, 78 p.

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

U. S. Atomic Energy Commission, 1974a, Final environmental statement related to the continued construction and proposed issuance of an operating license for the Brunswick Steam Electric Plant, units 1 and 2, Carolina Power and Light Company: p. I-1--XII-44, 6 app.

————1974b, Revised final environmental statement related to construction of Shearon Harris Nuclear Power Plant, units 1, 2, 3, and 4, Carolina Power and Light Company: p. 1-1--12-14, refs., 6 app.

U. S. Congress, 1973, Federal Water Pollution Control Act Amendments of 1972: United States Statutes at Large, Public Law 92-500, U.S. Government Printing Office, Washington, D.C., p. 816-903.

————1978, Clean Water Act of 1977: United States Statutes at Large, v. 91, Public Law 95-217, U.S. Government Printing Office, Washington, D.C., p. 1566-1611.

U.S. Department of Agriculture, 1978, Summary of North Carolina 1977 land utilization survey: North Carolina Crop and Livestock Reporting Service, Raleigh, 5-FR78-7, 7 p.

U.S. Department of Commerce, 1971, 1970 census of population, number of inhabitants, North Carolina: Bureau of the Census, 43 p.

————1981, 1980 census population and housing--North Carolina: Bureau of the Census, PHC80-V-35, 30 p.

U.S. Environmental Protection Agency, 1975a, A compendium of lake and reservoir data collected by the National Eutrophication Survey in the Northeast and North-Central United States: Corvallis Environmental Research Laboratory Working Paper 474, 210 p.

————1975b, National interim primary drinking water regulations: Federal Register, v. 40, no. 248, pt. IV, p. 59566-59574.

————1977, Quality criteria for water, 1976: U.S. Government Printing Office, Washington, D.C., 256 p.

————1981, Water quality criteria; corrections: Federal Register, v. 46, no. 156, p. 40919.

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

Vallentyne, J. R., 1974, The algal bowl: lakes and man: Ottawa Misc. Special Publication 22, Department of Environment, 185 p.

Vollenweider, R. A., 1971, Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication: Paris, Organization for Economic Co-operation and Development, 193 p.

Weiss, C. M., 1970, The relative significance of phosphorus and nitrogen as algal nutrients: Water Resources Research Institute of the University of North Carolina Report 34, 27 p.

————1971, Water quality characteristics of the New Hope and lower Haw Rivers, July 1966-February 1970, with estimates of the probable quality of New Hope Lake: Water Resources Research Institute of the University of North Carolina Report 48, 139 p.

————1974, Long term trends in water quality, lower Haw and New Hope Rivers, 1966-1973: Water Resources Research Institute of the University of North Carolina Report no. 101, 196 p.

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

Weiss, C. M., Yocum, T. W., and Minogue, J. E., 1972, Further characterization of the water quality of the New Hope and lower Haw Rivers including benthic macroinvertebrate diversity and trace metal analyses: Water Resources Research Institute of the University of North Carolina Report 73, 178 p.

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

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

Wilder, H. B., and Slack, L. J., 1971, Summary of data on chemical quality of streams of North Carolina, 1943-67: U.S. Geological Survey Water-Supply Paper 1895-B, 236 p.

Wright, R. F., and Gjessing, E. T., 1976, Acid precipitation: changes in the chemical composition of lakes: Ambio, v. 5, p. 219-223.

METRIC CONVERSION FACTORS

The following factors may be used to convert inch-pound units published herein to the International System of Units (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 (lb)	453.59	grams(g)
Specific Conductance		
micromho (µmho)per centimeter at 25°C.	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, formerly called mean sea level, is referred to as sea level in this report.