Water Quality of North Carolina Streams

United States
Geological
Survey
Water-Supply
Paper 2185 A–D

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

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

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PREFACE

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

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

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

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

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

ENGLISH-METRIC CONVERSION

MULTIPLY ENGLISH UNITS	BY	TO OBTAIN SI UNITS
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	.0929	square meter (m^2)
acre	4047	square meter (m^2)
	.4047	hectare (ha)
	.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
gallon (gal)	3.785	liter (L)
	.003785	cubic meter (m^3)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m^3/s)
cubic foot (ft^3)	.02832	cubic meter (m^3)
cubic foot per second per square mile ($ft^3s^{-1}mi^{-2}$)	.01093	cubic meter per second per square kilometer ($m^3s^{-1}km^{-2}$)
acre-foot	1233.5	cubic meter (m^3)
pound (lb avoirdupois)	0.4536	kilogram (kg)
short ton (2,000 pounds)	.9072	metric ton (t, 1,000 kilograms)
ton per cubic foot (tons/ft^3)	32.03	metric ton per cubic meter (t/m^3)
degree Fahrenheit (°F)	5/9 (°F-32)	degree celsius (°C)

National Geodetic Vertical Datum of 1929 is a geodetic datum drived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts and as such does not necessarily represent local mean sea level at any particular place. To establish a more concise nomenclature, the term "NGVD of 1929" is used in place of "Sea Level Datum of 1929" or "mean sea level."

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Chapter A

Program for Evaluating Stream Quality in North Carolina

By H. B. WILDER and C. E. SIMMONS

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WATER QUALITY OF
NORTH CAROLINA STREAMS

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Program for Evaluating Stream Quality in North Carolina

By H. B. Wilder *and* C. E. Simmons

Abstract

The design and objectives of the program for evaluating stream quality in North Carolina are described. Using water-quality and streamflow data collected since the 1940's, a study is underway to define certain variations in water quality, to quantify the effects of man's activities on water quality, and to determine long-term trends at key locations on the State's major rivers. Data collected from 47 unpolluted stream sites were used to estimate average concentrations for naturally occurring constituents during periods of high and low flow. Methods are described for estimating constituent loads derived from both natural sources and sources of pollution.

INTRODUCTION

In 1972, regional officials of the U.S. Environmental Protection Agency (then, U.S. Federal Water Quality Administration) issued a provisional set of water-quality monitoring guidelines to State pollution control officials in the Southeastern Region. The North Carolina Department of Natural and Economic Resources invited the U.S. Geological Survey to work with them in designing a program that would meet the requirements of these Federal guidelines as well as meet the combined requirements of the two agencies. A joint agency task group extracted the following six major objectives from the EPA guidelines and informally designated them as goals for the statewide water-quality monitoring program:

1. Determine the suitability of waters of the State for specific use.
2. Determine variations in water quality.
3. Determine pollution loads in streams.
4. Determine trends in water quality.
5. Detect contraventions of water-quality standards.
6. Collect data needed for water-quality modeling.

Guidelines from which these goals were extracted have since fallen into disuse, and most of these objectives are no longer obvious in the standards. They still, however, represent a worthy set of water-quality monitoring goals, and are retained as guiding principles for the cooperative program between the U.S. Geological Survey and the North Carolina Department of Natural and Economic Resources to investigate stream water quality. The purpose of this report is to describe the philosophy and methodology that are being used to approach the goals of the program.

None of the goals are mutually exclusive, and data collected primarily for any one of them are applicable to most of the others. It is economically impossible to collect enough data to accomplish every goal at every site at which water-quality data must be collected. Therefore, a division of responsibility was arranged under which the U.S. Geological Survey would make a detailed accounting of water quality at key locations; and the North Carolina Department of Natural and Economic Resources, with a larger more widely distributed staff, would sample a larger statewide network designed to furnish information on specific sources of pollution. Briefly, pollution is defined herein as those changes, both physical and chemical, in water quality caused by man's activities. Ultimately all data are melded in STORET (the U.S. Environmental Protection Agency data system), but arrangements were also made for prompt local interchange of data when desirable.

The final plan called for the U.S. Geological Survey to concentrate on studying water-quality variability, pollution loads, and trends at key locations on North Carolina's major rivers. These locations would be selected to provide a general picture of the present status of water quality across the State, and to allow the earliest possible prognosis of how water quality might be changing. To accomplish these objectives two networks of sampling stations were established:

1. A Primary Network within which presently existing water quality would be studied in detail; and
2. A Natural Quality Network intended to deduce what water quality would be if man had not significantly affected it.

Location of the stations in the two networks, as well as the federally-funded National Stream Quality Accounting Network (NASQAN) stations that make up the rest of the district program, are shown in figure 1. Data collection at the NASQAN station (Ficke and Hawkinson, 1975) is very similar to that of stations in the Primary Network and, for purposes of this discussion, are considered to be a part of that network. There are, however, some major differences in operational concepts between the primary stations and the five NASQAN stations operated in the North Carolina District. Perhaps

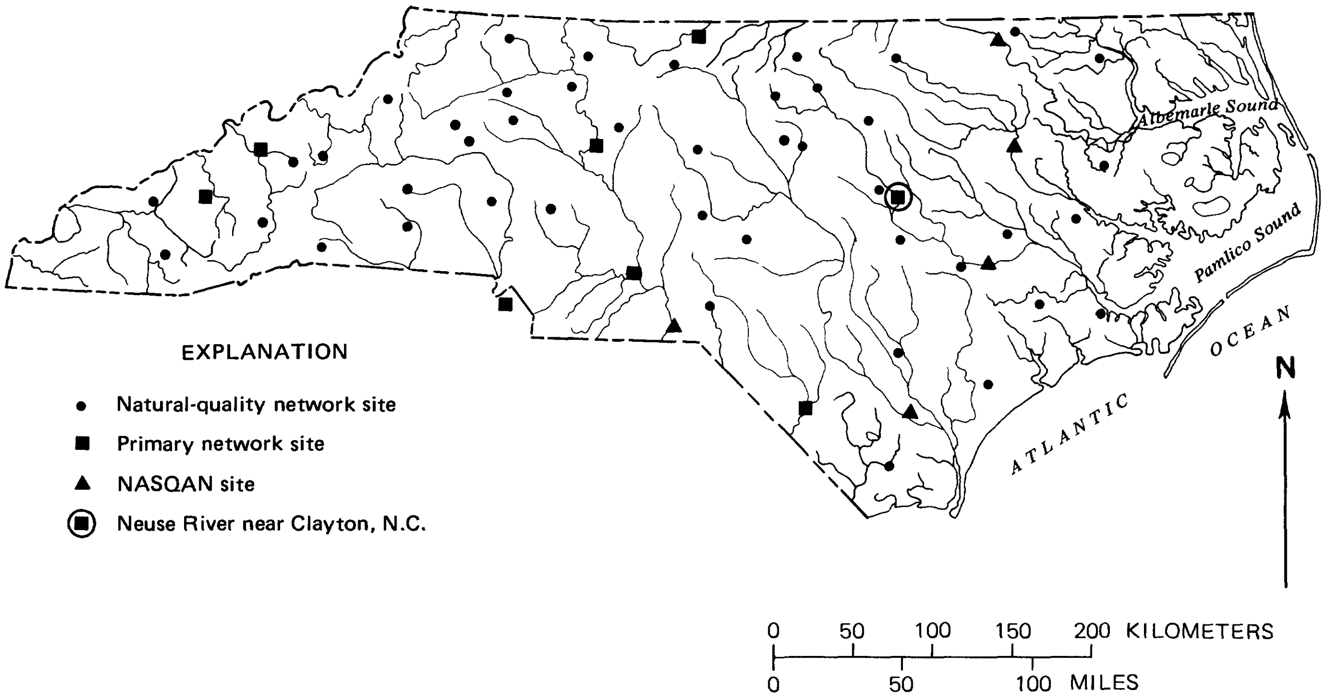


Figure 1. Sampling stations in North Carolina's water-quality program.

the major difference is that the North Carolina program emphasizes collecting samples when conditions warrant rather than sampling on some specified time schedule—a concept familiar in suspended-sediment studies but little used in chemical-quality investigations. An example of the type of coverage considered ideal is shown in figure 2. In actual practice, once a few floods are defined for a station it is often possible to discontinue rigorous coverage of floods, and adopt a more convenient sampling procedure based on continual evaluations of what kinds of data are needed to develop a comprehensive picture of water quality at a particular site. Daily or continuous measurements of specific conductance are made at all Primary and NASQAN sites. Our second departure from the NASQAN concept is that most stations in the Primary Network will be operated for one or two years, and then rotated on a 5–10-year schedule. This will allow us to obtain coverage at a much greater number of locations.

VARIATIONS IN WATER QUALITY

A major initial objective of the program was to gain a better understanding of how water quality at each station varies. Since an ultimate objective is to periodically account for the transport of as many materials as possible in the major rivers of the State, it is important to know how materials are being transported. Knowing that in freshwater streams most of the variations in materials transported are related to variations in streamflow, a rather detailed study of flow-related changes in quality is a first step in the operations of all of our primary stations. Figure 2 shows an example of the kind of sampling and analytical coverage needed early in the operation of each station. Also shown in figure 2 is a graph of specific conductance and values of dissolved-solids for each sample. This illustration is based on data from Neuse River near Clayton, which will be used as an example station throughout this report. It may also be good to note here that most of the data interpretations thus far have been based on dissolved solids, chiefly because most often a sufficient and reliable historical data base is available for this constituent.

Samples from the natural quality stations have been analyzed for a number of inorganic constituents, and nutrients were also determined on some of the samples. Although previous experience has indicated little need to sample pristine streams such as these for trace metals or pesticides, some samples will be analyzed for these constituents to provide background information.

To see how gross concentrations of ionized constituents varied throughout the two flood peaks depicted in figure 2, a plot of the relation between specific conductance and stream discharge (fig. 3) was made. This plot agrees with the findings of Hendrickson and Krieger (1964), as well as various other investigators, in that distinctive differences often are noticed between the quality of water for equivalent discharges on the rising and falling stages of floods. These differences were not significant, however, for the second of the two closely spaced floods, which demonstrates the effect antecendent conditions can have on the transport of materials by streams. These phenomena were investigated further by plotting daily values of specific conductance for rising, falling, and stable streamflows for a full year, as shown in figure 4. This disclosed that, while higher specific conductances (and therefore dissolved solids) do tend to occur on rising stages, there is enough intermixing of the points that, should it become desirable to estimate a dissolved solids value using discharge, there would be little advantage in differentiating between rising and falling stages. The goodness of fit of the points about a line also indicates that it might be possible to make a reasonable estimate of annual dissolved solids loads using streamflow data alone. This is probably true for unpolluted streams, but now, in most of the larger streams in North Carolina, the relation between conductance and streamflow is slowly changing.

Because specific conductance is the only continuous or daily value relative to chemical quality that is measured at most of this district's water-quality stations, the relationship between it and other dissolved constituents is of critical importance if calculations of loads are to be made. Steele (1970) has documented computer methodology for making such comparisons, and several of the same programs were used to compute statistical analyses and the correlation coefficients shown in table 1. Where significant, these correlations will eventually be used to calculate loads of individual constituents and investigate their relation to economic and population growth.

A subject of increasing interest recently has been the transport of trace metals by rivers. Wilder (1972) found that arsenic in Sugar Creek near Charlotte, N.C., was being transported primarily in conjunction with suspended sediment. Similarly, as shown in figure 5, the Neuse River also appears to transport lead in conjunction with the suspended material. The relations of total (suspended plus dissolved) lead and manganese to suspended sediment are shown in figure 6. Although far

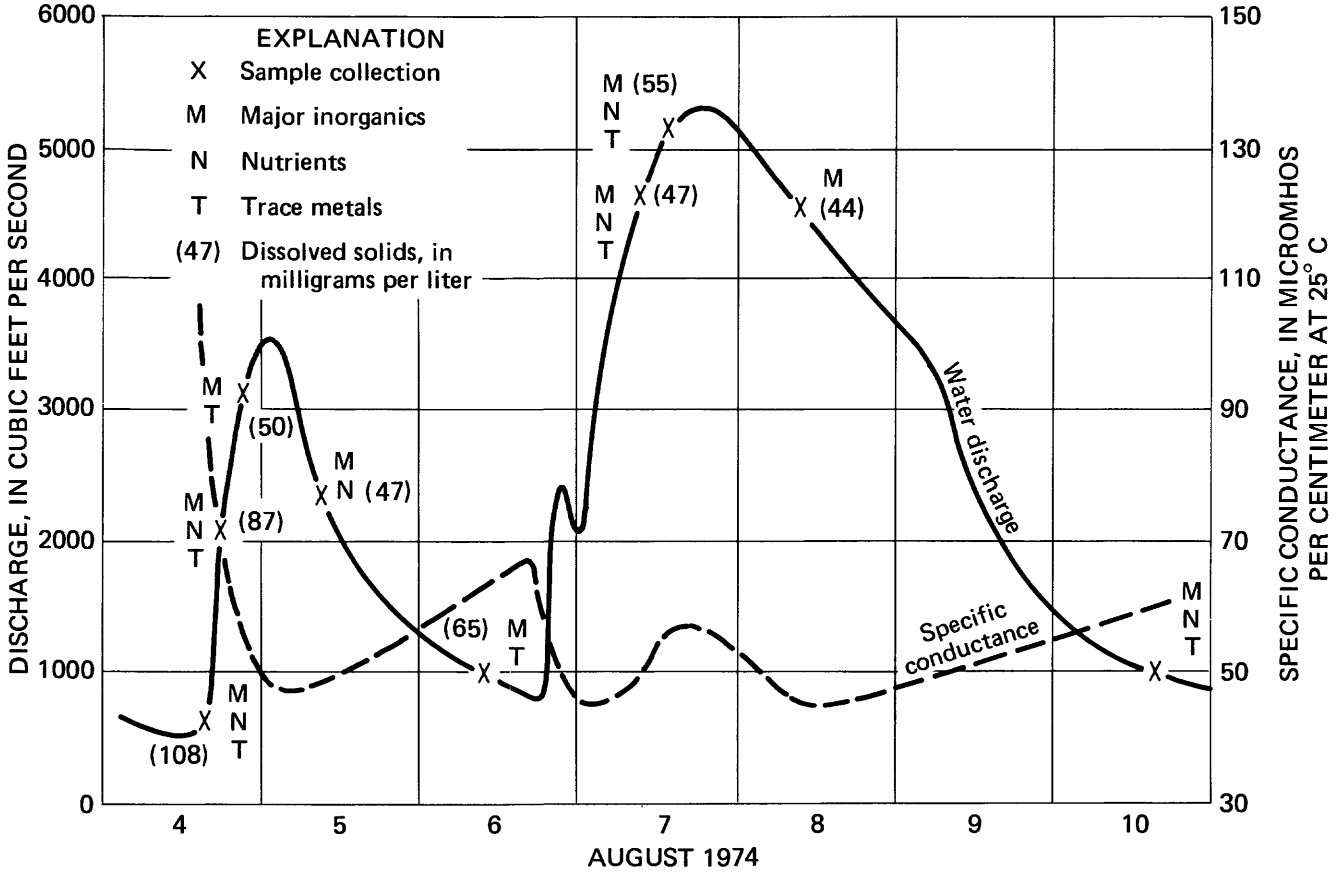


Figure 2. Flood peaks on Neuse River near Clayton showing water-quality samples collected, types of analyses, and values of specific conductance and dissolved solids.

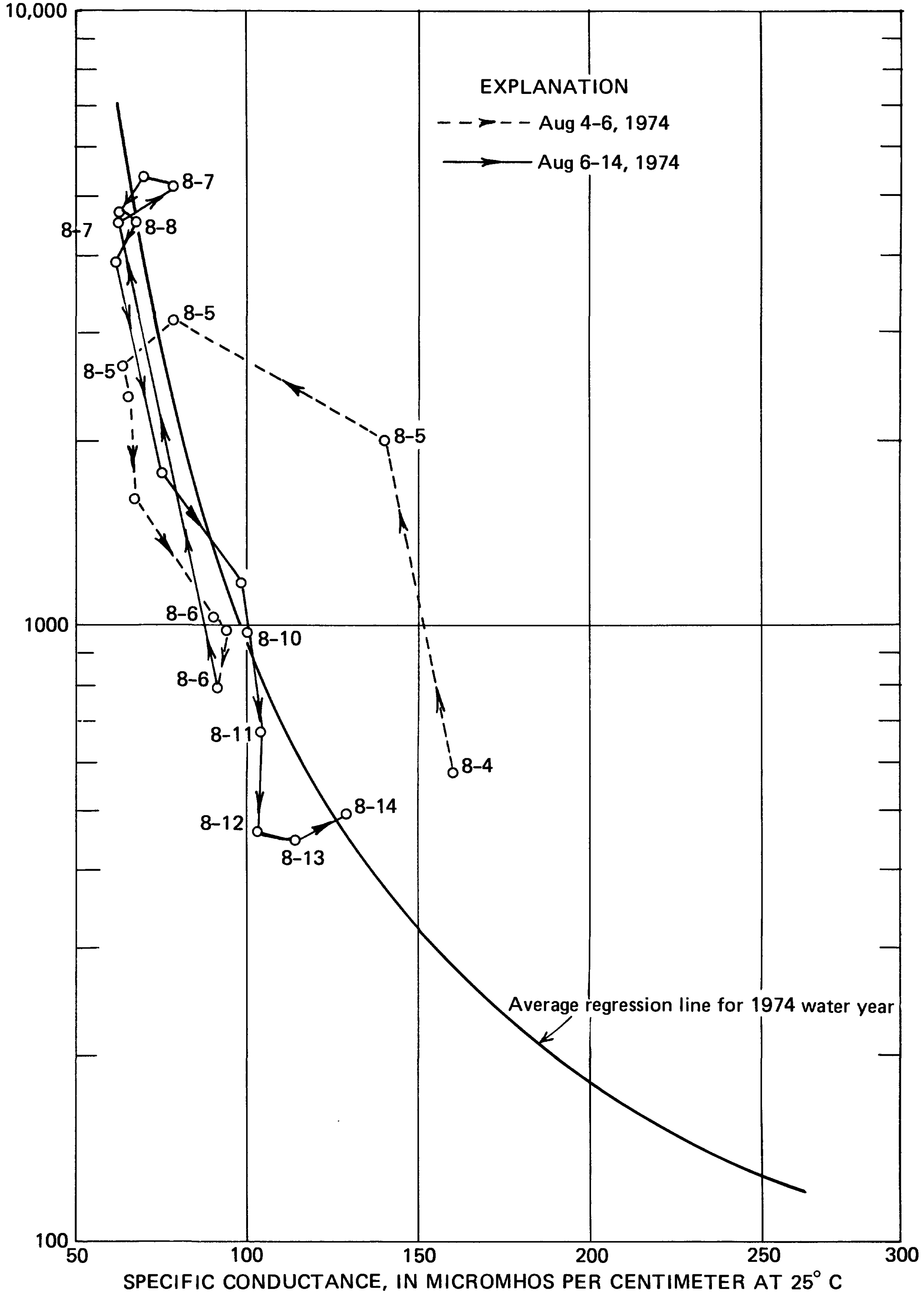


Figure 3. Variations in specific conductance over two closely-spaced floods, Neuse River near Clayton.

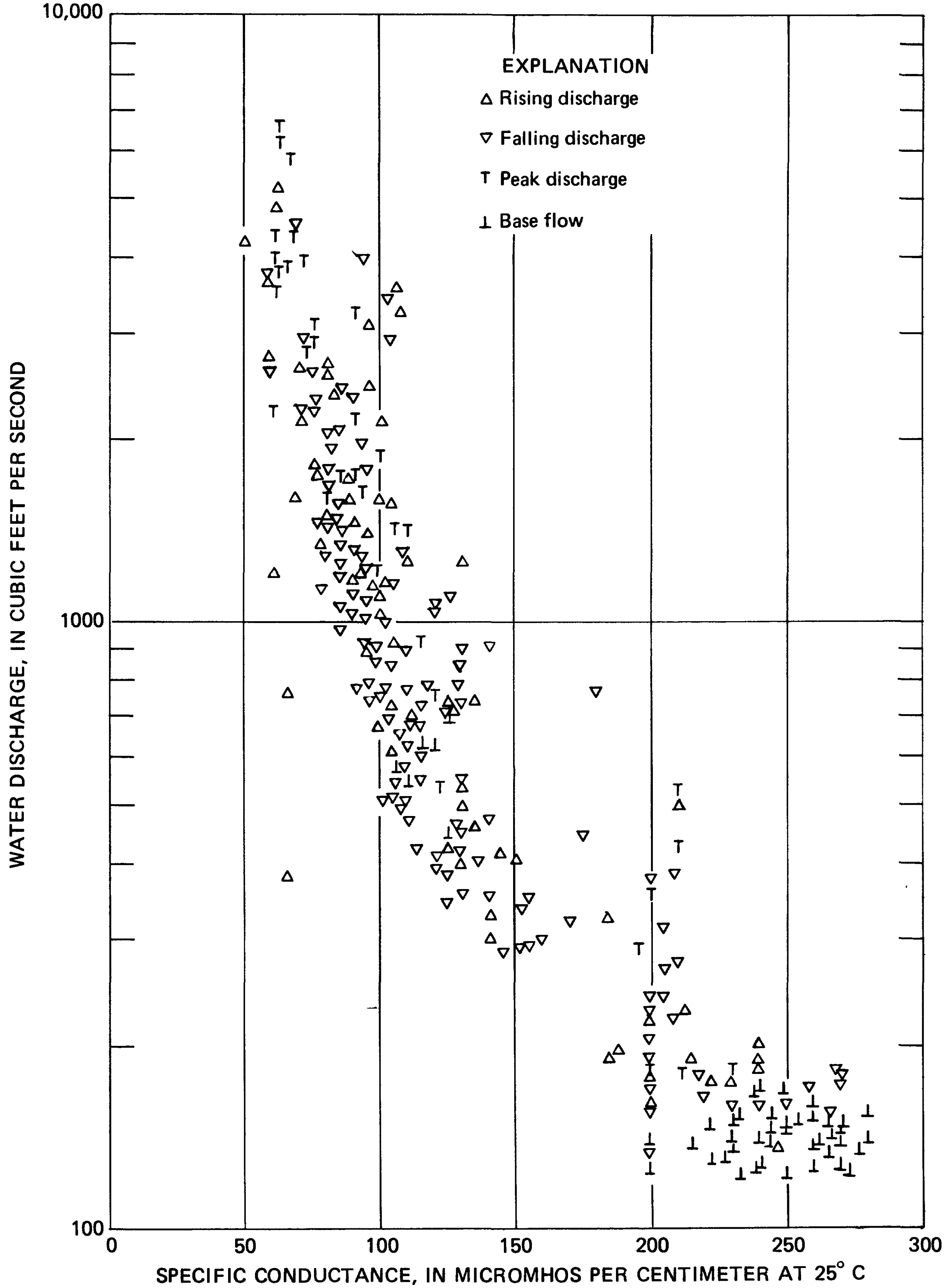


Figure 4. Relations of specific conductance to discharge for rising, falling, and stable stages of Neuse River near Clayton, 1974.

from perfect, these relationships might be useful in making rough estimates of the amount of lead and manganese being transported by the stream.

POLLUTION

Perhaps the most immediate goal of the primary network is to determine the extent to which surface waters of the State are already polluted. Although few streams are so contaminated that they are not suitable, with reasonable treatment, for almost any use, preliminary analyses of historical data (Wilder and Slack, 1971) indicate that man's activities have significantly changed their chemical characteristics. The U.S. Geological Survey, in cooperation with various State agencies, the most recent of which is the North Carolina Department of Natural and Economic Resources, began systematic investigations of the quality of streams in North Carolina in 1943. Other U.S. Geological Survey analyses have been available (Ray and Randolph, 1927) as early as 1906. There are not, however, enough historical data to determine directly the chemical character of most streams before man became a dominant influence on their quality. As an alternative to having adequate data for making "before and after" comparisons, some aspects of the degree of pollution in streams in North Carolina are being estimated using modern data. Current sources of water (and thus the sources of dissolved and suspended matter) over an idealized flood on a typical stream can be generalized as shown in figure 7. The placements of the division lines in figure 7 are, to a degree, arbitrary; and the chief purpose of the illustration is to delineate the components that control the quality of most streams.

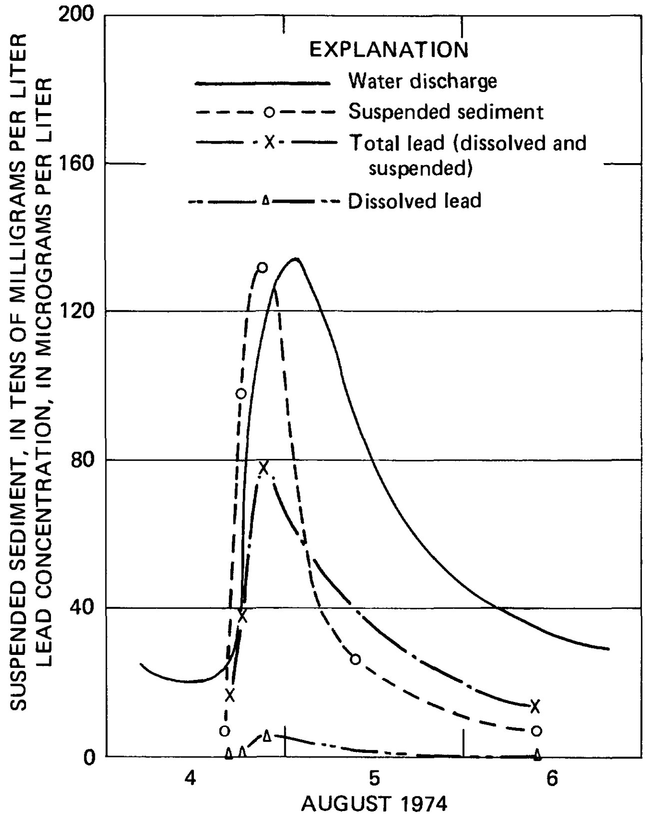


Figure 5. Suspended sediment, and total and dissolved lead, Neuse River near Clayton.

Table 1. Statistical summary of selected constituents and the results of regression analyses relating the concentration of constituents to corresponding values of specific conductance, Neuse river near Clayton (1974–75 water years)

Constituent	No. samples	Range	Standard error of estimate	Correlation coefficient
Water discharge, ft^3/s	36	209–16,200	...	0.64
Dissolved silica, mg/L	32	4.9–19	1.8	.86
Dissolved calcium, mg/L	32	3.3–9.6	.8	.89
Dissolved magnesium, mg/L	32	.9–2.8	.3	.76
Dissolved sodium, mg/L	32	2.6–37	2.1	.96
Dissolved potassium, mg/L	32	1.5–3.4	.3	.83
Bicarbonate, mg/L	32	9–50	3.6	.96
Dissolved sulfate, mg/L	32	6.3–15	1.9	.49
Dissolved chloride, mg/L	32	2.7–41	2.8	.94
Dissolved solids (sum), mg/L	32	34–163	9.2	.98

For periods when water quality is constant the total dissolved load of any constituent being transported by a stream can be calculated as follows:

$$L_t = kQ_tC_t, \qquad (1)$$

where L_t=total dissolved load for period,
k=constant depending on units of measurement used.
Q_t=total streamflow for period, and
C_t=concentration of the constituent.

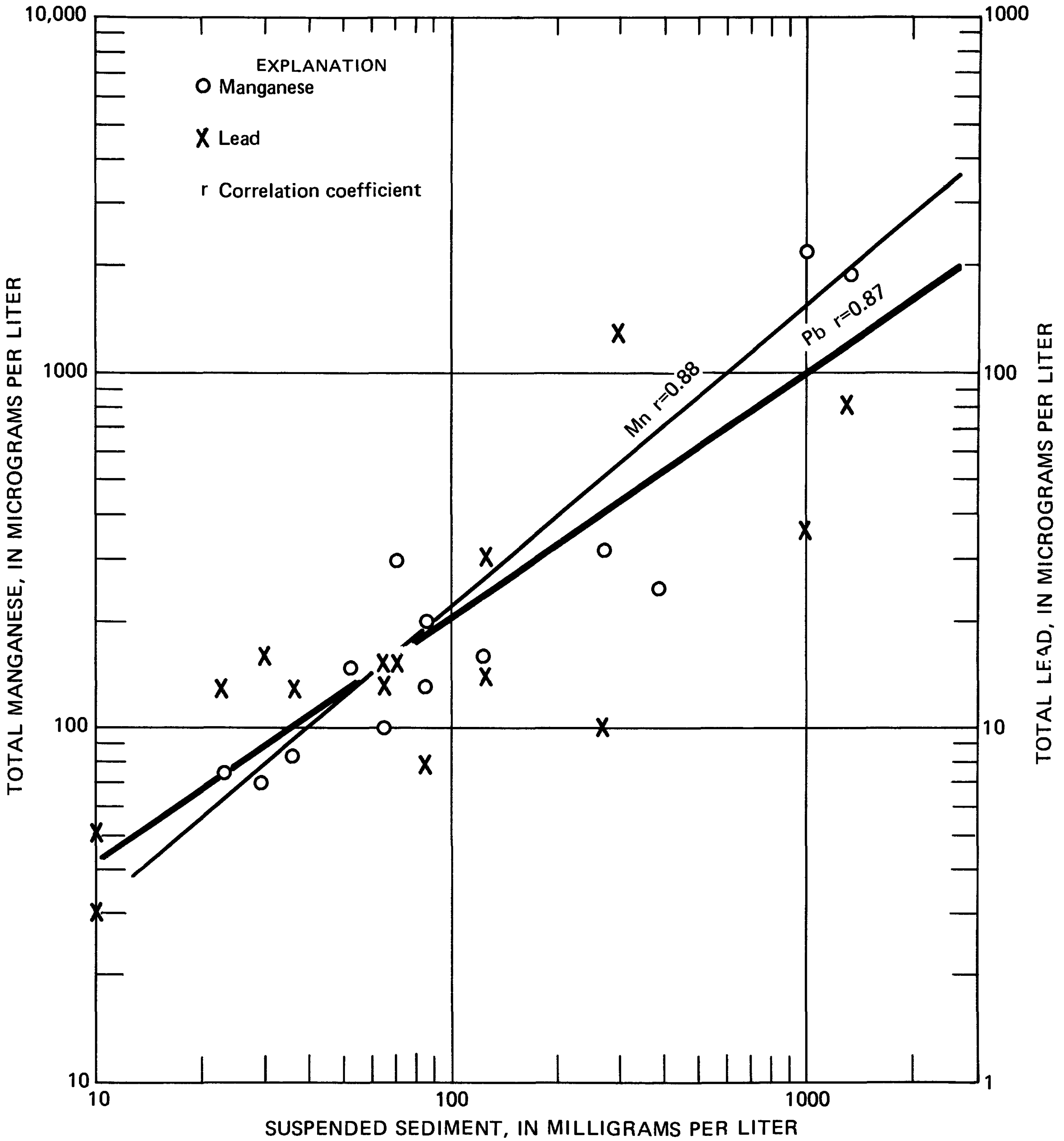


Figure 6. Regressions of lead and manganese with suspended sediment, Neuse River near Clayton.

From figure 7 it follows that:

$$\begin{array}{lllll} \text{total load} & = \text{overland runoff load } (L_{or}) & + \text{ground-water load } (L_{gw}) & + \text{pollution load } (L_p) & \\ L_t & = k\,(Q_{or}C_{or} & + Q_{gw}C_{gw} & + Q_PC_P), & (2) \end{array}$$

and, combining equations 1 and 2,

$$L_P = L_t - L_{or} - L_{gw} = k(Q_tC_t - Q_{or}C_{or} - Q_{gw}C_{gw}). \qquad (3)$$

Only Q_t and C_t are subject to direct measurement. If methods can be found to make usefully accurate es-

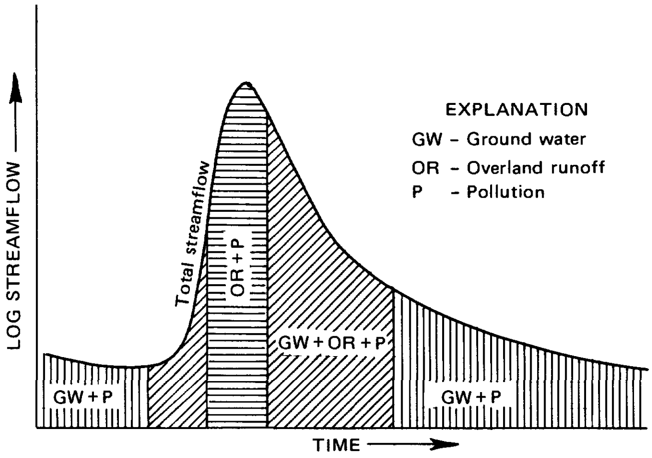


Figure 7. Current sources of water and transported materials for a flood in an idealized stream.

timates of the components needed to compute natural loads (C_{or}, C_{gw}, Q_{or}, and Q_{gw}), pollution could be separated from the total load being transported by a stream by use of equation 3.

NATURAL WATER QUALITY

To determine natural water quality of surface waters, streams were sought across the State that appeared not to be significantly affected by man's activities. More than 200 sites were investigated as possible candidates for a natural-water-quality network, and 47 were selected as being reasonably representative of pristine quality from the major hydrologic environments of the State. These sites have been sampled four times thus far—twice at baseflow and twice during floods. The baseflow samples are assumed to represent the quality of ground-water inflow to the streams, and the floodflow samples are assumed to represent the quality of overland runoff. These analyses have been used, in conjunction with geologic maps, to regionalize some aspects of natural quality. As an example, a regional map of natural dissolved solids is shown in figure 8.

To avoid significant amounts of pollution it was necessary to establish most of the natural-quality sites on streams with very small drainage areas—ranging from 0.3 to 17 mi^2 (0.8 to 44 km^2). A basic assumption of the program is that, under similar natural conditions, there is no significant difference between the quality of water in small streams and that in large streams. It is recognized that larger streams tend to be more deeply entrenched than smaller ones, but this would not seem to invalidate this assumption unless ground water from an aquifer containing more soluble materials is intercepted. The only area in North Carolina where this would appear to be a potential problem is in part of the Coastal Plain, where deeper entrenchement might introduce inflow from underlying formations. Admittedly, more study of the quality of very shallow ground water and its relation to stream quality is needed.

When information from the natural-quality network is transferred to larger drainage areas, multiple types of ground waters are often included. For these sites a set of values are calculated by summing the products of the individual values and their portion of the drainage area. For example, dissolved solids constants for Neuse River near Clayton (figure 8) are computed as follows:

Rock type (fig. 8)	(I) Part of basin in rock type	(II) Overland runoff constant	Adjusted overland runoff constant (I) × (II)	(III) Base runoff constant	Adjusted base runoff constant (I) × (III)
Group B	0.49	20 mg/L	10 mg/L	30 mg/L	15 mg/L
Group C	0.51	20 mg/L	10 mg/L	50 mg/L	26 mg/L
New constants		.....	20 mg/L	.....	41 mg/L

NATURAL LOADS OF DISSOLVED AND SUSPENDED CONSTITUENTS

To calculate natural loads for streams in which the quality of overland runoff and ground-water inflow are different, as determined by the natural-quality network, the amounts of overland runoff (Q_{or}) and ground water runoff (Q_{gw}) must be estimated. Although the influence of pollution on water quality is often dominant, the actual volume of polluted water entering fairly large streams is usually relatively insignificant compared to the total flow; and the influent water most often comes from the same stream in the first place. Therefore, it is usually satisfactory to assume that total flow is equal to overland runoff plus groundwater inflow ($Q_t = Q_{or} + Q_{gw}$). To estimate the amounts of each, it is necessary to separate the streamflow hydrograph into its component parts, namely Q_{or} and Q_{gw}.

There are a number of methods proposed in the literature for separating hydrographs. Most of these involve sketching a somewhat arbitrary "ground-water inflow" hydrograph on the total streamflow hydrographs and estimating Q_{or} as the difference between Q_t and Q_{gw} on a daily, or shorter period, basis. There are, however, pitfalls in these methods. The most obvious pitfall is that one never knows exactly where to sketch the ground-water inflow line. It is not the purpose of this report to discuss in detail the various proposals for hydrograph separation; however, a few representative suggestions for sketching the Q_{gw} hydrograph for a single idealized flood are shown in figure 9. It is doubtful if any of these except that of Daniel and others (1970) is

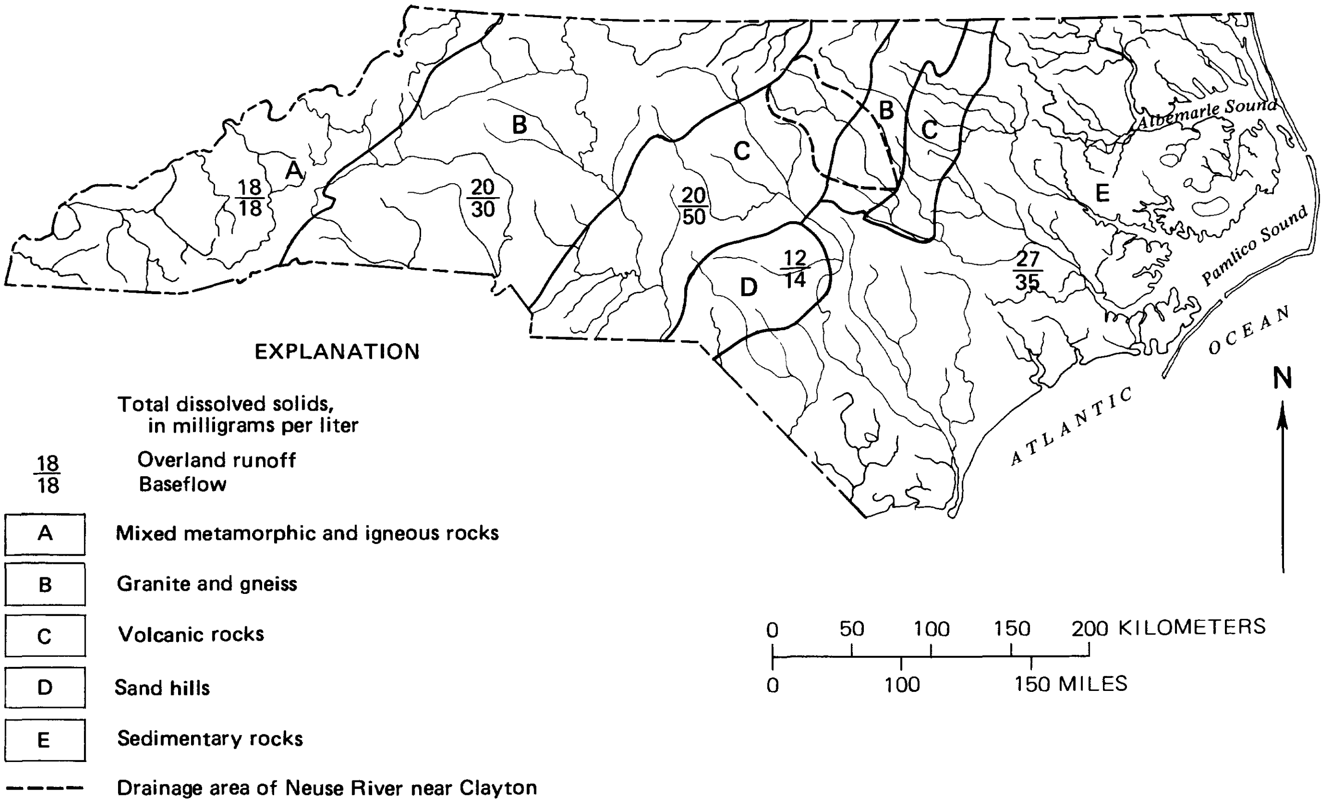


Figure 8. Regionalized dissolved-solids concentrations of natural surface waters during periods of overland runoff and baseflow.

experimentally defensible, but hydrologists can obtain useful answers with any of the methods. The answers are not, however, generally closely reproducible from hydrologist to hydrologist; thus line-sketching methods of hydrograph separation are more of an art than a science.

Another pitfall of importance in water-quality related separations is that there is no way of accounting for channel storage, which can be significant during the early rising and falling stages of a flood, thus making daily or other short-term calculations of loads subject to considerable error especially during recession.

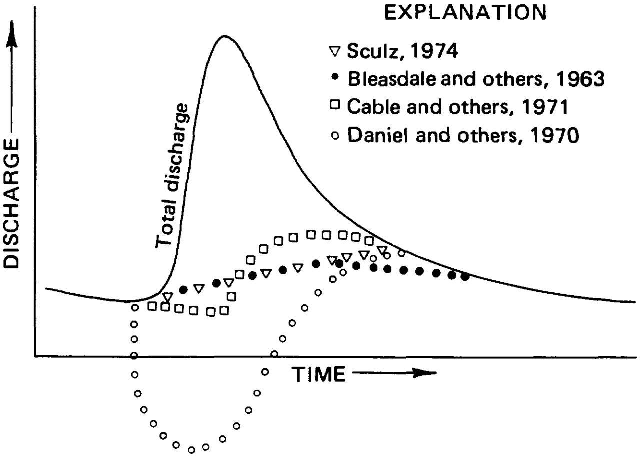


Figure 9. Diagram of various proposals for sketching ground-water contribution during a flood.

After evaluating several techniques for separating hydrographs the method adopted is based on one developed by Rorabaugh (1964) and Daniel (1976), which deals with "events" rather than time periods. Rorabaugh, using a heat-flow analogy, derived the following equation for ground-water discharge into one side of a unit length of stream, following a uniform impulse of recharge to the entire drainage area:

$$q=2T(h_0/a)\left(e^{-\pi^2 Tt/4a^2S}+e^{-9\pi^2 Tt/4a^2S}+e^{-25\pi^2 Tt/4a^2S}+\ldots\right), \qquad (4)$$

where: q=ground-water discharge per unit length of stream,
T=transmissivity of aquifer,
h_0=height of recharge impulse,
a=distance to ground-water divide,
t=time since recharge impulse occurred, and
S=storage coefficient of the aquifer.

By evaluating equation 4 Rorabaugh found that when $\frac{Tt}{a^2S}$ becomes about 0.2, a plot of the logarithm of discharge versus time becomes a straight line. Glover (1964) showed that this corresponds to the point at which one-half of the water from a recharge pulse will have entered a stream as ground-water inflow. At this point all of the terms in equation 4 except the first one become insignificant and the rate of ground-water inflow at any time thereafter can be calculated with the simpler equation:

$$q=2T(h_0/a)\,(e^{-\pi^2Tt/4a^2S}). \qquad (5)$$

Rorabaugh integrated equation 5 with respect to time to obtain the volume (V) of a recharge impulse remaining in storage on one side of a stream

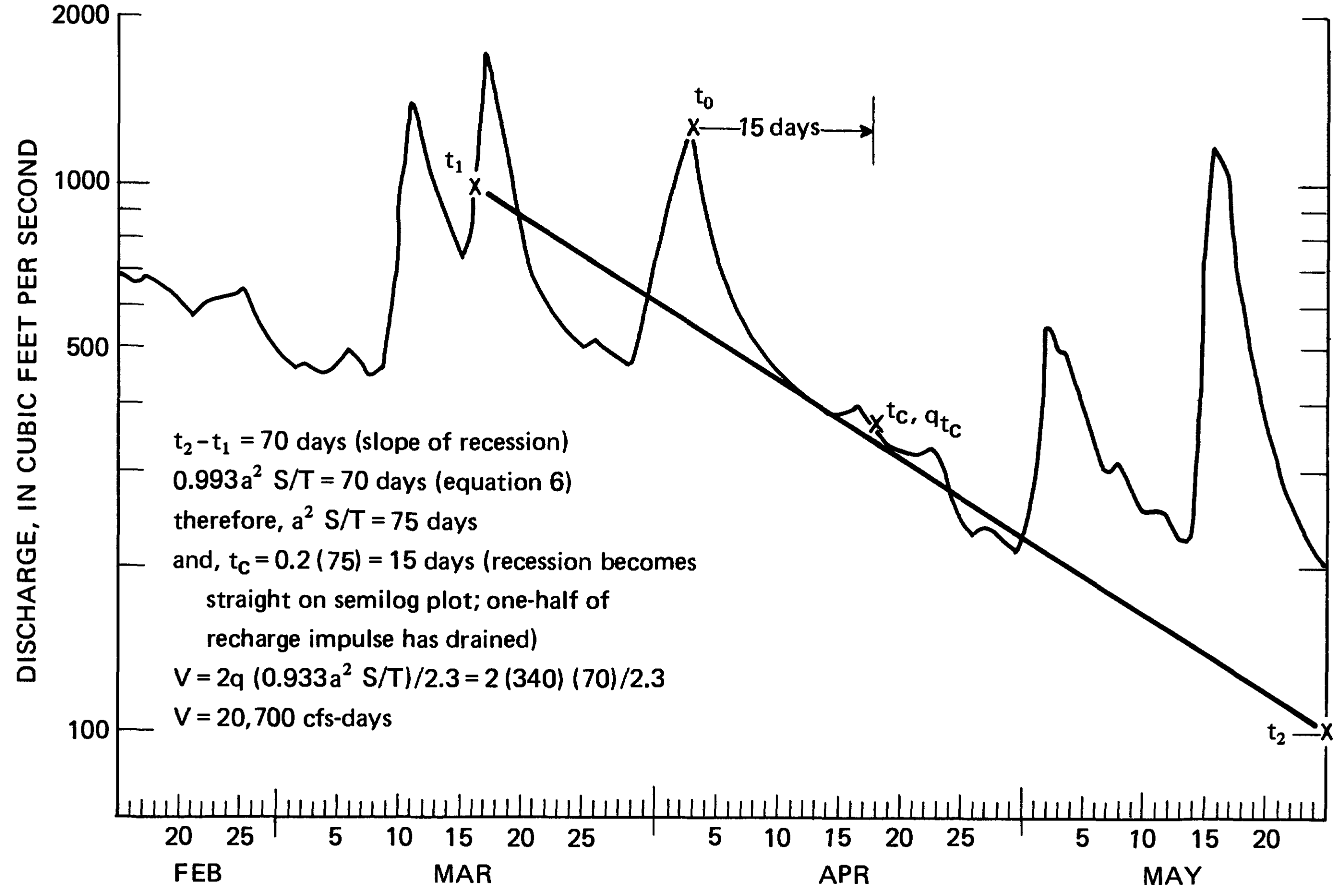
at any time, t, from $t \geq \frac{0.2a^2S}{T}$ to $T = \infty$:

$$V = q(\frac{4a^2S}{\pi^2T});$$

which when applied at $\frac{Tt}{a^2S} = 0.2$ is doubled and converted to base 10 logarithms to compute total recharge by the equation:

$$V = \frac{2q_c(.933\,\frac{a^2S}{T})}{2.3}. \qquad (6)$$

The quantity $0.933 \cdot \frac{a^2S}{T}$ is the slope of the recession described by equation 5. In practice this slope is determined empirically by seeking periods on the discharge hydrograph when the recession is allowed to go undisturbed (by precipitation, regulation, etc.) far enough beyond the point at which q becomes a straight line on a semilog plot, to make a visual determination of its trace. As illustrated in figure 10, this trace can then be extended across one log cycle to determine the slope of the recession. (Generally the slope determination is made during the non-growing season to eliminate the effects of evapotranspiration). Once the slope is known it can be used to calculate both $\frac{a^2S}{T}$ and the critical time (t_c) at which the recession becomes a straight line ($t_c = \frac{0.2a^2S}{T}$), if the time of the recharge impulse is known. Once both the slope of the recession and $\frac{a^2S}{T}$ are known they can be substituted into equation 6 along with the instantaneous discharge at t_c to calculate the undrained volume of



$t_2 - t_1$ = 70 days (slope of recession)

0.993a^2 S/T = 70 days (equation 6)

therefore, a^2 S/T = 75 days

and, t_c = 0.2 (75) = 15 days (recession becomes straight on semilog plot; one-half of recharge impulse has drained)

V = 2q (0.933a^2 S/T)/2.3 = 2 (340) (70)/2.3

V = 20,700 cfs-days

Figure 10. Procedure for calculating ground-water contribution from a single flood event, Neuse River near Clayton.

water from a given recharge impulse, which will be one-half of the total volume derived from the recharge impulse.

Throughout this discussion it has been assumed that the initial head difference, from the aquifer to the stream is caused by a recharge impulse that instantaneously raises the water table by an amount h_0 everywhere within the aquifer. Actually, the head at any time is a cumulative result of a number of factors that interact to produce an effective h_0 at the boundary of the stream channel. Among these factors are the amount and duration of rainfall, the initial depth to the water table, the dimensions of the aquifer, the amount of water stored in it; and, perhaps most important, the "backwater" effects created when rapidly rising stream levels create a reverse gradient from the stream to the aquifer. An additional consequence is that ground water entering the stream during any recession is a mixutre of water from the most recent precipitation with that from an indeterminate number of preceding periods of precipitation. From an operational standpoint this creates a problem of when to select time t_0, i.e., the time at which the recharge impulse necessary for the mathematical anayses is assumed to occur. J. F. Daniel (oral commun., 1976) suggests that t_0 be assigned at the point at which the flood hydrograph of the stream being studied reaches a peak. For some streams this may be too early and for others too late, but the effect on runoff volumes should not significantly affect the results of this investigation.

Other simplifying assumptions relative to basin geometry, aquifer characteristics, and recharge distribution that are inherent in the application of the theory to real situations are discussed by Rorabaugh (1964) and, more extensively, by Daniel (1976). In general these as-

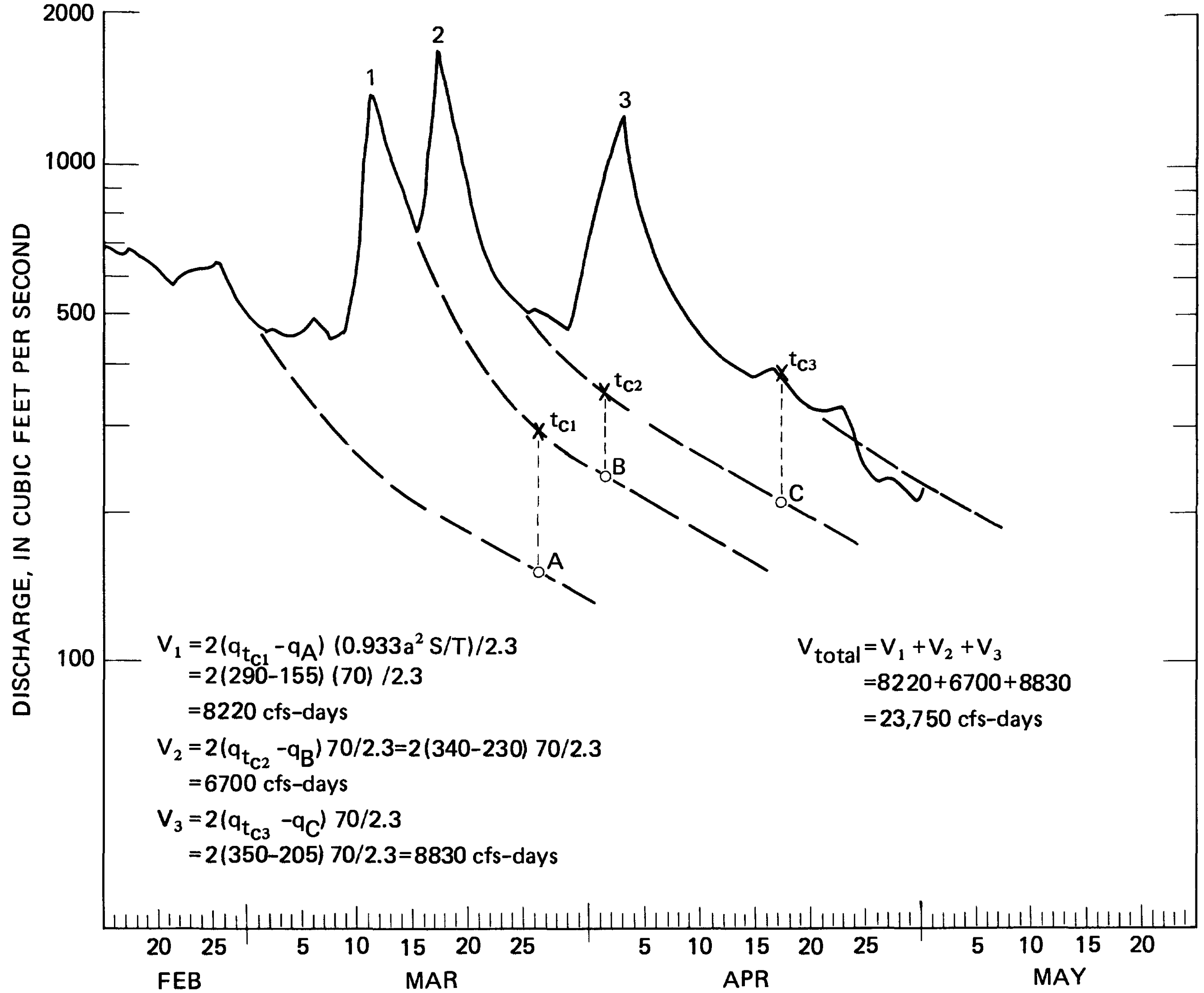


Figure 11. Method of computing ground-water contribution from more than one flood, Neuse River near Clayton.

sumptions become reasonably valid at and beyond the critical time, which is where the theory is applied in this instance.

A step-by-step example of the use of this method for estimating the contribution of ground water for a period including only a single flood is shown in figure 10. The smoothness of the recession curve in this example is marred by upstream diversions of water through two municipal water systems and its return through two municipal waste-treatment plants. The consumptive use of these diversions is relatively small and their effect on the general trace of the recession is minor.

In working with a single flood, as illustrated in figure 10, it is assumed that all ground water reaching the stream during the flood, and the following flow recession, results from the increase in ground-water heads caused by recharge in response to the precipitation that produced the flood. In humid regions, such as North Carolina, the time between recharge periods (and "floods") is seldom long enough for the effects of the preceding recharge period to disappear. In fact, most recessions do not proceed long enough to assume a straight-line shape on hydrographs. Under such conditions ground-water discharge resulting from more than one recharge period must be taken into account. When the critical time (t_c) is reached, the recession becomes linear (on semilog plot) and the principle of superposition is valid (Rorabaugh, 1964, p. 434). For a series of recharge-flood periods, the ground-water discharge at any time can be calculated as the sum of the incremental discharges of previous periods. Similarly, the volume of ground-water runoff for several recharge periods can be found by summing the calculated runoff for each event. Once the slope of a "type" recession is determined it is a simple matter to "extend" an abbreviated recession to t_c. An example of calculating ground-water inflow to Neuse River near Clayton for more than one recharge pulse is shown in figure 11.

After determining C_{gw} and C_{or} from the natural-quality network, plus Q_{gw} and Q_{or} by the method described above, natural loads (L_{n}) can be calculated as follows:

$$L_n=0.0027(Q_{gw}C_{gw} + Q_{or}C_{or}) \qquad (7)$$

It should be noted that Q_{gw} and Q_{or} as used in equation 7 are totals for an extended period (usually one year), and, as such, are actually volumes.

AMOUNT OF POLLUTION

Natural loads from equation 7 are subtracted from total loads from equation 1 to get an estimate of pollution loads. Usually total loads are computed as the sum of daily loads for the period in question. In some cases where discharge and concentrations are changing rapidly, however, it may be desirable to subdivide a day into shorter periods. Porterfield (1972) discusses how to determine when subdivision is advisable in suspended-sediment studies. His discussion should be helpful in studies of materials being transported in solution as well.

Under most conditions, daily concentrations are required for adequate computation of total loads. The only daily measurements made in this program are specific conductance and temperature. Therefore, the only constituents for which loads can be calculated are those that correlate meaningfully with specific conductance.

The degree to which a stream is polluted may be shown in other ways. The simplest is a visual comparison with data from similar environments that are not significantly polluted. Table 2 shows such comparisons for four streams in the Mountain and Piedmont—Coastal Plain provinces of North Carolina.

TRENDS

A major emphasis in many modern water-quality programs is the detection of water-quality trends. Thus far only a few reports have included methodology for determining trends on a practical level, and these methods have tended to be ambiguous or limited in scope. Statistical methods of testing water-quality data for trends have not been notably successful for a number of reasons. Perhaps the most important reason is that the matrix of data in which water-quality trends are buried is often so "noisy" that separation of the trends themselves is extraordinarily difficult. Some progress has been reported by Steele and others (1974), but it is still uncertain to what extent trends of one to three percent per year are separable from "noise" that can amount to a few hundred percent, as seems to be the common case in North Carolina.

Theoretical methods are available for compensating for the effects of "noise" produced by seasonal changes, serial correlations (not really noise), and others. These, however, force assumptions of distribution upon the data that are not usually valid for water-quality data other than perhaps temperature. Sherwani and Moreau (1975) have suggested that it is possible to avoid the effects of serial correlations by increasing the time interval between sampling. The main problem with the infrequent-sample method, however, is that it fails to define the system with sufficient accuracy to detect very small systematic changes. Sherwani and Moreau also stated (p. 91), "If the objective is to detect a certain percentage change, say, ten percent, in the mean concentration of a pollutant between one year and the next, the error in each of the annual means would have to be less than half that magnitude, i.e., 5 percent." An

Table 2. Comparison of selected constituents for stations in the Natural-Quality Network with stations in the Primary Network, October 1974—Semptember 1975

Constituent	Mountain province		Piedmont—Coastal Plain province	
	Cataloochee Creek at Cataloochee, N.C. (natural-quality)	French Broad River at Marshall, N.C. (primary)	Turner Swamp near Eureka, N.C. (natural-quality)	Neuse River near Clayton, N.C. (primary)
Total nitrogen (mg/L).	0.18–1.7	0.66–4.8	0.58–1.7	0.33–3.1
Dissolved phosphorous (mg/L).	.01–.02	.02–.09	.02–.05	.04–.90
Total phytoplankton (cells/mL).	[1]260–320	1700–1900	64–490	1700–28,000
Fecal coliform (col./100 mL).	[1]<10–2,000	20–10,000	[1]10–3700	40–3000
Biochemical oxygen demand (mg/L).	<1–2.0	.9–3.9	.3–3.1	1.6–6.1
Periphyton—biomass ash wt. (g/m²).	1.5–3.9	3.1–18	4.6–18	4.6–5.4
Periphyton—biomass dry wt. (g/m²).	2.3–6.2	4.6–21	6.2–18	6.9–8.5
Dissolved organic carbon (mg/L).	3.6–4.9	3.6–15	6.0–	7.4–12
Chromium (μg/L)				
Total	1–<10	<10–90	<10–10	0–10
Suspended	1–<10	<10–90	<10–10	0–10
Dissolved	0–1	0	0	0
Bottom	<10	<10	<10	10–20
Lead (μg/L)				
Total	0–58	4–250	4–21	2–130
Suspended	0–58	2–250	1–21	2–130
Dissolved	0–2	0–20	1–3	0–8
Bottom	<10–10	<10	<10–10	[2]<10–250
Zinc (μg/L)				
Total	5–40	30–440	4–10	7–40
Suspended	5–40	30–430	0–7	0–40
Dissolved	0	0–50	0–10	0–20
Bottom	20	40–60	10–60	40

[1] Single nontypical value not included.

[2] One value in this concentration range.

analysis of historical data will quickly disclose that this statement imposes severe limitations on the acceptable sampling interval for most streams. If it is assumed that an annual mean based on daily measurements (of most anything) is accurate, which in itself may be open to question, then means based on monthly or even weekly samples are not likely to be sufficiently accurate to reflect trends of the magnitude mentioned earlier (1 to 3 percent). In fact, after experimenting with some of our historical data it appears impractical, if not impossible, to detect trends using concentration data alone. Steele and others (1974) compensated for the effect of variations in annual discharge by using discharge-weighted daily values of specific conductance to define trends in a number of streams from different parts of the United States. His techniques will be evaluated for streams in North Carolina.

In North Carolina, and probably most other States, it is impossible to detect trends at the end of a one- or two-year study unless historical data are available for comparison. Therefore, a desirable prerequisite for establishing a primary network station at a site is that a daily sampling station should have been located there in the past. Fortunately, during the period 1943–67, daily stations were operated for at least one full year at 82 nonestuarine sites in North Carolina, which gives a large base of background information to compare with present data. Unfortunately, much of the information collected

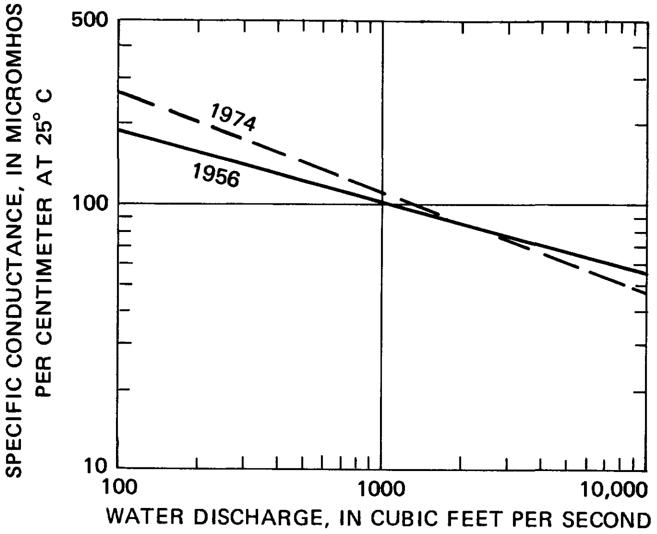


Figure 12. Relation between water discharge and specific conductance, Neuse River near Clayton.

Table 3. Transport of dissolved matter in Neuse River near Clayton during 1956 and 1974 water years

Source of dissolved matter	Average dissolved solids[1] (mg/L)	Average discharge (ft^3/s)	Total annual discharge (ft^3/yr)	Annual load[2] (tons/yr)	Unit load (tons/ million ft^3)
			1956		
Natural	.....	.....	.....	21,100	0.76
Pollution	.....	.....	.....	28,900	1.05
Total	75	874	2.76×10^{10}	50,000	1.81
			1974		
Natural	.....	.....	.....	25,400	0.76
Pollution	.....	.....	.....	36,700	1.09
Total	84	1064	3.36×10^{10}	62,100	1.85
			Increase (percent)		
Natural	.....	.....	.....	20	0
Pollution	.....	.....	.....	27	4
Total	12	.....	.....	24	2

[1] Computed as unweighted average of measurements.

[2] Computed as sum of daily loads.

in the historical program is not the kind that is receiving emphasis today. Historical data do, however, provide a basis for making some immediate estimates of how fast the quality of waters is changing.

Of the several possible methods for determining trends in water quality, the most reasonable results have been obtained using comparisons of water quality with discharge which, to some degree, compensate for variations in stream discharge. A quick comparison of whether water-quality changes have taken place over a period of time can usually be obtained by plotting specific conductance (or the concentration of the desired constituent) versus discharge for several widely spaced years, as shown in figure 12 for Neuse River near Clayton. Statistical tests of significance also need to be conducted in most cases. Such a method will also show at what flows the greatest concentration changes have occurred.

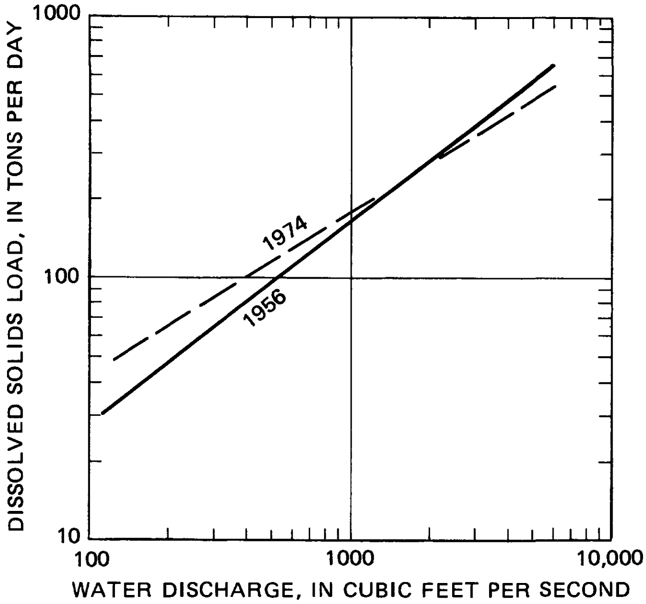


Figure 13. Relation between water discharge and dissolved-solids load, Neuse River near Clayton.

A second method for detecting changes involves plotting dissolved-solids loads versus stream discharge (fig. 13). This method, however, is more complex in that it requires the prior computation of daily loads. Referring to the two preceding illustrations of the Neuse River, the water quality as reflected by dissolved solids has apparently deteriorated during low flows since 1956 but has improved at extremely high flows. This situation might be explained by an increase in pollution from point sources, which would greatly affect water quality at low flows; whereas, a decrease in pollution from non-point sources, such as farming, has occurred during high flows and is reflected in lower concentrations of constituents in overland runoff.

It is also possible to summarize changing conditions at a station in tabular form as illustrated in table 3. Notice that gross loads are somewhat misleading when making comparisons because, as with concentrations, they are dependent upon the amount of streamflow, and even over a span of several years significant trends can be lost in the noise of an unusually wet or dry year. A somewhat more realistic means of comparing loads is by converting them to some unit value (for example, tons/million ft^3), as in table 3, which lessens the effects of nonuniform flow conditions because the value is determined by dividing the annual load by the total annual flow volume.

CONCLUSIONS AND FUTURE PLANS

What is presented here represents our initial efforts to design and implement a program that will meet both Federal and State needs for a continuing inventory of water-quality conditions in North Carolina. No implication is intended that this represents the ultimate in the design of programs to investigate water quality or that the methods of collecting and analyzing the data are a model for all to follow. In many respects this article is preliminary because methods of analyzing the data are still in a very rudimentary state. For example, in North Carolina we have only recently begun to investigate chemical constituents other than dissolved solids and the major ionic constituents. Socio-economic changes should be evaluated in conjunction with water-quality changes to establish a base for making predictions as to when certain aspects of water quality might become intolerable if present environmental practices are continued. Techniques used for regionalization of factors involved in natural quality and for separation of hydrographs must be refined and standardized.

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Chapter B

Water-Quality Characteristics of Streams in Forested and Rural Areas of North Carolina

By CLYDE E. SIMMONS and RALPH C. HEATH

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2185

WATER QUALITY OF
NORTH CAROLINA STREAMS

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Water-Quality Characteristics of Streams in Forested and Rural Areas of North Carolina

By Clyde E. Simmons *and* Ralph C. Heath

ABSTRACT

From late 1973 through 1978 water-quality samples were collected from a statewide network of rural stream sites. Data obtained from 39 of these sites, whose basins are 90 to 100 percent forested, were used to define unpolluted or baseline conditions. Stream quality at 20 other sites are believed to be affected by farming activities, which range from 15 to 55 percent of the land area of the basins. Data from these 20 sites were used for comparison with data from the 39 forested sites to determine the increase in constituent levels caused by man.

Baseline stream quality is largely influenced by basin geology and the quality of bulk precipitation. Concentrations of major dissolved constituents are greatest during low base runoff and are related primarily to the minerals comprising the soils and underlying rock in the basins. As a result of this study, five distinct geochemical zones were delineated. The chemical characteristics of surface waters in each zone are similar.

Mean and other statistical values for major dissolved constituents, nutrients and minor elements in base runoff and storm runoff for baseline conditions are presented in tabular and graphical format. Data from these forested basins indicate wide areal variations in concentrations of many constituents. Mean concentrations of dissolved solids range from 12 milligrams per liter (mg/L) in geochemical zone III to 61 mg/L in zone II. Mean nitrogen values, which are generally greater during storm runoff, range from 0.19 mg/L in zone I to 0.68 mg/L in zone V; whereas phosphorus values are less variable, ranging only from 0.01 to 0.03 mg/L. Arsenic, mercury, and selenium are generally below detection limits. Although chromium, copper, lead and zinc occur in most baseline streams, quanities are often near detection limits and seldom exceed 15 micrograms per liter.

Significant increases in concentrations of major dissolved constituents and nutrients occurred, especially during storm runoff, at most of the 20 sites affected by farming activities. During storm runoff, concentrations of several major constituents were two to three times those determined for baseline conditions. Also, in basins where farm activities accounted for 20 or more percent of total land use, phosphorus levels during storm runoff were 2 to 13 times greater than from forested basins. Concentrations of minor elements were essentially the same in both forested and developed basins.

Future plans to continue the study of baseline stream characteristics include an intensified collection of data throughout a full range of flow and seasonal variations at up to ten sites having totally forested basins.

INTRODUCTION

In 1972, the U. S. Geological Survey, as a part of its State cooperative water-resources program, activated a water-quality monitoring program in North Carolina designed to determine variations in stream quality and to determine pollution loads and trends at key locations on the State's major rivers. To accomplish these objectives, two different networks of stations were established in late 1973; (I) a baseline-quality network consisting of stations at points on small streams relatively unaffected by man's activities, and (2) an accounting network consisting of stations located on major streams whose quality is affected by wastes from municipalities, industries, and agricultural developments (fig.1).

A recent report by Wilder and Simmons (1978) describes methods for using data collected from these stations to determine pollution loads and other chemical characteristics of streams. The report also includes a detailed discussion of the program's design, operations, and objectives. One of the basic concepts described by Wilder and Simmons is that substances transported by streams are derived from both natural sources and wastes generated by man's activities. The primary purpose of the baseline-quality network is to determine the concentration of constituents in water derived from natural sources; however, it must be realized that even "natural sources" have been modified, such as by the fallout of air-borne constituents added to the atmosphere by man's activities. These concentrations can be used in conjunction with discharge data collected at the accounting-network stations on the major rivers to estimate the loads of dissolved substances in the rivers that are drived from natural sources. The difference between total loads determined at the sites on the major rivers and the natural loads estimated from data collected at the baseline network stations is a measure of man's impact on stream quality.

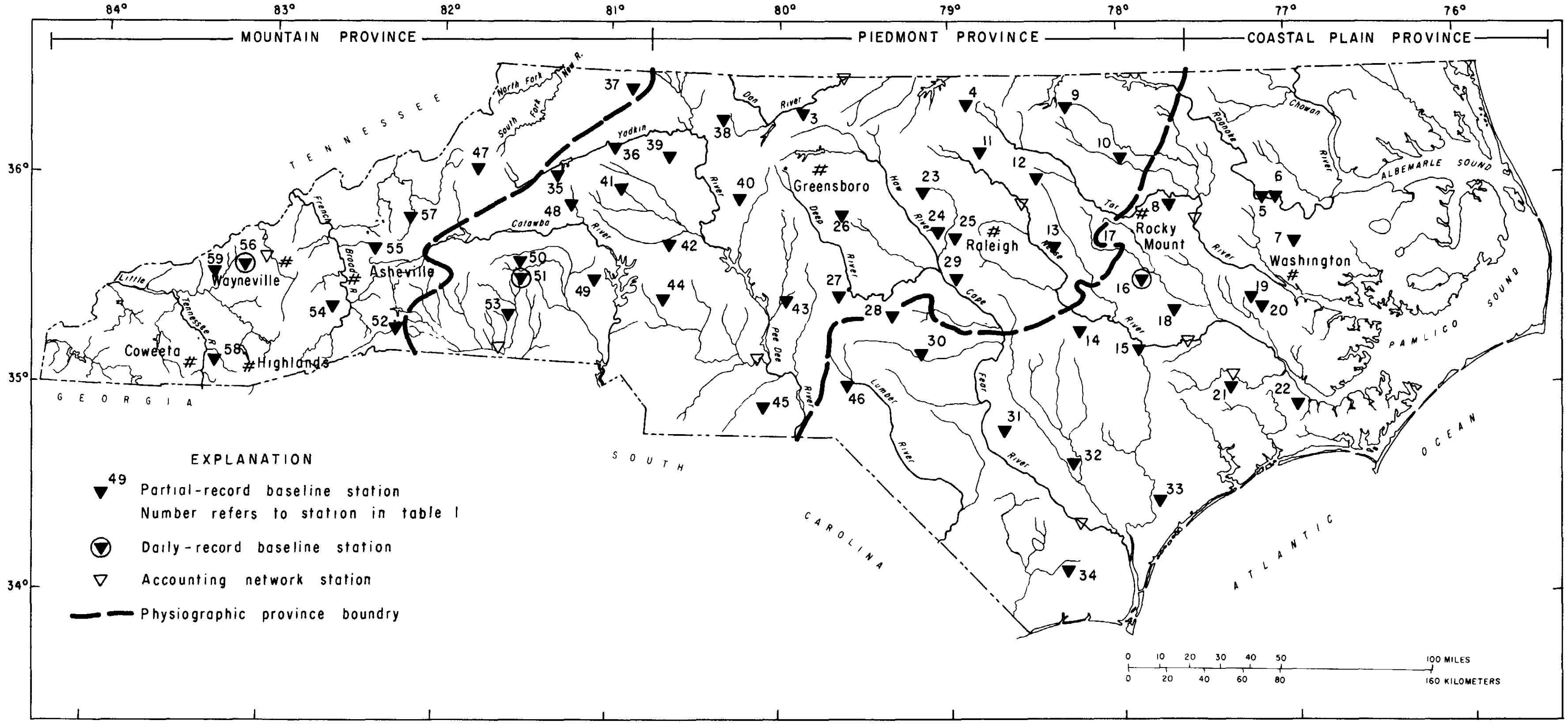


Figure 1. Location of stations in the baseline quality and accounting networks in North Carolina.

This report presents the preliminary findings obtained from the baseline network through 1978. For North Carolina, it represents the first known attempt to determine the concentrations of major chemical and trace constituents and nutrients contributed to the State's streams by natural processes. Thirty-nine rural streams, whose basins were 90 to 100 percent forested, were used to characterize baseline stream conditions during periods of base runoff and storm runoff. Except for the effects of air pollution, which currently cannot be quantified, the sites are believed to show minimal effects of man's activities. Using geochemical zones, areas underlain by soil and rock types having the same or similar chemical characteristics, mean values were determined, where possible, for the concentrations of various chemical constituents.

During the early phases of this study, 20 additional rural stations were in the baseline network but farming activities accounted for 15 to 55 percent of the total land area in these basins. Initially the effects of runoff from the farm areas on stream quality were unknown; however, chemical data collected during base and storm runoff periods quickly indicated concentrations which were considerably greater than those obtained from forested basins. Data from these 20 sites, therefore, are not used in the definition of baseline characteristics; rather, the data are used in a separate part of this report to illustrate the effects of the basins inhabitants and especially agricultural activities on baseline stream quality.

It should be noted that this report is a summary of the results of numerous hydrologic data; the chemical and related data for individual baseline stations are contained in publications issued annually by the U.S. Geological Survey (1974-78).

ESTABLISHMENT OF THE BASELINE NETWORK

As a first step in establishing the baseline network, topographic maps and aerial photographs were inspected to identify streams whose quality might not be affected by man's activities. This search was concentrated on forested basins drained by perennial streams. From the available maps and photographs it was not possible to clearly determine whether some areas where completely forested and the point at which perennial flows begin. Therefore, the initial selection process included about 200 sites relatively evenly distributed over the State. Each of these was visited to determine if the upstream areas were completely forested and, if not, the level of development (that is, the number of houses and the acreage in farms and pastures).

During the field study, specific conductance was determined for streams draining both undeveloped areas and for those draining areas in which it appeared the development would have a negligible effect on water quality. Conductivity was used as the primary screening parameter because it provides an easily measured estimate of most of the total dissolved mineral matter. Therefore, it was assumed that the effect of significant development would be reflected by higher conductivity values. The fact that such values reflected man's effects rather than a natural condition, was confirmed from review of the field notes on activities upstream from the sampling sites. As a result of this evaluation, only 47 of the initial 200 sites were determined to be essentially free of man's influence and were retained in the baseline network. These sites are on streams which are as free of man's effects as possible in that (1) they have no known upstream point sources of pollution, (2) the streams are unchannelized, and (3) the basins in most cases are unpopulated. In a few areas no suitable sites were found in the first attempt, and new sites were located on the basis of additional map review and field inspections. As shown in figure 1, the final network resulted in a relatively uniform geographic distribution of 59 stations.

Table 1 includes all stations that have been operated as a part of the baseline network. As noted in the REMARKS section, data collection activities were terminated at nearly half of the stations listed in table 1 because preliminary analysis of the data indicate effect from agricultural activities or because major changes, such as the initiation of timber cutting, occurred in the basin after data collection began. The location of all baseline network stations listed in table 1 are shown in figure 1.

The drainage areas of the baseline sites, as shown in table 1, range in size from 0.04 to 49.2 mi^2 and all streams are perennial except possibly during severe droughts. Table 1 also shows a breakdown of land use into forest and agriculture. Forest includes both mature forest and previously cleared areas that are being returned to forest. Agriculture includes both pastures, small grain, hay and row crops. Because of the absence of large, totally wooded basins in several areas, especially in the heavily-farmed Coastal Plain region, it was necessary to include in the network a few basins that contain active agricultural operations of significant size. To minimize the possibility of using values influenced by agriculture, data from sites where agricultural operations exceeded ten percent of the area were not used in determining the water-quality characteristics of unpolluted streams that are discussed in a following section of this report.

DATA COLLECTION PROGRAM

Two types of sampling operations were conducted at the stations in the baseline network (table 2). At a majority of the stations, samples were collected only under

Table 1. Names, locations, and physical characteristics of baseline sampling sites.

Map number (fig. 1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
1	02053021. Jacks Swamp near Pleasant Hill	Lat 36°30'55", long 77°32'35", Northampton County, at Secondary Road 1203, 1.2 miles south-south east of Pleasant Hill.	6.10	V	80	20	U.S. Highway I-95 crosses upper part of basin. Sampling discontinued in 1977.
2	02053249. Deep Creek near Cofield	Lat 36°22'25", long 76°56'00", Hertford County, at State Highway 45, 1.7 miles northwest of Cofield.	3.00	V	75	25	Sampling discontinued in 1977.
3	02070806. Huffines Mill Creek near Bethany	Lat 36°20'00", long 79°51'26", Rockingham County, at Secondary Road 2359, 1.8 miles north of Bethany.	1.60	I	80	20	Sampling discontinued in 1977.
4	02077629. Mayo Creek Trib. near Allensville	Lat 36°23'55", long 78°54'05", Person County, at bridge on Secondary Road 1520, 1.0 mile northwest of Allensville.	0.68	II	80	20	Paved county road crosses basin. Sampling discontinued in 1977.
5	02081026. Indian Creek Trib. near Cahaba	Lat 36°01'02", long 77°10'38", Bertie County, at Secondary Road 1123, 2.0 miles southwest of Cahaba	0.50	V	100	0	Station established in March 1978.
6	02081031. Coniott Creek near Cahaba	Lat 36°00'41", long 77°08'05", Bertie County, at Secondary Road 1108, 2.4 miles southwest of Cahaba.	2.80	V	95	5	Station established in October 1977, but abandoned because of farm activities immediately upstream from sampling point.
7	02081082. Hardison Creek near Roberson Store	Lat 35°43'20", long 76°57'30", Martin County, at Secondary Road 1543, 1.6 miles southeast of Roberson Store.	14.00	V	95	5	Large-scale timber clearing operation underway since 1973.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
8	02082625. Walnut Creek at Kingsboro	Lat 35°55'35", long 77°40'34", Edgecombe County, at Secondary Road 1225, 0.6 mile north of Kingsboro.	0.80	V	100	0	Station established in March 1978.
9	02082824. Fishing Creek near Middleburg	Lat 36°23'06", long 78°19'05", Vance County, at Secondary Road 1501, 1.1 miles south-southwest of Middleburg.	3.30	I	55	45[a]	Railroad and major highway cross extreme upper part of basin. Sampling activities discontinued in 1978.
10	02082920. White Oak Swamp near Action	Lat 36°09'59", long 78°00'05", Nash County, at Secondary Road 1004, 3.2 miles west-northwest of Aventon.	4.10	II	75	25	Farming activities increased in basin during spring-summer 1976. Sampling activities discontinued in 1976.
11	02086300. Rocky Creek near Bahama	Lat 36°10'30", long 78°49'20", Durham County, at Secondary Road 1616, 3.3 miles northeast of Bahama.	2.40	II	90	10	Military rifle range and living quarters constructed in basin during late 1976. Paved county road crosses upper part of basin. Sampling activities discontinued.
12	02087173. Horse Creek Trib. near Pocomoke	Lat 36°02'33", long 78°31'03", Franklin County, at Secondary Road 1140, 2.7 miles southeast of Pocomoke.	1.1	I	80	20[a]	Sampling discontinued in 1977.
13	02087499. Neuse River Trib. near Clayton	Lat 35°39'05", long 78°24'11", Johnston County, 0.2 mile above Secondary Road 1705, 3.0 miles east of Clayton.	1.30	I	80	20[a]	Sampling discontinued in 1977.
14	02088314. Beaverdam Creek near Dobbersville	Lat 35°17'56", long 78°15'57", Wayne County, at Secondary Road 1009, 5.3 miles north-northwest of Dobbersville.	2.60	IV	50	50	Major increase in agriculture in 1976. Paved county road crosses upper part of basin. Sampling activities discontinued in 1977.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
15	02089168. Mill Creek near Seven Springs	Lat 35°14'14", long 77°52'57", Wayne County, in Cliffs of the Neuse State Park, 2.0 miles west of Seven Springs.	0.79	IV	95	5	Located in Cliffs of the Neuse State Park.
16	02090625. Turner Swamp near Eureka	Lat 35°34'10", long 77°52'40", Wayne County, at Secondary Road 1505, 2.0 miles north of Eureka.	2.2	V	60	40[a]	Continuous-record station. Sampling activities discontiued in 1976.
17	02090666. White Oak Swamp near Mount Pleasant	Lat 35°48'55", long 78°04'42", Nash County, at Secondary Road 1956. 1.8 miles east of Mount Pleasant.	1.00	V	45	55[a]	Lightly-travelled county road crosses upper part of basin. Sampling activities discontinued in 1978.
18	02091476. Rainbow Creek near Browntown	Lat 35°24'00", long 77°34'50", Greene County, at U.S. Highway 258, 1.5 miles north of Browntown.	5.00	IV	60	40[a]	Lightly-travelled county road encircles basin. Sampling discontinued in 1977.
19	02091949. Clayroot Swamp near Shelmerdine	Lat 35°27'16", long 77°13'12", Pitt County, at bridge on Secondary Road 1786, 2.4 miles east of Shelmerdine.	0.60	V	90	10	Approximately 25 percent of wooded area is covered with underbrush and young timber.
20	02091961. Creeping Swamp near Wilmar	Lat 35°25'42", long 77°10'40", Beaufort County, on Sutton Road, 2.7 miles northwest of Wilmar.	0.2	V	100	0	Station established 1978.
21	02092551. Crooked Run near Trenton	Lat 35°02'25", long 77°22'07", Jones County, at Secondary Road 1123, 2.1 miles south-southwest of Trenton.	17.00	V	90	10	Most of basin drains from Hoffman State Forest.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See Fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
22	02092569. Brice Creek at Croatan	Lat 34°57'56", long 76°58'26", Craven County, at Secondary Road 1100, 0.4 mile southwest of Croatan.	0.80	V	100	0	Located in Croatan National Forest.
23	02096845. Cane Creek near Buckhorn	Lat 36°01'19", long 79°10'29", Orange County, at Secondary Road 1126, 2.5 miles southeast of Buckhorn.	1.00	II	95	5	Approximately 45 percent of wooded area is young timber and underbrush.
24	02096975. Ward Creek near Bynum	Lat 35°46'40", long 79°05'44", Chatham County, at Secondary Road 1700, 1.7 miles east of Bynum.	1.29	II	90	10	Large housing development started in basin in early 1977. Sampling activities discontinued.
25	02097715. New Hope Creek Tirb. near Farrington	Lat 35°47'08", long 79°01'50", Chatham County, at bridge on Secondary Road 1715, 1.5 miles southwest of Farrington.	0.30	II	95	5	Site now (1979) affected by land-clearing operations for B. Everett Jordan reservoir.
26	02100459. Sandy Creek Trib. at Melancton	Lat 35°50'26", long 79°39'17", Randolph County, at Secondary Road 2261, 0.8 mile southeast of Melancton.	3.30	II	80	20[a]	Sampling discontinued in 1977.
27	02100749. Grassy Creek near Jugtown	Lat 35°29'13", long 79°37'30", Moore County, at Secondary Road 1003, 2.2 miles southeast of Jugtown.	3.20	II	70	30[a]	Several dairy and poultry farms in basin. Sampling activities discontinued in 1977.
28	02101357. Big Governors Creek Trib. near Carthage	Lat 35°23'05", long 79°19'56", Moore County, at bridge on Secondary Road 1660, 5.2 miles northeast of Carthage.	2.90	II	90	10	State Highway crosses upper part of basin.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
29	02102237. Parkers Creek Trib. near Cokesbury	Lat 35°32'19", long 78°55'17", Harnett County, at mouth, 0.1 mile below Secondary Road 1450, 1.2 miles northwest of Cokesbury.	0.45	II	98	2	Station established in December 1977.
30	02102908. Flat Creek near Inverness	Lat 35°10'54", long 79°10'40", Hoke County, at culvert on Manchester Road, 3.6 miles east of Inverness.	7.65	III	100	0	Isolated section of Fort Bragg Military Reservation. Continuous-record streamflow station.
31	02105524. Ellis Creek Trib. near White Oak	Lat 34°46'02", long 78°41'24", Bladen County, at Secondary Road 1325, 1.4 miles northeast of White Oak.	1.6	IV	100	0	
32	02107154. South River Trib. at Tomahawk	Lat 34°42'15", long 78°20'25", Sampson County, at N.C. Highway 41, 0.9 mile southwest of Tomahawk.	2.80	IV	95	5	
33	02108608. Lillington Creek near St. Helena.	Lat 34°30'27", long 77°48'57", Pender County, at Secondary Road 1520, 5.9 miles east-southeast of St. Helena.	7.60	V	90	10	Most of basin lies in Holly Shelter State Game Management Area.
34	02109481. Juniper Creek near Prospect	Lat 34°06'07", long 78°18'25", Brunswick County, at State Highway 211, 4.2 miles north-northeast of Prospect.	6.40	IV	100	0	
35	02111275. Big Warrior Creek Subtributary near Boomer	Lat 36°03'04", long 81°15'47", Wilkes County, at Secondary Road 1116, 1.2 miles southwest of Boomer.	0.30	I	95	5	

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
36	02112202. Grays Creek near Clingman	Lat 36°10'27", long 80°58'03", Wilkes County, at Secondary Road 2318, 2.2 miles west-southwest of Clingman.	2.20	I	60	40[a]	State highway crosses part of basin. Sampling discontinued in 1977.
37	02112401. Endicott Creek near Blevins Store.	Lat 36°28'15", long 80°50'06", Surry County, at Secondary Road 1338, 1.4 miles northwest of Blevins Store.	3.20	I	98	2	
38	02114256. East Prong Little Yadkin River Trib. near Capella	Lat 36°21'49", long 80°21'08", Stokes County, at Secondary Road 1166, 1.9 miles west of Capella.	0.50	I	90	10	
39	02115496. Little Forbush Creek near Forbush	Lat 36°11'13", long 80°34'59", Yadkin County, at Secondary Road 1584, 0.9 mile southwest of Forbush.	1.70	I	80	20[a]	Sampling discontinued in 1975.
40	02115946. Fryes Creek Trib. near Midway	Lat 35°57'30", long 80°14'32", Davidson County, at Secondary Road 1506, 1.4 miles west of Midway.	0.40	I	50	50[a]	Lightly-travelled paved road transverses mid-basin. Sampling activities discontinued in 1977.
41	02117485. Olin Creek near Union Grove	Lat 35°59'15", long 80°55'16", Iredell County, at Secondary Road 1868, 4.0 miles southwest of Union Grove.	2.00	I	90	10[a]	Several dairy farms throughout basin.
42	02120507. Tributary to Third Creek Trib. near Barber	Lat 35°44'02", long 80°39'04", Rowan County, 0.4 mile above Secondary Road 1741, 1.0 mile northwest of Barber.	0.04	I	99	1	Station established in December 1977.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
43	02123532. Spencer Creek at Uwharrie	Lat 35°25'22", long 79°59'53", Montgomery County, at Secondary Road 1303, 0.6 mile northeast of Uwharrie.	6.90	II	99	1	Located in Uwharrie National Forest. Station established in October 1977.
44	02124193. Park Creek near Kannapolis	Lat 35°29'53", long 80°42'58", Cabarrus County, at Secondary Road 1624, 4.3 miles west of Kannapolis.	5.20	I	70	30[a]	Active dairy farming at several places in basin. Paved county road crosses part of basin. Sampling discontinued in 1977.
45	02127228. Goulds Fork near Wadesboro	Lat 34°57'23", long 80°07'23" Anson County, at Secondary Road 1205, 2.7 miles southwest of Wadesboro.	3.80	II	99	1	Station established in October 1977. Lightly-travelled, unpaved road crosses part of basin.
46	02129028. Bones Fork Creek near Hoffman	Lat 35°01'26", long 79°38'02", Richmond County, at bridge on Secondary Road 1487, 4.8 miles west of Hoffman.	6.96	III	95	5[a]	Located primarily in Sandhill Game Management Area.
47	02140304. Wilson Creek near Gragg	Lat 37°05'49", long 81°48'28", Avery County, at bridge on U.S. Highway 221, 2.7 miles northwest of Gragg	0.74	I	100	0	
48	02142122. Lower Little River Trib. near Taylorsville	Lat 35°53'24", long 81°13'52", Alexander County, at Secondary Road 1124, 3.4 miles southwest of Taylorsville.	2.60	I	90	10	Small dairy farm in lower part of basin.
49	02142692. Killian Creek near Denver	Lat 35°32'10", long 80°03'13", Lincoln County, at Secondary Road 1349, 1.4 miles west of Denver.	2.60	I	70	30[a]	Paved secondary road encircles basin. Permanent pastures and cattle (less than 100 head) in upper part of basin. Sampling activities discontinued in 1978.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
50	02142988. Henry Fork Trib. near Pleasant Grove	Lat 35°39'07", long 81°36'28", Burke County, at Secondary Road 1924, 1.9 miles northwest of Pleasant Grove.	3.20	I	95	5	Most of basin in South Mountains Management Area.
51	02143040. Jacob Fork at Ramsey	Lat 35°35'26", long 81°34'02", Burke County, at Secondary Road 1924, 0.6 mile north of Ramsey.	25.4	I	96	4	Continuous-record streamflow station. Sampling discontinued in 1977.
52	02149716. Silver Creek near Mill Spring	Lat 35°18'35", long 82°12'10", Polk County, at Secondary Road 1138, 2.4 miles west-northwest of Mill Spring.	1.20	I	98	2	
53	02152514. Little Hsrris Creek near Campbell	Lat 35°22'34", long 81°35'45", Cleveland County, at Secondary Road 1821, 1.3 miles east of Campbell.	1.20	I	65	35[a]	Most of cleared land is inactive pasture. Sampling activities discontinued in 1977.
54	03445376. North Fork Mills River above Mills River	Lat 35°24'25", long 82°38'47", Henderson County, at bridge on Natural Forest Road, 4.7 miles west-northwest of Mills River.	18.60	I	100	0	Located in Pisgah National Forest.
55	03450000. Beetree Creek near Swannanoa	Lat 35°39'11", long 82°24'20", Buncombe County, 1,000 feet above Beetree Reservoir, 3.8 miles north of Swannanoa.	5.46	I	100	0	Located in protected municipal watershed area.
56	03460000. Cataloochee Creek near Cataloochee	Lat 35°40'02", long 83°04'23", Haywood County, at bridge on State Highway 284, 2 miles north of Cataloochee.	49.2	I	98	2[a]	Continuous-record streamflow station. Located in Great, Smoky Mountains National Park.

Table 1. Names, locations, and physical characteristics of baseline sampling sites.—Continued

Map number (fig.1)	Station number and name	Location	Drainage area (mi^2)	Geochemical zone (See fig. 4)	Land use, in percent of total drainage area		Remarks
					Forest	Agriculture	
57	03463292. Locust Creek near Celo	Lat 35°48'42", long 82°11'52", Yancey County, at Secondary Road 1158, 3.0 miles south of Celo.	1.80	I	95	5[a]	
58	C3500741. Peeks Creek near Gneiss	Lat 37°07'08", long 83°17'40", Macon County, at Secondary Road 1678, 1.3 miles southeast of Gneiss.	2.00	I	97	3[a]	
59	03510815. Mingus Creek at Ravensford	Lat 35°31'12", long 83°18'30", Swain County, at bridge on U.S. Highway 441, 0.9 mile northwest of Ravensford.	4.70	I	100	0	Located in Great Smoky Mountains National Park.

a - Partly inactive.

Table 2.—Data-collection operations at stations in the baseline network.

[C, continuous; D, once-daily; M, monthly; S, semiannually]

Type of station	Number of stations	Flow conditions sampled		Type of data available and frequency						
		Full flow range	Estreme low and high flows only	Stream discharge	Water temperature	Specific conductance	Major constituents	Nutrients	Minor elements	Biological
Daily record	3	Yes	No	C	D	D	M	M	M	M
Partial record	56	No	Yes	None	S	S	S	S	S	none

extreme flow conditions; that is, (1) during low flows caused by long dry periods when the streams were at "base" flow, and (2) during high flows caused by rains resulting from the passage of major weather fronts. For convenience, these stations will be referred to as *partial-record stations.* The purpose of this sampling schedule was to determine the quality of both the ground-water inflow to the streams and overland flow if it occurred. It was logistically impossible to sample all sites during any one sampling period. Thus, different groups of stations were sampled at different times as suitable flow conditions occurred. Over the several years that samples were collected, both low-flow and high-flow samples were obtained at most of the sites during all seasons of the year.

We recognized that the "grab" samples obtained at the partial-record stations, as described above, left much to be desired. For example, we could not determine from such samples whether we ever succeeded in obtaining samples composed exclusively of overland runoff. If funds and manpower had permitted, we would have preferred to operate a continuous-record gaging station at each site and to obtain, in addition to daily flows, hourly measurements of conductivity and temperature. Although this was not feasible, five of the sites were located at existing stream-gaging stations (Nos. 16, 30, 51, 55, and 56 in table 1). At three of these, sites 16, 51, and 56, which represent each of the major physiographic provinces, daily values of conductivity and temperature were obtained and water samples were collected at about monthly intervals, depending on the flow conditions. For convenience, the latter three sites will be referred to as *daily-record stations.* Data from these stations were extremely valuable in the interpretation of data from the partial-record sites.

Brief descriptions of the basins sampled at the daily-record stations are contained in the following paragraphs:

Site No. 16, Turner Swamp near Eureka.—The Turner Swamp station is located in the west-central part of the Coastal Plain, two miles north of Eureka, Wayne County. Turner Swamp is the smallest stream in the daily-record group and at the sampling point has a drainage area of only 2.2 mi^2. Topography of the basin is gently rolling hills with elevations ranging from 90 to 130 feet. Average stream gradient is 17 ft/mi.

The basin is sparsely populated and has only 20 homes which are mostly on the perimeter of the basin. Dense forests and underbrush account for approximately 60 percent of the land use, and cleared land accounts for the remaining 40 percent. Of the cleared land, about half is under active cultivation while the remainder is used for pasture and idle croplands. Most of the forest land is along the water courses, thereby serving as buffer zones between the streams and cleared areas. A lightly traveled paved road encircles most of the basin. During the 1974–75 sampling period, no concentrated sources of significant pollution such as livestock feeding pens, pig farms, or intensive agricultural operations were present in the basin.

Site No. 51, Jacob Fork at Ramsey.—The Jacob Fork station is located about 0.4 miles north of Ramsey, Burke County. Most of the upper headwaters, comprising about 60 percent of the 25.4 mi^2 basin, is in the protected South Mountains Management Area. Typical of the western Piedmont region, the land is steep and average stream gradient is 120 ft/mi.

Although the basin is 96 percent forested, approximately 40 residences are located in the lower part of the basin. Approximately two percent of the land area is used periodically for crop cultivation and two percent is used for cattle pastures. Several paved and unpaved roads are in the lower part of the basin. There were no known point sources of stream pollution during the sampling period (1975–76). During 1974, an attempt to construct a mountain resort community about a mile upstream from the station failed because of economic reasons. Several homes were completed before construction ceased, but occupancy of these homes is mostly during the summer and weekends.

Site No. 56, Cataloochee Creek near Cataloochee.—The Cataloochee Creek sampling station is located in western North Carolina, about two miles north of Cataloochee, Haywood County. The drainage basin lies entirely in the Great Smoky Mountains National Park and has an area of 49.2 mi^2 at the station.

Cataloochee Creek is completely surrounded by mountains with elevations ranging from 2,460 feet on the valley floor to mountain peaks exceeding 5,500 feet. The average gradient of the main stream is 160 ft/mi. The basin is 98 percent forested and a ranger station at Cataloochee, located about 2½ miles upstream from the gage, is the basin's only permanent residence. There is no farming in the basin but it is a popular hiking and horseback riding area from mid April to September. Most of the recreation occurs in the upper headwaters. According to the National Park Service (Mr. Thomas Kloos, personal comm., 1977), several thousand horseback riders and hikers visited the area each year during the sampling period (1974–77). A narrow paved road crosses the headwaters region and terminates at a small wilderness campground. A sand and gravel road, State Highway 284, parallels the creek at a distance of a few hundred feet for about a mile upstream from the station. Both roads are lightly traveled.

SAMPLING AND LABORATORY PROCEDURES

To ensure the collection of representative water samples and consistency in sampling techniques, all samples were collected using depth-integrating methods as discussed by Guy and Norman (1970). A hand-held aluminum DH–48 sampler (Guy and Norman, 1970, p. 16) was used to obtain samples from shallow, wadable streams. A weighted sampler capable of holding up to four 1–liter bottles was used on deeper, slow moving streams. Samples from deep, swift streams were obtained using a bronze, 24-lb sampler, the DH–59; and a much heavier sampler, the 62-lb D–49, was used during high-flow conditions when complete depth integration was not possible with lighter samplers. To prevent contamination, the samplers used to collect samples for trace-metal analyses were coated with epoxy paint.

Water samples obtained for determination of dissolved constituents were filtered through a 0.45 μm membrane immediately after collection. All filtering was performed using a Skougstad filtration unit and compressed air or nitrogen (Skougstad and Scarboro, 1968). To minimize loss of solutes by oxidation and (or) precipitation, trace-metal samples were treated with nitric acid immediately after filtering. Samples collected for nutrients were chilled immediately after collection and were kept in this condition until analyzed.

Except for determinations of unstable parameters such as pH, dissolved oxygen, specific conductance and alkalinity, all of which were determined at the time of sampling, all chemical analyses were performed in the USGS Central Laboratory at Doraville, Georgia. The methods and procedures used by the Central Laboratory are in compliance with guidelines established in Chapter 5, National Handbook of Recommended Methods for Water-Data Acquisition (Federal Interagency Work Group, 1977). Analyses of suspended sediment were made in the district sediment laboratory located in Raleigh.

FACTORS AFFECTING BASELINE WATER QUALITY

The quality of water at the sites in the baseline network depends primarily on the quality of the precipitation and on the changes in quality that occur as the precipitation moves over and percolates through the ground. Every effort was made to identify areas free of agricultural and other human-related activities so that the quality of the water leaving the areas would be dominated by natural processes with man's effects at a minimum. As is apparent in table 1, however, it was necessary to include several sites in the network that were partly affected by some development in order to obtain adequate areal coverage. Because of air-borne pollution, however, even data from sites completely free of all development cannot, strictly speaking, be assumed to reflect only natural water quality.

Particles and gases released to the atmosphere by man's activities affect even the most remote parts of earth and clearly have an important effect on the water quality at the baseline sites. For this reason the term "baseline" quality is generally used in this report rather than the term "natural" quality. The following sections deal with several of the most important factors affecting the water quality at baseline sites.

Precipitation

North Carolina is located in the humid temperate zone and receives abundant rainfall distributed rather

Table 3.—Chemical composition of bulk precipitation in North Carolina.

Location	Dissolved constituent (mean concentrations, in mg/L)								
	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	NH_4
Hatteras[1]	0.41	0.59	4.36	0.10	-	1.97	8.20	0.23	Generally less than 0.05 mg/L
Washington[1]	.73	.20	.82	.10	-	2.02	1.15	.34	
Rocky Mount[1]	.57	.18	.74	.10	-	1.91	.74	.70	
Raleigh[1]	.41	.13	.39	.10	-	1.99	.34	.63	
Greensboro[1]	.52	.13	.36	.10	-	2.56	.37	.69	
Waynesville[2]	.85	.10	.52	.17	2.0	2.26	.20	-	
Coweeta[3]	.19	.04	.21	.07	-	-	.35	.12	

[1] Gambell and Fisher (1966). Means of monthly samples collected August 1962 through July 1963.
[2] Unpublished data (USGS). Means of nine periodic samples collected July 1962 through March 1963.
[3] Swank and Henderson (1976). Means of weekly samples collected June 1972 through May 1973.

uniformerly throughout the year. Based on long-term weather records, rainfall amounts range from about 37 inches per year at Asheville to about 80 inches at Highlands. The statewide yearly average is about 50 inches.

Precipitation contains constituents of local origin and some that have been transported by winds from distant sources. Also, during rainless periods, there is a "dry" fallout of mineral and organic dust from the atmosphere. Because precipitation is the source of water in North Carolina streams, it's chemical composition must be considered in any water-quality study which has as one of its objectives the identification of sources of constituents. It was not feasible to collect data on the chemical composition of precipitation as a part of this study but enough data exist to show that significant quantities of the major ions, except silica, are contained in precipitation. Data from other studies for selected sites located across the State are presented in table 3. The data in table 3 are referred to as "bulk precipitation" because the analyses include constituents deposited both by rainfall and by dry fallout. These data show the variability of the chemical composition of rainwater. Concentrations of several of the major constituents, such as chloride, sodium and magnesium, are greatest along the coast and decrease inland, thereby indicating that the ocean is a primary source. Relatively uniform values of other major constitutents, however, indicate apparent contribution from land or non-marine sources. Gambell and Fisher (1966) and others also show that concentrations of many constitutents in rainwater vary seasonally and from one storm to another.

In addition to contributing major chemical constituents, precipitation also serves as an indirect source of minor elements and nutrients. Most of these constituents probably enter the atmosphere as gaseous or particulate matter generated during man's activities and return to earth absorbed or suspended in raindrops and snow flakes. Of recent concern are the quantities and forms of the nutrients, nitrogen and phosphorus, which are contributed by both wet and dry precipitation. Gambell and Fisher (1966) showed that concentrations of nitrate in precipitation increased in a westward direction across North Carolina with lowest values occurring along the coast and highest values in the mountains. By comparing annual constituent loads derived from precipitation with loads in four major eastern North Carolina rivers, Gambell and Fisher estimated that the total nitrate load could have been derived entirely from precipitation. In a recent study of seven eastern North Carolina streams, Kuenzler, Mulholland, Ruley and Sniffen (1977) reported weighted-mean concentrations of 0.36 and 0.06 mg/L respectively for total nitrogen and phosphorus in bulk precipitation. Other studies, such as Joyner (1974) and Ellis, Erickson, and Wolcott (1978) also show that concentrations of nitrogen and phosphorus are often greater in precipitation than in unpolluted natural streams.

Soils and Rocks

Prior to reaching the land surface, precipitation becomes slightly acidic as a result of absorption of carbon dioxide and other gases from the atmosphere. After precipitation reaches the land surface its chemical composition is modified as it comes in contact with plants, decaying organic matter, soils, and rocks below the soil zone. The rate and extent of this modification depends on the chemical composition of the precipitation and on the solubility characteristics of the soil and rock particles.

The rocks underlying North Carolina are described by Stuckey (1965). These range from relatively soluble

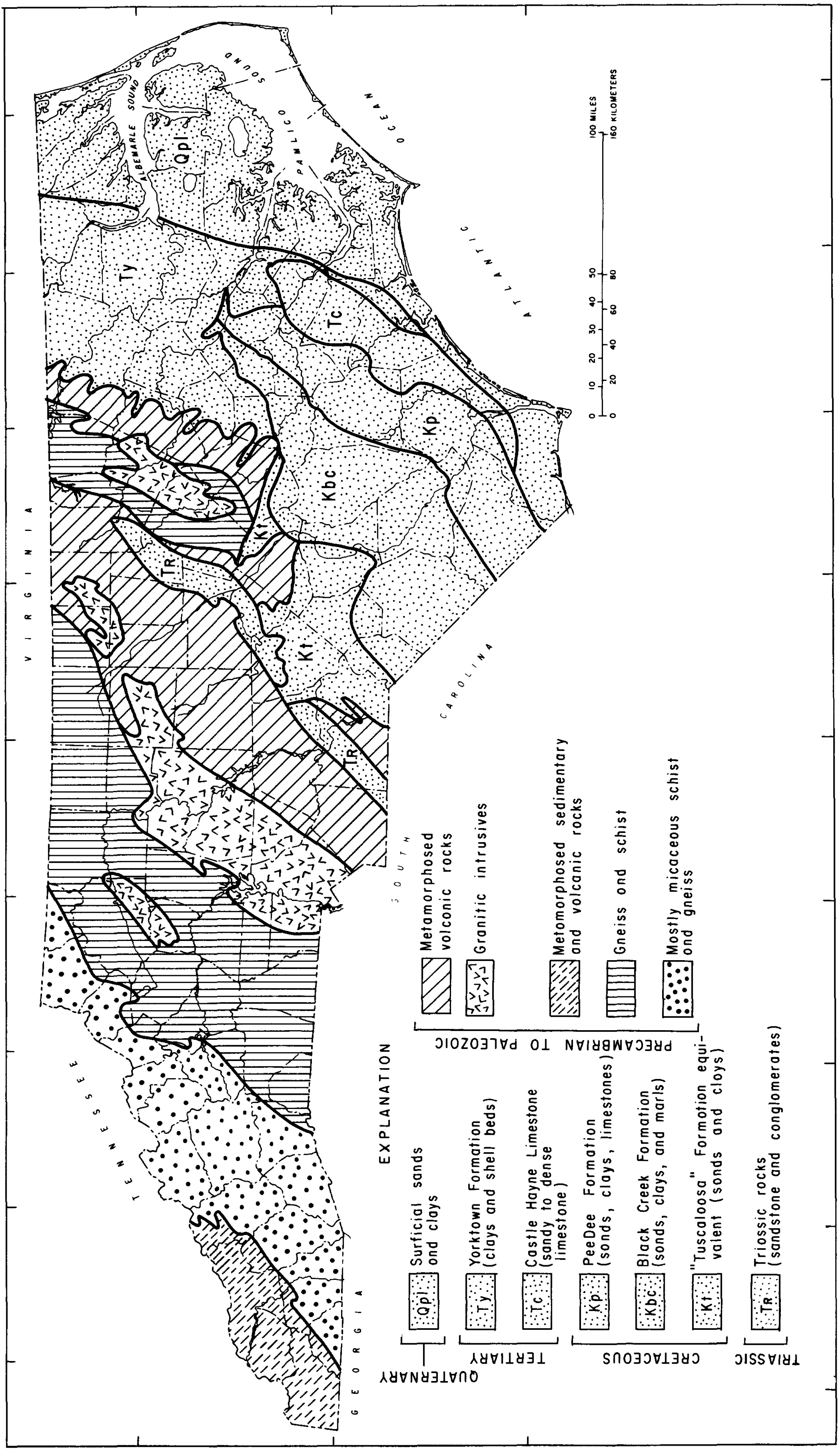


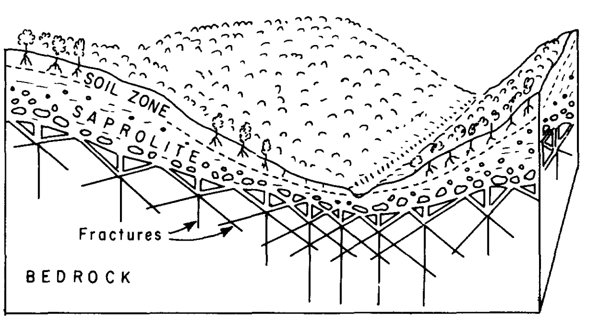
Figure 2. Generalized geologic map of North Carolina (modified from North Carolina Department of Conservation and Development, 1958).

beds of limestone and mollusk shells, which underlie parts of the Coastal Plain region, to relatively insoluble rocks such as granite, mica schist, and slate, which underlie large areas in the Piedmont and mountain regions. A generalized geologic map of the State is shown in figure 2. The geology of the State is far more complex than indicated on figure 2 which shows only major rock types and formations. The generalized map is used, however, because it is not within the scope of this report to relate stream quality characteristics to complex localized geologic conditions but rather to relate, where possible, these characteristics to large-scale regional geologic properties.

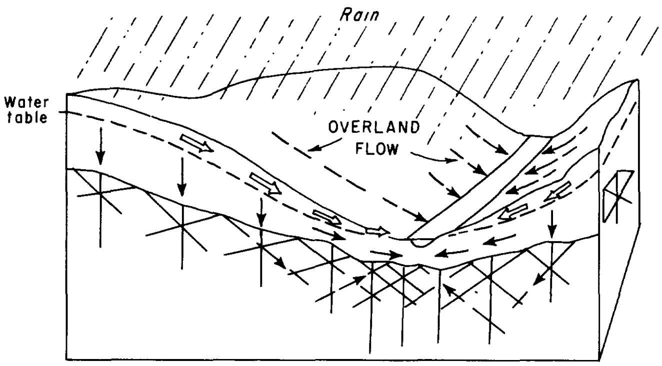
Because of the wide range in lithology and solubility of the rocks underlying North Carolina, it is reasonable to expect a wide range in the concentration of substances dissolved in water that reaches streams, especially during low-flow periods. The most soluble rocks underlie parts of the Coastal Plain region, and, as might be expected, baseflow in these areas contains relatively large concentrations of substances that are dissolved as the water percolates through the ground-water system. The rocks underlying the Piedmont and mountain regions are less soluble but, as LeGrand (1958) pointed out, there are significant differences in solubility between the different rocks underlying these regions. Using chemical analyses of water from wells and springs, he showed that the igneous and metamorphic rocks underlying the Piedmont and mountain areas form two distinct groups. One group, referred to as the granite group and composed of granite, granite gneiss, mica schist, slate, and rhyolite flows and tuffs, yields a soft, slightly acidic water that contains a low concentration of dissolved constituents. The other group, referred to as the diorite group and composed of diorite, gabbro, hornblende gneiss, and andesite flows and tuffs, yields a harder slightly alkaline water relatively high in dissolved constituents.

Runoff Conditions

It is apparent from the preceding discussions that the chemical content of water in the streams of the baseline network depends primarily on the chemical content of precipitation and on the amount of material added to the water from vegetation, surface litter, and the soils and rocks with which it comes in contact. Thus, the water quality is often dependent upon runoff conditions and the path taken by runoff in reaching the stream system. It is, therefore, necessary to consider, at least briefly, these paths or sources of water in the baseline streams.



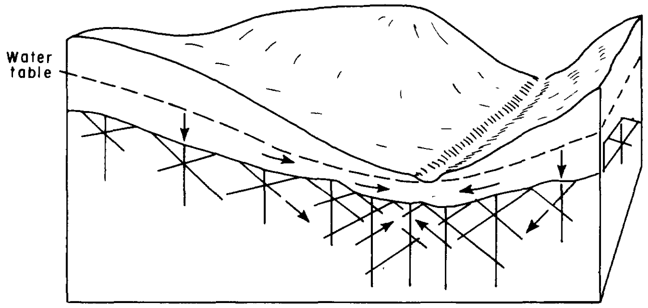
A. Forested area in the Piedmont and Mountains.



B. Runoff conditions during storms

<⇐ Seepage through surface litter and soil zone.

←— Seepage through lower part of saprolite and bedrock



C. Runoff conditions during base flow.

←— Seepage through saprolite and bedrock

Figure 3. Basin cross section showing idealized runoff conditions from wooded areas in the Piedmont and mountain regions.

Runoff conditions are quite variable across the State and, to a large degree, are controlled primarily by various characteristics of the underlying soils and rocks, topography, and ground cover. Figure 3 shows runoff conditions during storms and during baseflow from a hypothetical wooded area located in the Piedmont or mountains. Both the Piedmont and mountains are underlain by bedrock that has been broken along an intricate network of fractures (fig. 3A). The bedrock is overlain, except where exposed at the surface, by a layer of disintegrated (weathered) rock referred to as saprolite or residuum. The upper zone of saprolite, generally ranging in thickness from a few inches to several feet, forms the soil zone. The soil zone of wooded areas in the Piedmont and mountains is covered by a layer of forest litter averaging several inches in thickness which is capable of absorbing water at a relatively high rate.

During storm runoff as depicted in figure 3B, rain infiltrates into the highly permeable surface litter and soil zone and moves quickly downslope to discharge into the nearest stream. In forested basins, overland runoff is rare and occurs only during intense rainfall (1) when the rainfall exceeds the infiltration capacity of the soil zone and (or) (2) only near streams and along depressions where the water table is at or near the land surface. In forested areas of North Carolina, most soluble materials have previously been leached from the shallow soil zone and waters flowing in this zone usually contain low concentrations of dissolved matter. Concentrations of solid particles and constituents sorbed on particles, however, often reach maximum levels during storm runoff as a result of being swept into suspension by increased stream velocities.

During periods following rains, the lateral movement of water through the soil zone in the Piedmont and mountains ceases and water reaching the streams is ground water that has moved through the deeper saprolite and bedrock (fig. 3C). As these deeper zones are less weathered than the soil zone, they generally contain more soluble materials, and waters draining these zones most often contain greater concentrations of dissolved mineral matter than waters that move only through the shallow zones. During baseflow conditions, concentrations of suspended solids are minimal because stream velocities are most often insufficient to transport significant amounts of material in suspension.

LeGrand (1958, fig. 1) presented the following chemical data obtained from springs and wells located in the Piedmont and mountains:

Type of rock	Source of water	Dissolved-solids median concentration (mg/L)
Granite	springs	39
Granite	wells	71
Diorite	springs	99
Diorite	wells	233

Data obtained from springs are indicative of shallow ground-water conditions whereas the wells are generally representative of much deeper saprolite and (or) bedrock conditions. LeGrand's data illustrates large differences in ground-water chemistry between major rock types and further shows that waters derived from shallow surficial materials are the least mineralized.

Runoff conditions in the Coastal Plain region differ from those in the Piedmont and mountains primarily because of differences in geology and topography. The relatively flat surface slopes of the Coastal Plain result in a slow movement of water both on the surface and underground. Unlike the mountains and Piedmont, which are generally underlain by bedrock at relatively shallow depth, most of the Coastal Plain region is underlain by surficial deposits of sands and at greater depths by layers of clay, sand, marl, and limestone. Runoff derived from the deeper marls and limestone contains greater concentrations of dissolved substances than does runoff which comes from the shallow and less soluble soil zone. In general, however, most of the hydrologic and geochemical processes evident in the mountains and Piedmont are also characteristic of streams in the Coastal Plain.

WATER-QUALITY CHARACTERISTICS OF UNPOLLUTED STREAMS

As has already been mentioned, water samples were collected at the baseline stations both during or immediately after storms and during fair weather periods when no rain had fallen for at least several days. In addition, daily measurements of conductivity were made at three of the stations. The results of this sampling program provide information on three important aspects of baseline (unpolluted) water quality. These are:

1. Areal differences in water quality resulting both from differences in the chemical composition of precipitation and from differences in soil and rock solubility.
2. Differences in the chemical quality of streams during periods of high flow and baseflow.
3. The effect of agricultural land use on water quality.

Definition of Surface-Water Geochemical Zones

During the early phases of the study, the data collected at baseline sites were analyzed to determine the extent to which the water quality differed from one part of the State to another. This analysis indicated a high degree of variability between many constituents when viewed on a Statewide basis. However, it was observed that the chemical quality of streams underlain by the same rock type was noteably similar. Figure 4 shows the sites at which data are representative of baseline conditions. The fractions near the symbols for each site show the mean total dissolved solids of (1) samples collected during periods of high flow (upper number), and (2) samples collected during periods of baseflow (lower number). The boundaries of the five geochemical zones were drawn on the basis of the contacts of the major geologic units shown on figure 2 and, where available, the similarity of the chemical composition in both high flow and low flow.

Although several methods can be used to substantiate the locations of the geochemical boundaries, a computerized multiple group discriminant analysis program, BMD-07M (University of California, 1974), gives one of the best visual displays of these differences. This program

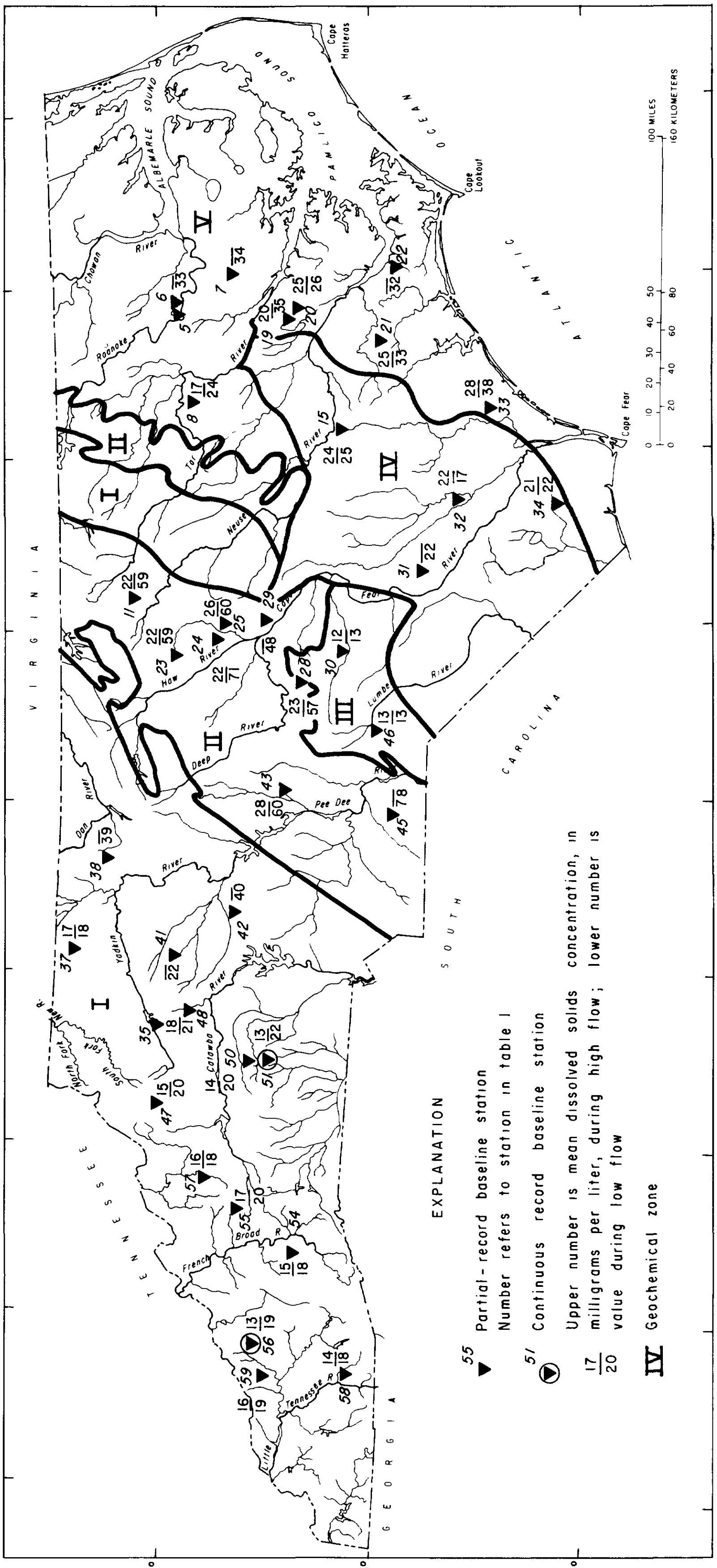


Figure 4. Locations of unpolluted baseline quality stations, mean dissolved-solids concentrations, and major geochemical zones.

uses a number of complex statistical procedures to group sites having similar characteristics. For each sampling site, mean concentrations of total dissolved solids, sulfate, chloride, sodium, and calcium were used in the program as input variables. Along with various statistical values, the program produces a multidimensional plot that is converted to a two-dimensional plot of these data which shows optimal separation of similar groups. Figure 5 is a plot derived from using the above major constituents for unpolluted sites in the baseline network. Each number on the plot represents a baseline site. Its position was determined by evaluating the first two canonical variables, which are those linear combinations of the input variables that yields the greatest and second greatest statistical separations among the five geochemical zones. As shown in figure 5, the close grouping of stations which lie in the same geochemical zones indicates (1) that the boundaries of the zones are logically located, and (2) that in regards to the major dissolved constituents used in the comparison, the chemical characteristics of unpolluted streams within each zone are generally similar.

As will be shown later in this report, many constituents show little or no variations between zones and therefore appear to be unrelated to differences in geology or soil types. Enough of the major constituents show a correlation with geology, however, to justify the zone boundaries; and, to facilitate the discussion of constituents, the geochemical zones are used throughout the report regarding references to geographic locations. A brief discussion of major characteristics of individual zones follows:

Geochemical zone I is probably the most complex

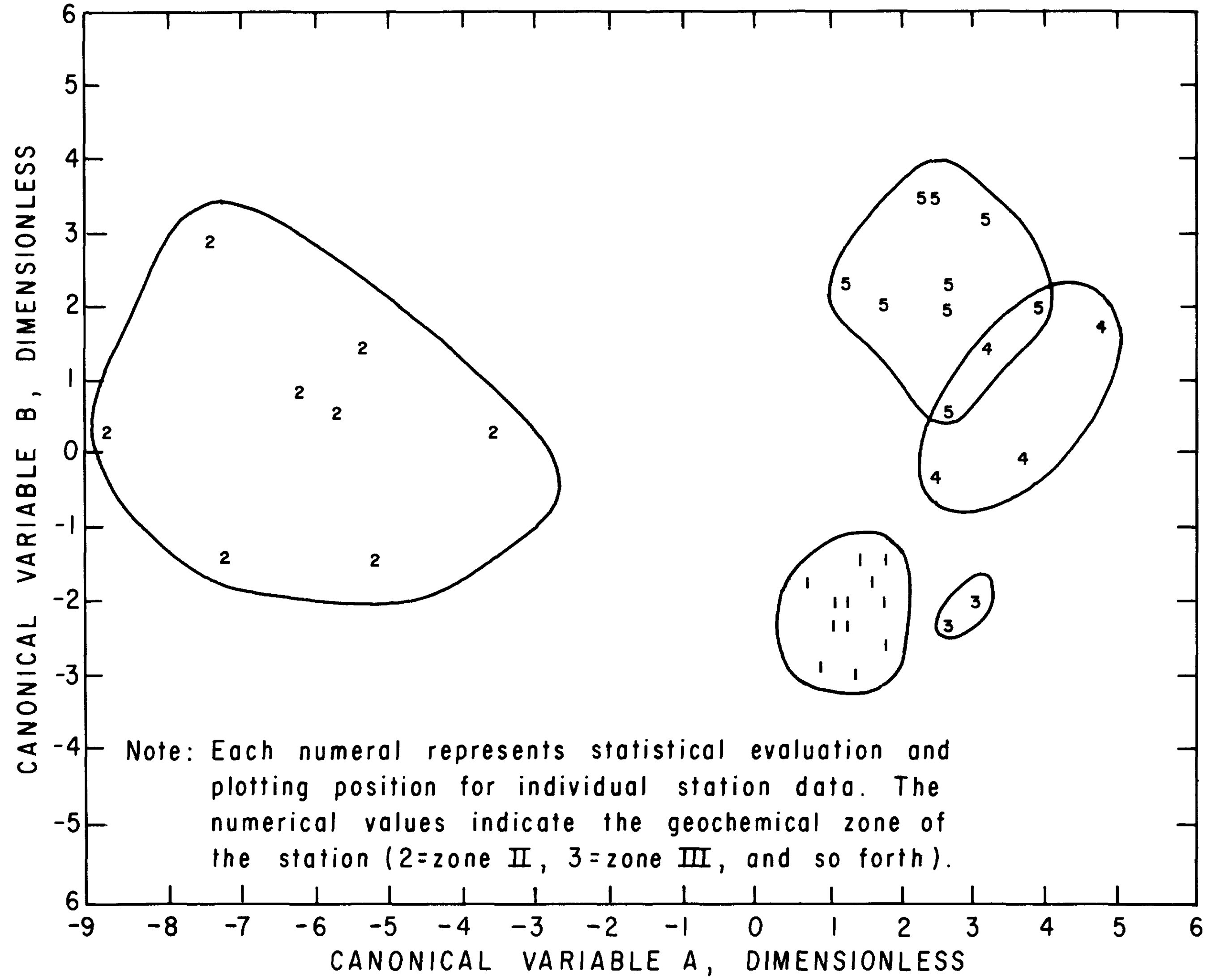


Figure 5. Computer plot showing ideal close grouping of baseline sites obtained from comparing stream-quality data and geochemical zones of sites by multiple group analysis.

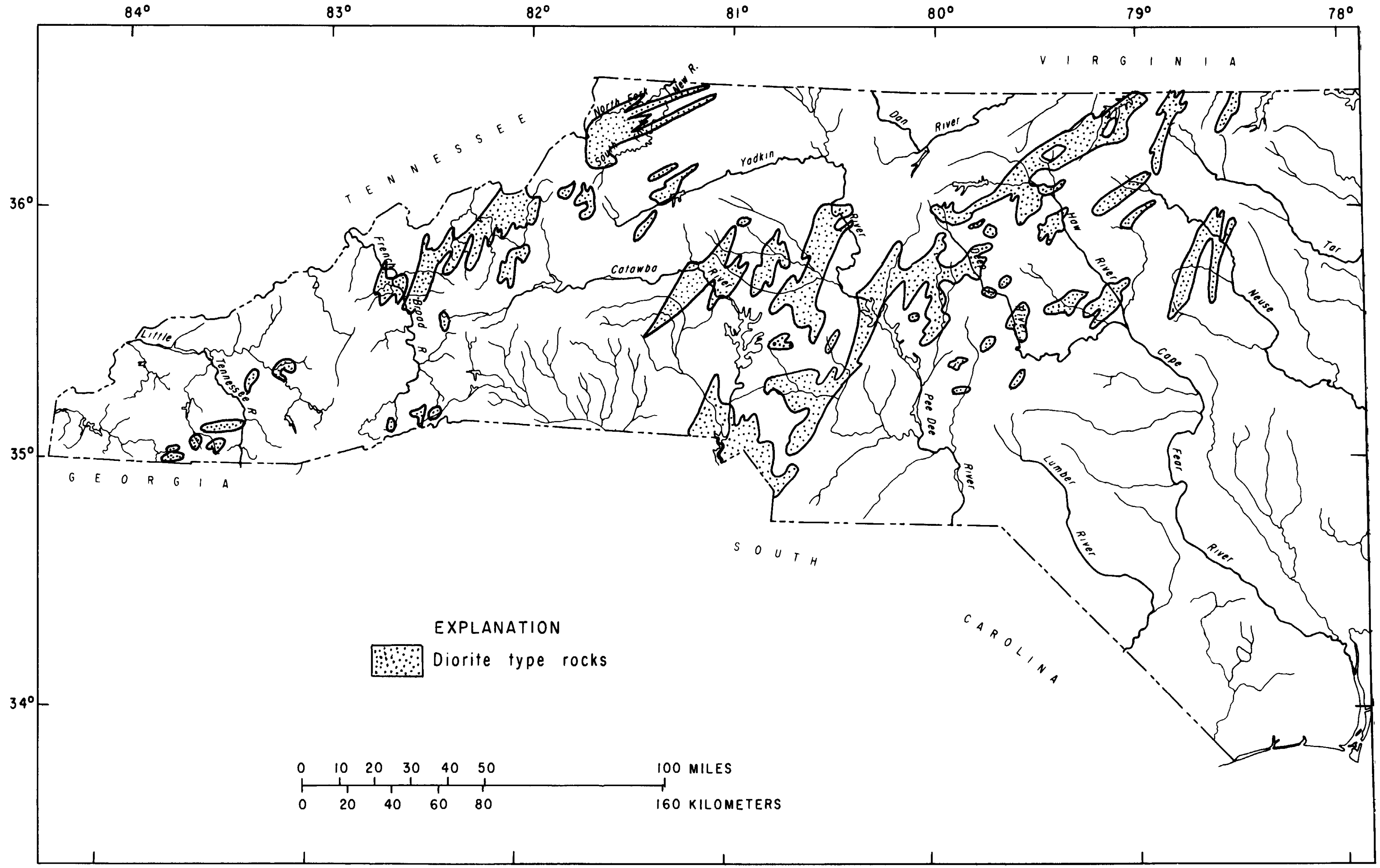


Figure 6. Areas underlain by rocks of the diorite group.

from the standpoint of rock composition. Although it includes the four major rock units shown on figure 2, the composition of the rocks underlying this zone is far more complex than shown. On the large-scale geologic map referred to earlier the four major rock units are subdivided into 21 units. However, the similarity of water quality at the 16 baseline sites in this zone suggests that the different rock units produce waters of very similar chemical composition. The largest differences in water quality are observed between the granite and diorite groups described by LeGrand (1958).

Of the baseline sites in zone I on figure 4, all are in granite-group rocks except site 42. Site 42 is in rocks of the diorite group. As shown on figure 4, water at this site contains significantly more dissolved mineral matter than does water at sites in the granite group. It might have been appropriate to divide zone I into two or more zones composed respectively of these rock groups. We chose not to do this because, as shown on figure 6, diorite-group rocks underlie only about ten percent of the area, and most of the areas underlain by these rocks are relatively small and are surrounded by extensive areas of granite-group rocks. Consequently, on an areal scale relatively little streamflow originates from the diorite-group rocks.

Geochemical zone II coincides with the Carolina Slate Belt and the Durham and Wadesboro Triassic basins. The Slate Belt is underlain by metamorphosed volcanic and metamorphosed sedimentary rocks. The Triassic basins are underlain by cemented conglomerates, sandstones, siltstones, and shales. Although high flows originating in zone II are only slightly more mineralized than those in zone I, concentrations during low flows are considerably greater in zone II.

The coastal Plain region of the State is divided among three zones, III, IV, and V. Geochemical zone III coincides with the Sand Hills section of Cumberland, Harnett, Hoke, Moore, Richmond, and Scotland Counties. This area is underlain by a surficial layer of quartz sand ranging in thickness from a few feet to about 150 feet. Because of the highly permeable nature of this sand, water readily infiltrates into it and little overland flow occurs. Thus, as shown on figure 4, there is no significant difference in dissolved solids of high flow and low flow. Also, because quartz is relatively insoluble, the water in this zone is less mineralized than water from any other zone.

Geochemical zone IV coincides with the outcrop area of the Black Creek and Pee Dee Formations of Cretaceous age. These formations consist of interbedded layers of sand, clay, and marl. Much of the area is underlain by a surficial layer of quartz sand. As a result, little or no overland runoff occurs and the chemical quality of both high flows and low flows are very similar. Furthermore, because most of the water moves only through the surficial quartz sand, the dissolved solids are relatively low compared to that originating in most of the other geochemical zones.

Geochemical zone V encompasses the remainder of the Coastal Plain and includes the areas underlain by the Castle Hayne Limestone and the Yorktown Formation of Tertiary age, and the surficial sands, shell beds, and clays of Quaternary age. Both the limestone and the shell beds are relatively soluble with the result that water in this zone tends to be somewhat more mineralized than water in zone IV. However, because neither the Castle Hayne nor the shell beds in the Yorktown Formation are continuous over the area, dissolved solids in water from this zone tend to vary more widely than in most other zones of the Coastal Plain region.

Chemical Characteristics

The chemical composition of water from the baseline sites is summarized in tables 4–6. The values shown include the number of samples, mean, range, standard error of the mean, and standard deviation of constituents in both high flow and baseflow. These values also indicate the reliability of the data, which in some cases might be doubtful primarily because of an insufficient data base in some zones. Because the number of samples were different for different stations, mean values for a geochemical zone were computed from mean values for stations located within the zone rather than from individual sample analyses. Data for the three daily-record stations are shown separately in table 4 to permit comparison of the site data with the mean values for zones in which the sites are located. It should be noted that the data for Turner Swamp was not averaged with the other data from zone V because of the significant level of agricultural land use in the Turner Swamp basin.

The areal variations in baseline quality are most readily apparent from figures 7 and 8 which show the mean values for selected constituents during both high flow and baseflow for each geochemical zone. The major inorganic constituents and total dissolved solids are shown in figure 7 and nutrients are shown in figure 8. For those constituents such as magnesium, potassium, and phosphorus, which show little variation in concentrations between geochemical zones and (or) different flow conditions, it might be appropriate to determine a single representative value for the entire State. For purposes of this report, however, individual constituents values have been determined for each zone and flow condition, and presented accordingly to show the presence and extent of regional variations.

The most significant aspect of the data presented in tables 4–6 is the small concentration of substances found in the water. It is not surprising that the smallest values occur in waters of zone III which, as previously noted,

Table 4. Statistical summary of major inorganic constituents, in milligrams per liter, in unpolluted streams.

[SD, standard deviation; SE, standard error of mean; ND, not determined]

Geo-chemical zone	Base-line site(s)	Runoff condition and number of analyses	Calcium				Magnesium				Sodium				Potassium				Bicarbonate			
			Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE
I	All	Storm(13)	1.3	0.5-3.0	0.8	0.2	0.4	0.3-.9	0.2	0.1	0.8	0.4-1.3	0.3	0.1	0.6	0.4-.9	0.2	0.1	5.1	2.0-8.0	1.8	0.5
		Baseflow(31)	1.3	.7-2.1	.4	.1	.6	.3-.9	.2	.1	1.5	1.0-2.2	.4	.1	1.0	.3-1.9	.5	.1	7.4	6.0-9.5	1.2	.4
	Cataloo-chee Cr.	Storm(2)	2.3	.6-1.9	ND	ND	.4	.2-.5	ND	ND	.4	.4	ND	ND	.7	.6-.8	ND	ND	3.5	3.0-4.0	ND	ND
		Baseflow(8)	1.8	.9-2.6	ND	ND	.5	.1-1.1	ND	ND	1.4	.9-2.0	ND	ND	.6	.2-.8	ND	ND	6.7	5.0-8.0	ND	ND
	Jacob Fork	Storm(2)	1.2	.7-1.7	ND	ND	.3	.3	ND	ND	.4	.4	ND	ND	.8	.7-.8	ND	ND	3.5	3.0-4.0	ND	ND
		Baseflow(8)	1.7	.7-2.9	ND	ND	.5	.2-.9	ND	ND	1.4	1.1-1.8	ND	ND	.9	.7-1.3	ND	ND	9.4	6.0-16	ND	ND
II	All	Storm(6)	2.6	2.1-3.2	.4	.2	1.0	.7-1.1	.2	.1	1.8	1.3-2.5	.5	.2	1.1	.3-1.8	.6	.2	5.0	3.0-6.0	1.1	.4
		Baseflow(12)	5.6	2.9-10	2.1	.7	2.4	1.1-4.1	1.0	.3	5.9	4.7-7.3	1.1	.4	1.0	.3-1.8	.5	.2	34	21-44	7.4	2.6
III	All	Storm(3)	.4	.1-.8	ND	ND	.4	.3-.5	ND	ND	.9	.8-1.0	ND	ND	.2	.1-.2	ND	ND	.5	0-1.0	ND	ND
		Baseflow(4)	.6	.5-.6	ND	ND	.4	.3-.4	ND	ND	1.3	1.0-1.5	ND	ND	.5	.5	ND	ND	3.5	3.0-4.0	ND	ND
IV	All	Storm(5)	1.5	1.1-1.9	.5	.4	.4	.3-.6	.2	.2	2.3	2.1-2.5	.3	.2	.6	.4-.7	.2	.2	0	0	0	0
		Baseflow(7)	.6	.4-.7	.1	.1	.4	.3-.8	.2	.1	2.3	2.0-2.5	.2	.1	.5	.1-1.0	.4	.2	1.0	0-4.0	2.0	1.0
V	*All	Storm(7)	1.6	.4-3.7	1.2	.6	.6	.5-.7	.1	.1	2.3	1.8-2.7	.4	.2	.6	.1-1.1	.4	.2	.4	0-1.0	.5	.2
		Baseflow(14)	2.3	.2-4.0	1.2	.4	.8	.3-1.5	.4	.1	3.6	2.8-4.8	.7	.2	.9	.4-1.9	.5	.2	4.0	0-7.5	2.8	1.0
	Turner Swamp	Storm(4)	2.4	1.4-3.2	ND	ND	.3	.3-.5	ND	ND	.4	.2-.7	ND	ND	1.2	1.2-1.3	ND	ND	4.0	3.0-4.0	ND	ND
		Baseflow(6)	3.4	1.8-4.8	ND	ND	.9	.5-1.2	ND	ND	5.7	5.2-6.0	ND	ND	1.2	.9-1.5	ND	ND	10	7.0-14	ND	ND

Geo-chemical zone	Base-line site(s)	Runoff condition and number of analyses	Sulfate				Chloride				Fluoride				Silica				Total dissolved solids (sum)			
			Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE
I	All	Storm(13)	2.2	0.8-5.7	1.4	0.4	0.7	0.0-1.9	0.5	0.2	0.1	0.0-.5	0.2	0.1	6.6	3.6-8.6	1.6	0.5	15	12-18	1.9	0.6
		Baseflow(31)	2.2	1.0-3.9	.9	.3	.9	.1-2.0	.6	.2	.1	.05-.15	.0	.0	8.1	5.9-9.5	1.1	.3	19	16-22	1.8	.5
	Cataloo-chee Cr.	Storm(2)	2.2	1.8-2.5	ND	ND	.6	.3-.8	ND	ND	0	0	ND	ND	4.8	4.2-5.4	ND	ND	13	12-14	ND	ND
		Baseflow(8)	1.7	.6-2.7	ND	ND	.8	.4-20	ND	ND	.1	0-.2	ND	ND	8.5	7.5-9.2	ND	ND	19	17-21	ND	ND
	Jacob Fork	Storm(2)	3.6	3.2-4.0	ND	ND	1.2	.9-1.4	ND	ND	0	0	ND	ND	3.6	3.2-3.7	ND	ND	12	11-14	ND	ND
		Baseflow(8)	1.9	1.4-2.8	ND	ND	1.1	1.0-1.3	ND	ND	.1	0-.1	ND	ND	9.4	8.1-11	ND	ND	22	18-24	ND	ND
II	All	Storm(6)	6.8	5.5-8.1	1.1	.5	2.1	1.4-2.9	.5	.2	.1	0-.2	.1	.0	5.8	3.1-8.8	2.3	.9	24	22-28	2.6	1.0
		Baseflow(12)	2.6	1.2-8.2	2.3	.8	5.4	3.1-10	2.4	.8	.1	0-.1	.1	.0	22	12-29	6.1	2.1	61	48-78	9.8	3.5
III	All	Storm(3)	3.0	2.6-3.4	ND	ND	2.0	1.5-2.5	ND	ND	.2	.1-.3	ND	ND	4.5	4.5-4.6	ND	ND	12	12-13	ND	ND
		Baseflow(4)	2.2	2.0-2.5	ND	ND	1.4	1.1-1.8	ND	ND	.1	0-.1	ND	ND	4.8	4.5-5.1	ND	ND	13	13	ND	ND
IV	All	Storm(5)	8.3	7.8-8.8	.7	.5	4.2	3.1-5.4	1.6	1.2	.2	.1-.3	.1	.1	5.2	1.6-8.7	5.0	3.5	23	22-25	2.5	1.8
		Baseflow(7)	7.6	5.2-12	3.4	1.7	3.4	2.7-4.2	.7	.3	.1	0-.1	0	0	5.9	1.9-9.0	3.1	1.6	22	17-25	3.3	1.7
V	*All	Storm(7)	8.9	5.7-12	2.5	1.1	3.7	1.9-5.3	1.3	.6	.2	0-.5	.2	.1	4.4	3.5-5.6	.8	.4	23	17-28	4.4	2.0
		Baseflow(14)	9.2	5.6-12	2.5	.9	5.3	3.6-7.6	1.1	.4	.1	0-.2	.1	0	7.2	5.2-11	1.9	.7	32	24-38	4.9	1.7
	Turner Swamp	Storm(4)	4.0	3.5-5.4	ND	ND	3.0	.8-5.1	ND	ND	.1	0-.1	ND	ND	1.5	1.4-2.4	ND	ND	16	12-18	ND	ND
		Baseflow(6)	3.5	1.8-5.4	ND	ND	7.5	6.4-8.7	ND	ND	.1	0-.3	ND	ND	11	8.8-12	ND	ND	40	31-44	ND	ND

*All sites except Turner Swamp

Table 5. Statistical summary of nutrient values by geochemical zone and flow condition in unpolluted streams.

[SD, standard deviation; SE, standard error of mean; ND, not determined]

Geo-chemical zone	Runoff condition and number of analyses	Nitrate nitrogen				Ammonia nitrogen				Organic nitrogen				Total nitrogen				Total phosphorus			
		Mean	Range mg/L	SD	SE	Mean	Range mg/L	SD	SE	Mean	Range mg/L	SD	SE	Mean	Range mg/L	SD	SE	Mean	Range mg/L	SD	SE
I	Storm (18)	0.17	0.01-.62	0.18	0.06	0.01	0.00-.01	0.00	0.06	0.13	0.02-.29	0.07	0.02	0.30	0.14-.92	0.23	0.07	0.01	0.00-.03	0.01	0.00
	Baseflow(21)	.08	.00-.17	.07	.02	.00	.00-.01	.00	.00	.11	.00-.27	.10	.00	.19	.00-.36	.13	.04	.01	.00-.02	.01	.00
II	Storm (9)	.07	.00-.26	.10	.04	.01	.01-.02	.00	.00	.48	.37-.69	.11	.05	.56	.34-.73	.14	.06	.03	.03-.04	.00	.00
	Baseflow(10)	.16	.00-1.00	.34	.12	.01	.00-.07	.03	.01	.22	.07-.51	.15	.05	.40	.07-1.50	.47	.17	.02	.01-.05	.02	.01
III	Storm (5)	.04	.04-.05	.01	.01	.01	.00-.01	.00	.00	.34	.31-.38	.05	.04	.40	.37-.43	.04	.03	.01	.00-.01	.00	.00
	Baseflow(3)	.11	.04-.19	.11	.08	.01	.00-.01	.01	.01	.22	.20-.24	.02	.02	.34	.28-.40	.09	.06	.01	.00-.01	.01	.01
IV	Storm (10)	.02	.01-.07	.03	.01	.01	.01-.02	.01	.00	.45	.23-.66	.18	.09	.49	.30-.69	.16	.08	.02	.01-.03	.01	.00
	Baseflow(9)	.02	.00-	.03	.01	.00	.00	.00	.00	.35	.15-.51	.15	.08	.37	.21-.51	.13	.06	.02	.01-.03	.01	.01
V	Storm (10)	.07	.00-.15	.06	.03	.02	.01-.04	.01	.00	.58	.34-.99	.22	.09	.68	.49-1.19	.25	.10	.03	.02-.04	.01	.00
	Baseflow(11)	.01	.00-.05	.02	.01	.01	.00-.06	.02	.01	.45	.15-.72	.18	.07	.48	.15-.72	.20	.08	.01	.01-.02	.00	.00

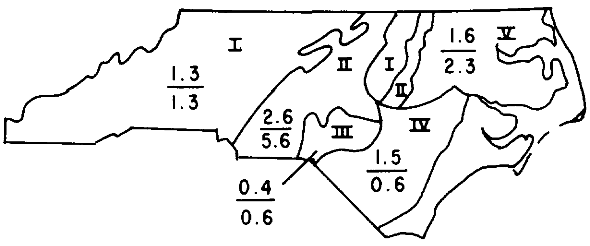
Table 6. Statistical summary of minor elements, in micrograms per liter, by geochemical zone and flow conditions in unpolluted streams.

[SD, standard deviation; SE, standard error of mean; ND, not determined]

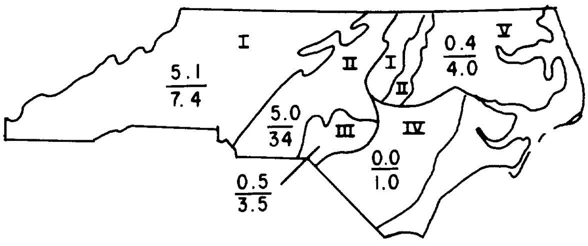
Geochemical zone	Runoff condition and number of analyses	Arsenic				Chromium				Copper				Iron			
		Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE
I	Storm(18)	0	0	0.0	0.0	11	10-20	3.5	1.3	4	1.5-12	3.8	1.3	1800	20-3600	2800	990
	Baseflow(22)	.1	0-1	.3	.1	13	10-20	6.5	2.1	4	0-9	2.6	.8	460	60-3000	870	260
II	Storm(10)	1.2	0-3	1.1	.4	12	10-20	4.1	1.7	4	2-11	3.4	1.4	5100	770-13000	5400	2200
	Baseflow(9)	.6	0-2	.8	.3	12	10-20	4.1	1.7	4	0-10	2.9	1.1	610	160-2100	670	250
III	Storm(2)	.5	0-1	ND	ND	10	10	ND	ND	1	1	ND	ND	8	7-9	ND	ND
	Baseflow(2)	0	0	ND	ND	15	10-20	ND	ND	2	0-4	ND	ND	510	420-590	ND	ND
IV	Storm(6)	.7	0-1	.5	.3	10	10	0	0	2	1-2	.9	.7	250	250	0	0
	Baseflow(6)	0	0	0	0	15	10-20	5.8	2.9	4	3-5	.8	.4	460	80-1200	510	250
V	Storm(8)	.9	0-2	.7	.3	10	10	0	0	3	0-5	2.1	.9	740	130-2000	720	290
	Baseflow(12)	.3	0-1	.5	.2	11	10-15	2.3	.8	2	1-4	1.0	.3	590	200-1000	495	175

Geochemical zone	Runoff condition and number of analyses	Lead				Mercury				Selenium				Zinc			
		Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE	Mean	Range	SD	SE
I	Storm(18)	9	2-25	7.1	2.5	0.4	0.3-.5	0.1	0.0	0	0	0	0	14	0-30	3	4.5
	Baseflow(22)	5	0-16	4.3	1.4	.3	0-.5	.2	.1	0	0	0	0	12	0-30	11	3.8
II	Storm(10)	7	4-10	2.2	.9	.3	0-.5	.2	.1	0	0	0	0	11	10-15	2	.8
	Baseflow(9)	6	4-11	2.5	1.0	.4	0	.2	.5	0	0	0	0	7	0-10	5	1.8
III	Storm(2)	7	7-8	ND	ND	0	0	ND	ND	0	0	ND	ND	10	0-20	ND	ND
	Baseflow(2)	4	1-8	ND	ND	.1	0-.1	ND	ND	0	0	ND	ND	15	10-20	ND	ND
IV	Storm(6)	6	5-6	.9	.7	.2	0-.3	.2	.2	0	0	0	0	10	10	0	0
	Baseflow(6)	4	1-7	2.5	1.3	.4	.1-.5	.2	.1	0	0	0	0	10	10	0	0
V	Storm(8)	4	0-11	4.1	1.7	.3	0-.5	.3	.1	0	0	0	0	11	0-20	6	2.7
	Baseflow(12)	6	4-14	3.4	1.2	.4	.3-.5	.1	0	0	0	0	0	12	5-20	5	1.9

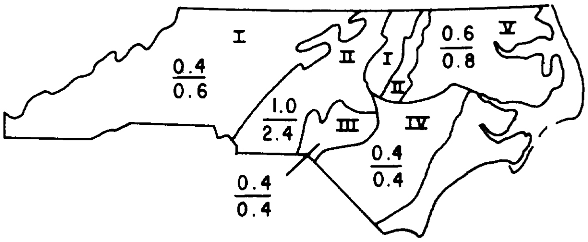
CALCIUM



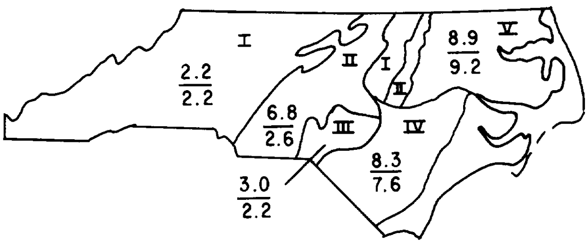
BICARBONATE



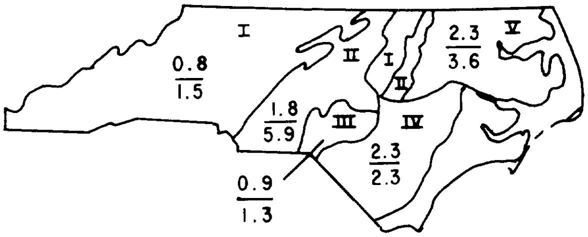
MAGNESIUM



SULFATE



SODIUM



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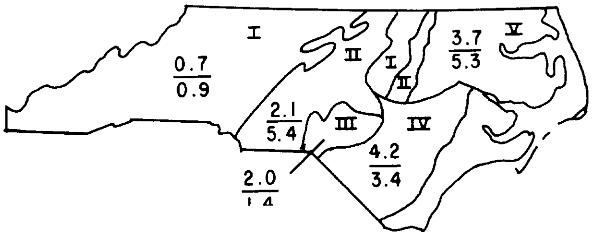

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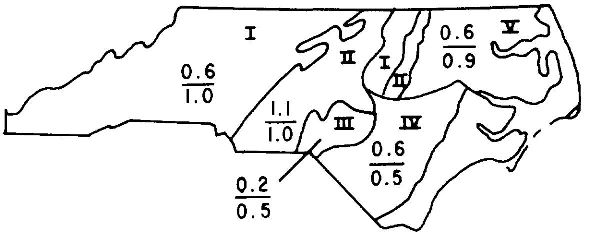

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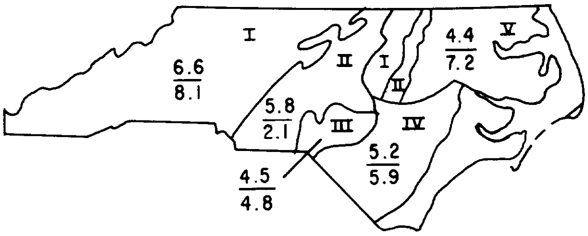
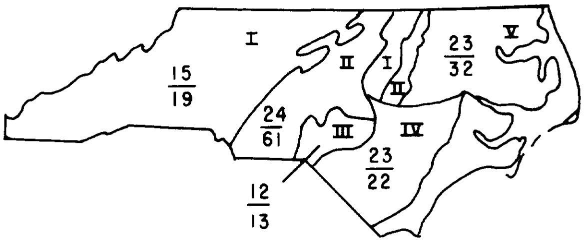


TOTAL DISSOLVED SOLIDS (SUM)



EXPLANATION

V Geochemical zone

Mean constituent concentration in milligrams per liter

$\frac{1.8}{5.9}$ 1.8 High flow, 5.9 Low flow

Figure 7. Mean concentrations of major dissolved inorganic constituents and total dissolved solids in unpolluted streams of North Carolina.

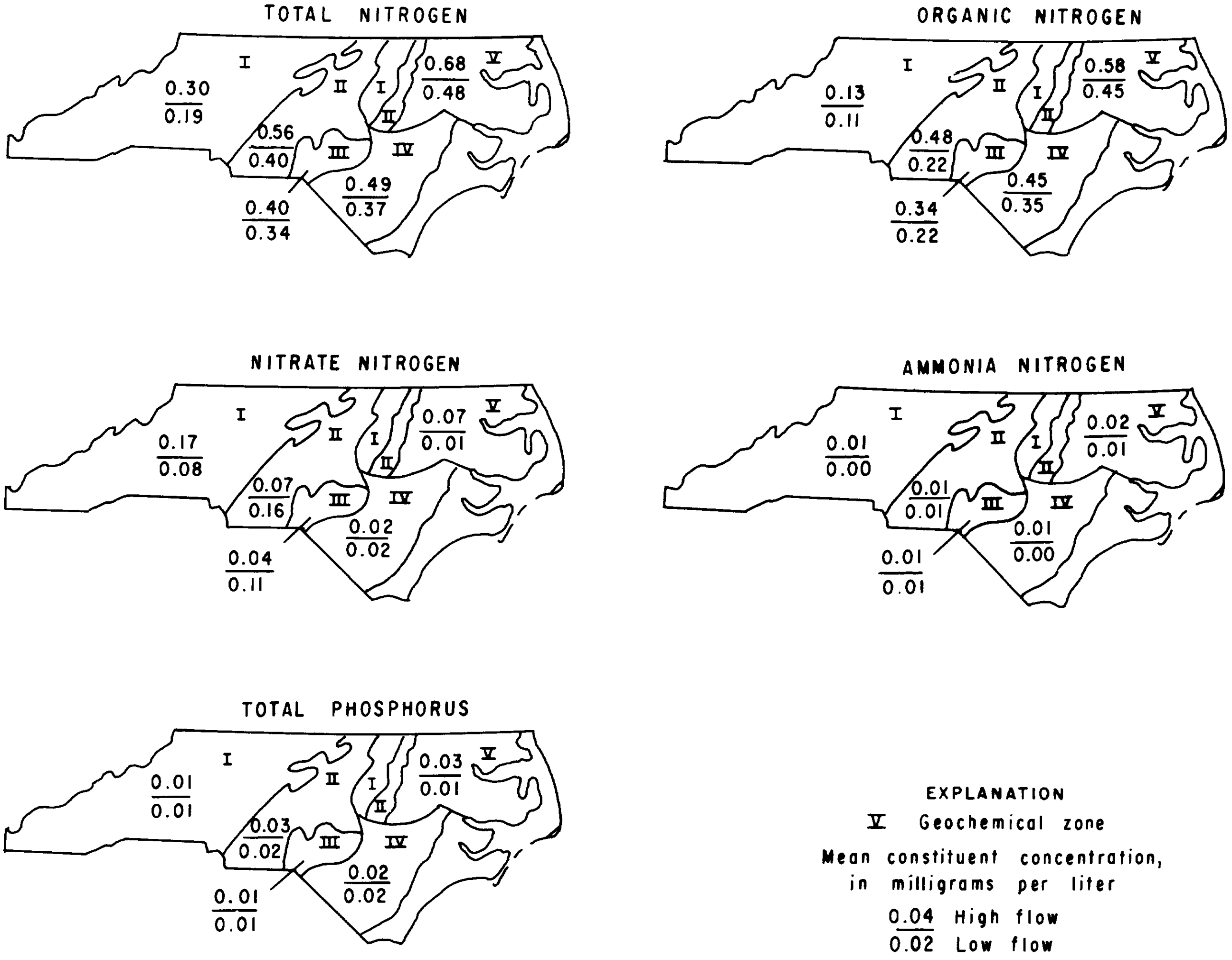


Figure 8. Mean concentrations of nutrients in unpolluted streams of North Carolina.

coincides with the Sand Hills. Because of the highly permeable nature of the sand underlying this area, nearly all precipitation infiltrates into the ground. However, because the sand is composed almost entirely of relatively-insoluble quartz, there is little opportunity for the water to dissolve additional material. Thus, there is no significant difference in quality between high-flow and baseflow conditions.

The largest concentration of most substances is in waters of zone II. This zone includes the Carolina Slate Belt and the Triassic basins. The explanation for the larger concentrations in this zone is not readily apparent. The constituents showing the largest increases, when compared with data from the other zones, are bicarbonate and silica. The bicarbonate may be derived from solution of calcite and other carbonates which are relatively common as fracture fillings in the Slate Belt. The higher silica content may indicate the presence in zone II of relatively decomposable forms of silicate minerals. Also, zone II is located in the most populated and industrialized area of the State and it is possible that air pollution has a greater effect on water quality in this zone than in the other zones.

Comparison of the data shows that the chemical quality of the runoff from forested areas is remarkably similar for both high-flow and baseflow conditions in all zones. This is consistent with the runoff conditions depicted in figure 3 where it is postulated that nearly all water reaching streams in these areas has either percolated through the soil zone or through the groundwater system. The concentration of some major inorganic substances tends to be somewhat higher in baseflow than in high flow (table 4), indicating that a larger proportion of the streamflow during baseflow conditions is derived from deeper aquifers where waters are generally more mineralized than in the soil zone and shallow aquifers.

The concentrations of nutrients, as shown in table 5 and figure 8, differ from the major inorganic substances in that they tend to increase during high flow. This is consistent with observations that precipitation and organic matter on the surface and in the soil zone, which are the primary paths of flow during storm runoff, are also the primary sources of nutrients in forested areas. Figure 9 shows mean concentrations of total and organic nitrogen in both baseflow and high flow for each geochemical zone.

As shown in table 6, the occurrence of most minor elements, except iron, appears to be unrelated to flow conditions or geographic location. Maximum concentrations of iron in the State's baseline streams occur in storm runoff in zones I and II. Selenium was not found in detectable quantities at any of the baseline sites. Levels of the remaining constituents shown in table 6 are similar across the State thereby indicating a uniform distribution from a single source such as air pollution.

The relation between streamflow and water quality is obviously more complex than indicated by the mean values of different constituents in high flow and baseflow. Figure 10 shows the daily discharge and daily specific conductance for 1975 for Cataloochee Creek and Jacob Fork. The flow of the streams tends to be largest during the winter and spring and smallest during the summer and fall. These pronounced seasonal differences in flow are caused primarily by differences in the loss of water withdrawn by evapotransporation processes. Specific conductance is a measure of the amount of substances dissolved in water; thus, increases in concentrations produce larger values of specific conductance. Comparison of streamflow and conductivity shows the conductivity is smallest when the flows are the largest.

In order to determine how the concentrations of chemical constituents vary during floods, a series of samples were collected at the three daily stations in the baseline network during several storms. Figure 11 shows the changes in stream discharge and concentrations of selected inorganic constituents observed during storms at two of these stations. As expected, the concentrations decreased rather abruptly when the flow started to increase. Minimum concentrations occur at or slightly ahead of the peak flow and as the flow begins to decline the concentrations begin a rapid return to preflood levels. It is apparent from these graphs that, because of their small drainage areas, floods on the streams in the baseline network are short-period events and that samples showing extreme effects of storm runoff on many chemical constituents must be collected at or very shortly before the time of peak flow.

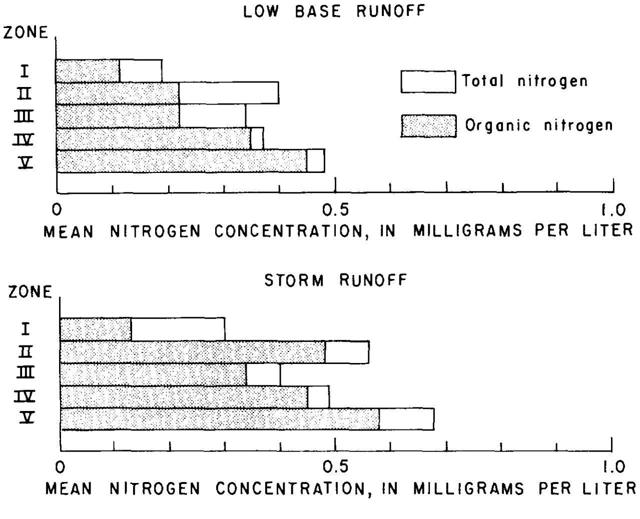


Figure 9. Mean concentrations of total and organic nitrogen during periods of base and storm runoff in unpolluted streams of North Carolina.

The role of bulk precipitation as a source of chemical constituents has already been briefly discussed. Using constituent concentrations from table 3 and ET (evapotransporation) data presented by Heath, Thomas, and Dubach (1975, p. 151, fig. 8.2), the amounts of certain constituents contributed by precipitation can be roughly estimated. In making these estimates it is necessary to assume that the chemical constituent for which the estimate is to be made remains in solution in the water, that is, the constituent is not affected by chemical and biological processes that would affect its concentration and that the concentration of the constituent is increased by the return of water to the atmosphere by evaporation and plant transpiration. Using calcium as an example, the computational procedure is shown in the following table:

Location	Waynesville	Raleigh	Washington
Geochemical zone	I	I	V
(a) Runoff (100 - ET[1]) (percent).	45	35	35
(b) Quality factor [100÷(a)].	2	3	3
(c) Calcium in precipitation[2] (mg/L).	0.85	.41	.73
(d) Calcium in runoff from bulk precipitation [(b)×(c)] (mg/L).	1.7	1.2	2.2

[1] From Heath, Thomas and Dubach (1975, p. 151, fig. 8.2).
[2] From table 3.

Comparisons of the concentrations of calcium shown above with those determined at baseline sites (fig. 7) indicate that bulk precipitation may be the major source of calcium in streams in geochemical zones I and V and presumably also in the other three zones. The importance of bulk precipitation as the source of a large part of the dissolved material in streamflow from forested basins is further illustrated in figure 12 which

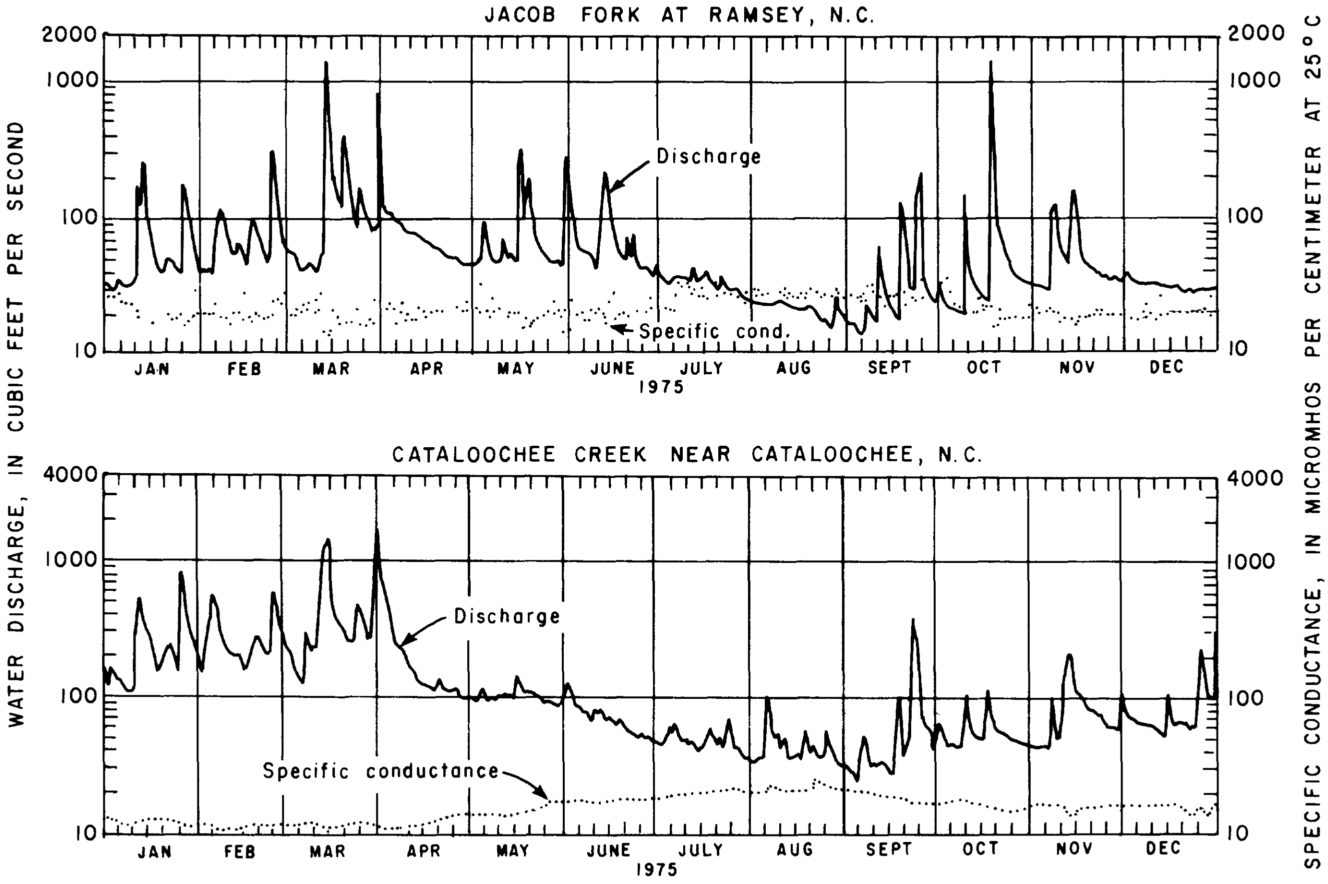


Figure 10. Daily values of water discharge and specific conductance for Jacob Fork and Cataloochee Creek during 1975.

shows estimated quantities of major dissolved constituents contributed by bulk precipitation in the Waynesville area as compared to quantities determined in nearby baseline streams. It should be noted that the constituents shown in figure 12 as contributed by bulk precepitation have been increased using the method illustrated in the preceding table to account for the effects of evapotranspiration.

Suspended-Sediment Runoff

The collection of suspended-sediment samples was begun during early 1977 to determine the concentration of sediment in runoff from those basins in the baseline network in which there has been little or no disturbance of the natural soil cover. Thus, samples were obtained only from basins that do not contain roads, timber cutting operations, active grazing and agricultural lands, or other possible sources of sediment which are related to man's activities. In the forested basins sampled for suspended sediment, leaf litter and vegetation cover the forest floor, and, except in the stream channel itself, little soil material is exposed to erosion. Also, little, if any, overland runoff occurs in these basins except possibly during very intense rainfall. Thus, except during unusual storms, none of which occurred during the sampling period, the stream channels are believed to be the primary source of suspended sediment.

Suspended-sediment concentrations vary considerably with flow conditions and reach maximum levels during intense storm runoff. Concentrations also vary from one geochemical zone to another as a result of differences in topography, stream gradients, and the characteristics of the material composing the sides and bottoms of the channels. The results of suspended-sediment samples collected during storm runoff in forested basins are shown in the following table:

Geochemical zone	No. sites sampled	No. samples	Range in concentration (mg/L)	Mean concentration (mg/L)
I	7	8	6–58	19
II	6	6	39–235	110
III	1	5	81–145	119
IV & V	7	10	5–25	13

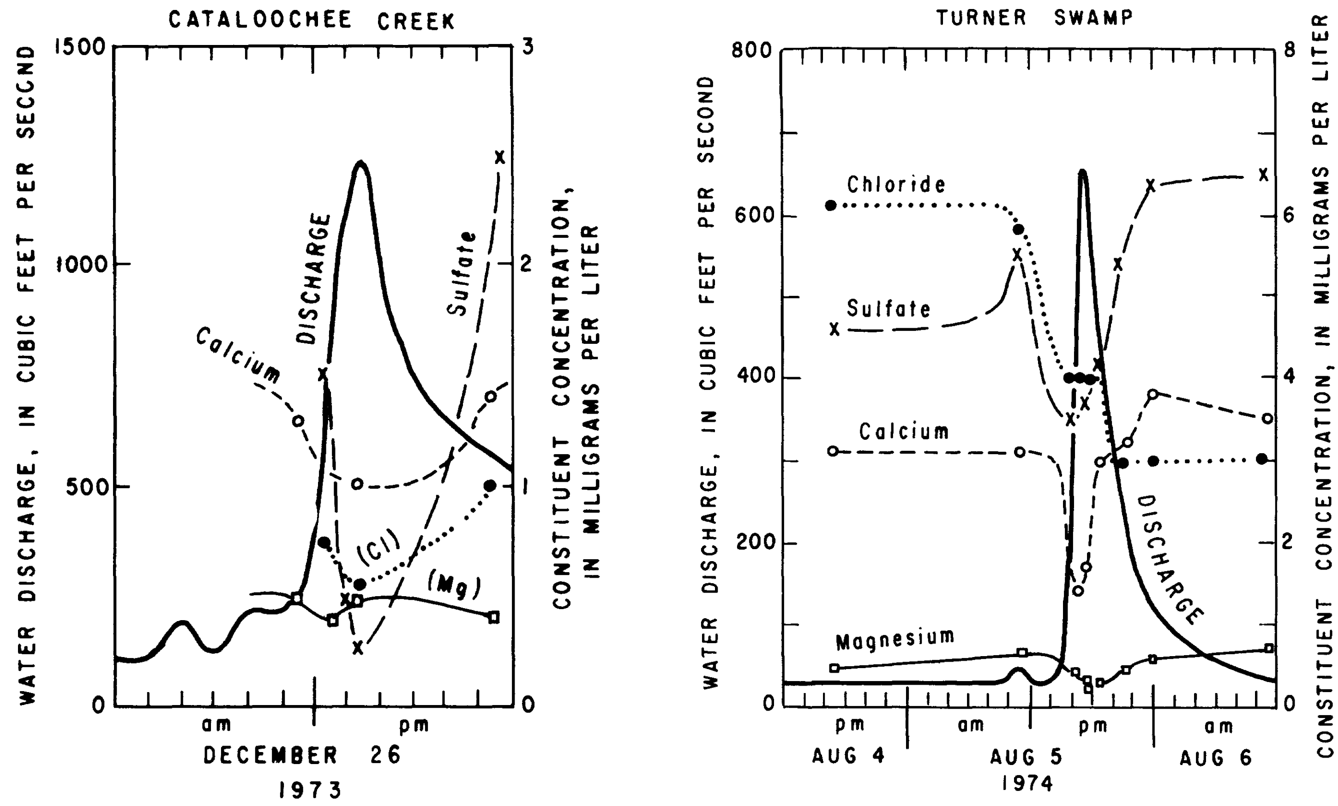


Figure 11. Concentrations of several major dissolved constituents and discharge during varying flow conditions in Cataloochee Creek and Turner Swamp.

Because no severe storms occurred during the collection period the values are representative of flows which, on the average, were near or less than the mean annual flood (that flood flow which is expected to occur, on the average, about every 2.3 years). Greater concentrations than those shown in the table are expected to occur during severe flooding when stream velocities and erosion are at a maximum. Concentrations during low base runoff seldom exceed 10 mg/L and a representative statewide average is about 6 mg/L.

Suspended sediment transported by the baseline streams includes both rock particles and organic matter. Organic matter is readily available in the baseline basins in the layer of litter that covers the forest floor. The relation between suspended-sediment concentration and percent of organic matter at baseline sites is shown in figure 13. It should be noted that the smaller the concentration of suspended sediment, the larger the proportion of organic matter.

As expected, both the range in concentration of suspended sediment and the mean concentration were smallest in zones IV and V in the Coastal Plain where the topography is relatively flat and stream gradients are small. The differences in concentration between zone I in the mountains and western Piedmont and zone II in the central Piedmont was not expected. However, zone II coincides with the Carolina Slate Belt and the Triassic Basins, both of which are underlain by relatively impermeable clayey soils. The larger concentration of suspended sediment being produced from the forested basins in this zone, therefore, may indicate more overland runoff and more easily-eroded soils in this zone than in zone I, which is underlain by coarser-grained and more permeable soils.

The concentration of suspended sediment in zone III, which coincides with the Sand Hills area, also appears, at first glance, to be unusually large. The relatively large concentration in this area, however, may result from the relatively steep gradients of the small, tributary streams whose channels are composed of fine-grained sand.

EFFECTS OF AGRICULTURAL ACTIVITIES ON WATER-QUALITY CHARACTERISTICS

As mentioned previously, 20 of the basins sampled as a part of the baseline network contained agricultural activities that occupied more than ten percent of the area which we suspected might significantly affect water quality. This suspicion was confirmed during analysis of

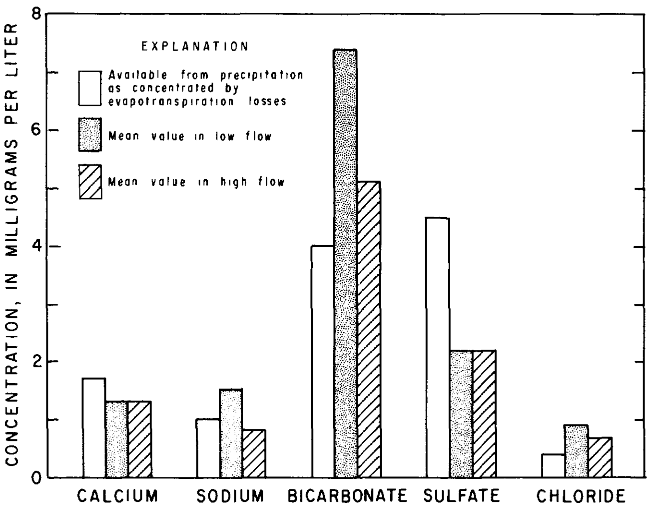


Figure 12. Estimated quantities of major dissolved constituents derived from precipitation compared with mean concentrations determined for unpolluted streams in the vicinity of Waynesville, geochemical zone I.

the data and, as a consequence, data from these basins were not used to define baseline water quality. The areas in these basins occupied by houses and by farming operations range from about 15 percent to about 50 percent of the total area (see table 1). Although the data from these basins could not be used to define baseline quality, the data were useful in showing the effect of rural land use on water quality.

Activities in the 20 basins that most likely affect water quality include:

1. The use of fertilizers, pesticides, and herbicides on row crops and pastures,
2. Pollution from farm animals, especially cattle and poultry,
3. Pollution originating from septic tanks used for the disposal of domestic wastes, and
4. Exposure of the land to erosion during the cultivation of fields and land clearing for buildings, roads, or other developments.

The first three items were expected to increase the concentrations of substances dissolved in water leaving the basins. The last item was expected to increase concentrations of suspended sediment and constituents sorbed on or in some way associated with sediment.

Figure 14 shows mean concentrations of selected dissolved constituents in high-flow samples from forested basins in zone I (ten percent or less of the areas affected by agricultural land use) and from basins in which agricultural land use affects more than ten percent of the total area. Streams draining basins where agricultural activities exceed ten percent of the basins land area are generally more mineralized than the baseline streams; and, as shown in figure 14, concentrations of major dissolved constituents are often two to three times greater than those determined for baseline streams.

The 20 basins that include significant land use occur in all the geochemical zones except zone III. Therefore, to determine the effect of the land use on water quality, a method was needed which would eliminate the differences in quality between the different zones. Figure 15 shows one method that partly solves this problem. Each of the 59 basins is represented by two points on each graph; one relating to the total nitrogen and the other to total phosphorus. As has previously been discussed, the 39 basins in which non-forest land uses were ten percent or less were used to calculate the mean baseline concentration of different constituents in each zone. In figure 15, the mean concentrations of nitrogen and phosphorus for each of these basins were divided by the mean concentration for the zone in which the basin occurs. The result is plotted on figure 15 versus the percent of the basin in agriculture. Because the basins in which agricultural land use was ten percent or less were used in calculating the zone values, the points for these basins tend to cluster around the factor of one on the vertical axis.

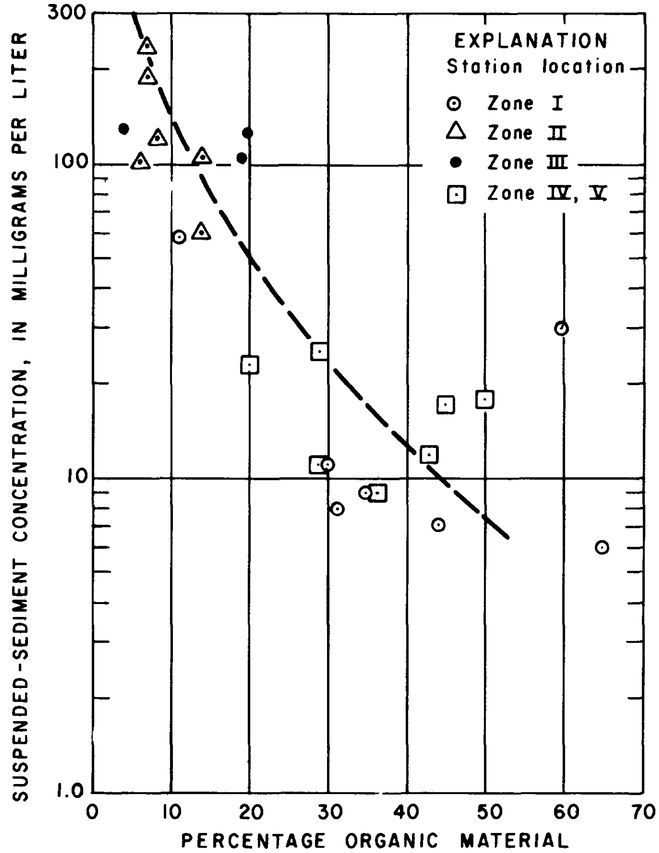


Figure 13. Relation of percentage organic material in suspended sediment to suspended-sediment concentration for streams in forested basins during storm flow.

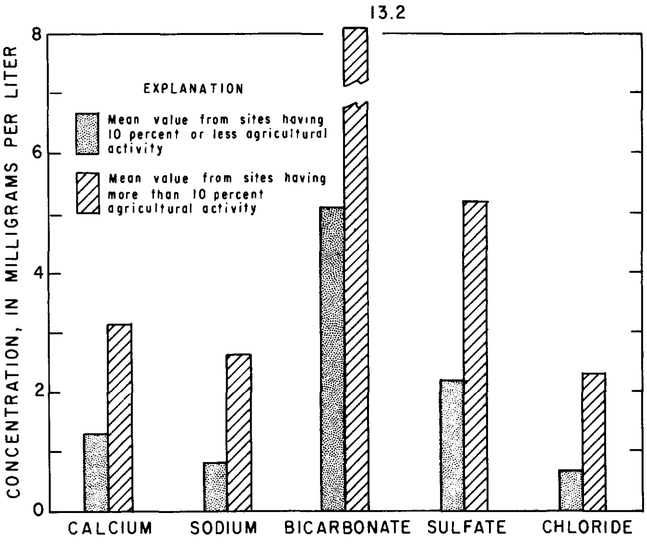


Figure 14. Comparison of mean constituent concentrations in zone I during storm runoff at unpolluted streams with those for sites where agricultural activities exceed 10 percent of basin land use.

It may be noted in figure 15A that in basins in which agricultrual land use was 20 percent or more, total phosphorus was increased by a factor ranging from 2 to 13 times above baseline levels during periods of storm runoff. The increase in total nitrogen was less, ranging from no increase (a factor of one) to about 5½ times. As shown in figure 15B, during base runoff the increases in nutrient concentrations related to land use are much smaller than those in storm runoff.

Concentrations of minor elements remained near baseline levels at the 20 sites affected by agricultural activities. This suggests that few or no minor elements are applied in the study basins or that, if applied, the elements are bound up by soils or biologic processes in such a manner that little escapes. If increases occurred, they were below analytical detection limits.

FUTURE PLANS

Although data collection activities were discontinued at baseline stations during late 1978, efforts to characterize unpolluted stream conditions will continue. A modified baseline data program is scheduled to begin operation in late 1979. Whereas the data used in this report were obtained largely from grab samples obtained at partial-record stations, the revised data network will be composed of approximately ten continous-record stations located in totally forested basins. Operations at three of these planned stations will begin during October 1979. Other new stations will be added to the network as funds permit. The collection of data will be intensified and will include continuous records of streamflow and specific conductance and a sufficient number of water samples to define a full range of flow conditions.

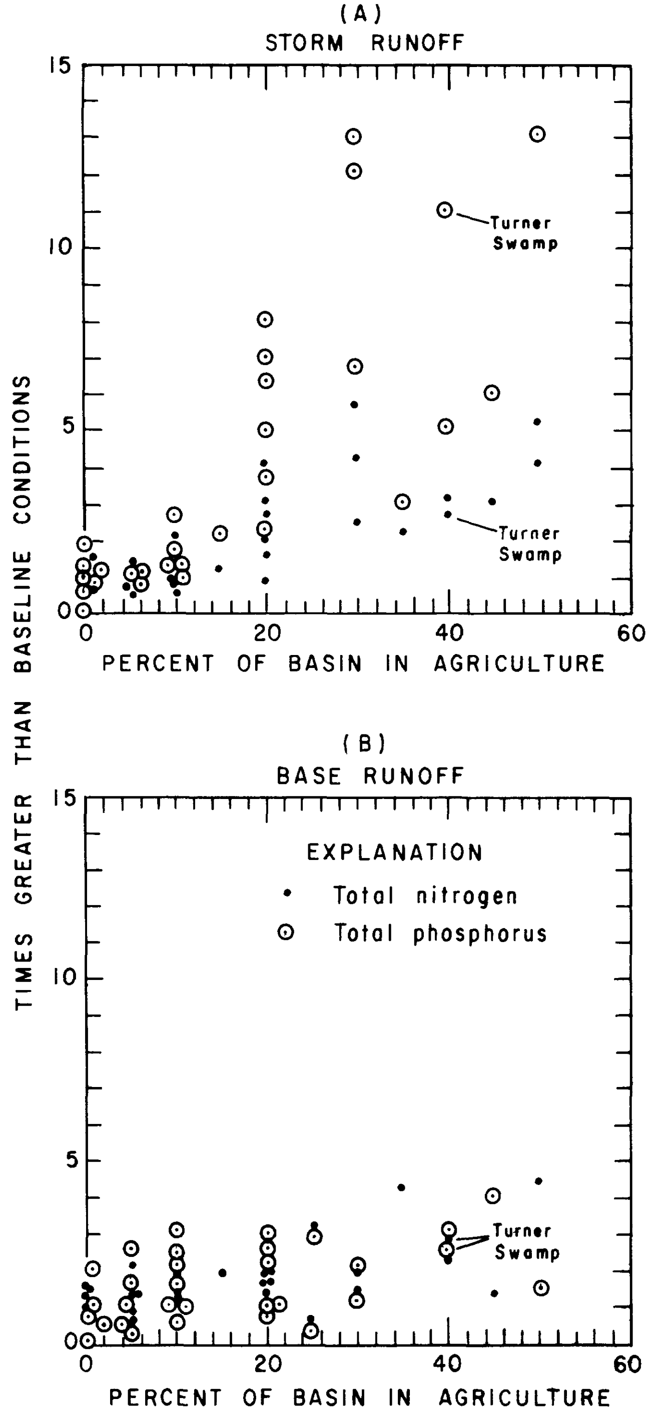


Figure 15. Relation of percent of basin used for agriculture as compared to increase in nutrients over baseline levels. A, storm runoff; B, base runoff

The new program also contains plans to better define the major contributors of stream runoff. Networks of ground-water wells are planned for installation in several forested basins, thereby, providing information needed to determine the quantity and quality of groundwater runoff.

In the future better information on atmospheric contributions to stream quality will be obtained from the National Atmospheric Deposition Program (NADP). Established in 1978, the NADP is a nationwide program supported by several Federal and State agencies, universities, and private groups from both the United States and Canada. Five of the network's 46 precipitation stations (as of 1978) are located in North Carolina. Data obtained at these stations over the next several years should greatly enhance our knowledge of precipitation as a source of chemical constituents in streams.

Although we do not expect data obtained from the new network to invalidate the findings of this preliminary study, some adjustments in constituent values may result from the more intensive data coverage.

SUMMARY

Data obtained on 39 rural streams, whose basins were 90 to 100 percent forested, were used to characterize baseline stream conditions during periods of base runoff and storm runoff. Except for the effects of air pollution, which currently cannot be quantified, the sites are believed to be relatively free of man's activities. Baseline stream quality is primarily influenced by the quality of precipitation and by the types of rocks and soils underlying the stream basin. To facilitate comparisons of water-quality characteristics on a statewide basis, the State was divided into five geochemical zones in which baseline quality within individual zones is similar. Each geochemical zone is underlain by one or more major rock types having the same or similar chemical characteristics.

The sources of flow often play a prominent role in baseline stream quality. Although the differences might only be slight, water derived from overland runoff and (or) the shallow soil zone generally contains lower concentrations of major dissolved constituents and higher concentrations of nutrients than waters derived from deeper subsurface sources. When compared statewide, the chemical characteristics of baseline streams are surprisingly similar during intense storm runoff; however, large differences in concentrations of major constituents and nutrients often exist during base runoff. Except for iron, concentrations of minor elements, when in detectable quantities, are relatively uniform in streams across the State and remain relatively constant throughout changing flow conditions.

Data obtained from an additional 20 rural sites, which were affected by farming activities, show significant increases above baseline levels in concentrations of major dissolved constituents and nutrients. The effects of farming were most pronounced during intense storms. At most of these 20 sites, concentrations of several major dissolved constituents during storm runoff averaged 2 to 3 times greater than those determined for baseline conditions while total phosphorus levels were 2 to 13 times greater and total nitrogen as much as five times greater.

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Chapter C

Water Quality of the French Broad River, North Carolina—An Analysis of Data Collected at Marshall, 1958–77

By C. C. DANIEL III, H. B. WILDER and
M. S. WEINER

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2185

WATER QUALITY OF
NORTH CAROLINA STREAMS

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Water Quality of the French Broad River, North Carolina—An analysis of data collected at Marshall, 1958–77

By C. C. Daniel III, H. B. Wilder, *and* M. S. Weiner

ABSTRACT

An investigation of water quality in the French Broad River in North Carolina has resulted in the definition of variations in water quality, a determination of the degree to which the quality of water in the river has been affected by man's activities and, an analysis of trends in the changing chemical quality of the river. This investigation centers on data collected during 1958–77 at the U.S. Geological Survey's station at Marshall, N.C.

The French Broad River drains 1,667 square miles of the Blue Ridge Mountains Province in western North Carolina. The river basin is the most industrialized basin in the mountain region of the State, with 30 percent of the employed population engaged in manufacturing. Between 1940 and 1970 the total population upstream from Marshall increased by 40 percent to 218,000 inhabitants.

The quality of water in the French Broad River at Marshall is suitable for most uses. None of the major dissolved constituents and nutrients, nor defined properties such as hardness, alkalinity and color, exceed suggested limits for drinking waters. Chromium, lead, selenium, and zinc are the only trace metals to occasionally exceed drinking-water standards. Dissolved oxygen levels are high year round, remaining near or above the saturation level even at higher summer temperatures. Results of tests for biological oxygen demand and chemical oxygen demand characterize the French Broad at Marshall as a clean river. However, fifty-eight percent of samples analyzed for fecal-coliform bacteria during 1974–77 exceeded recommended limits for bathing waters.

Most water-quality variations are associated with variations in streamflow. The variation of specific conductance with streamflow follows a non-linear, inverse relation. Similarly, concentrations of constituents transported primarily in solution generally decrease at higher flows, whereas concentrations of materials that tend to be associated with suspended sediment increase with flow. Most trace metals clearly tend to be transported in association with suspended sediment. At the low concentrations measured, the mode of transportation for arsenic, cadmium, selenium, and mercury is not clearly defined. Arsenic and mercury are apparently carried in solution, selenium seems to be mostly in solution, and cadmium appears to be associated with the sediment. No demonstrable correlation between stream discharge and nutrient concentrations has been observed.

Man's activities in the basin have resulted in deterioration of water quality in the French Broad River. In 1958, an estimated 64 percent of the dissolved solids load in the river at Marshall was due to pollution. By 1966, 74 percent of the dissolved load could be attributed to pollution. Loads of dissolved solids, sodium, sulfate, and calcium showed the most dramatic increases, coinciding with general increases in population and industrial employment. Perhaps as early as 1967, but certainly since 1974 the amount of inorganic constituents has decreased dramatically in spite of increased population and industrial growth. New waste-water treatment facilities and improved industrial technology have apparently combined to curb pollution and reverse the earlier trend. In 1977 water quality had returned at least to levels of 1958.

INTRODUCTION

This report presents the results of an investigation of the quality of water in the French Broad River at Marshall, N.C., that is based on data collected during the period 1958–77. Major objectives of the study were: (1) to define variations in water quality; (2) to determine the degree to which the quality of water in the river is affected by man's activities; and, (3) to identify past and present trends in the chemical quality of water in the river. This investigation was made by the U.S. Geological Survey in cooperation with the Environmental Management Division of the North Carolina Department of Natural Resources and Community Development.

The water-quality program, of which this study is a part, is explained in the report, *Program for Evaluating Stream Quality in North Carolina*, by H. B. Wilder and C. E. Simmons (1978).

Water-quality data were collected on a daily basis at Marshall from 1958–67 as part of a statewide survey of the chemical quality of surface waters of the State. Collection of data was resumed at Marshall from

1973–77 as part of a new program to collect additional information on water quality, and to evaluate the effects of man's activities on the quality of waters in North Carolina's major rivers. Including the station at Marshall, there are a total of nine sites in the French Broad River basin where daily samples have been collected for a period of one year or more; these are shown in figure 1. A summary of data-collection activities at these sites is presented in figure 2 and data from these as well as other stations in the basin are summarized in Wilder and Slack (1971).

In addition to the data collected for this study, the North Carolina Department of Natural Resources and Community Development maintains a network of 81 stations in the basin to monitor water quality at sites known to be affected by specific sources of pollution (North Carolina Environmental Management Commission, 1976).

The authors also acknowledge critical reviews by David H. Howells, former Director of the Water Resources Research Institute of the University of North Carolina, and Roy M. Davis, North Carolina Department of Natural Resources and Community Development, that added significantly to the accuracy of this report.

BASIN CHARACTERISTICS

Physical Setting

The French Broad River flows from its headwaters on the North Carolina-South Carolina state line northward across the state into Tennessee. Upon entering Tennessee the river turns to flow in a westwardly direction, into Douglas Lake, and from there on to Knoxville where it joins the Holston River to become the Tennessee River.

In North Carolina, the French Broad River drains 1,667 mi^2 (square miles) of which 1,332 mi^2 are upstream from the station at Marshall. Marshall is the most downstream site in North Carolina at which both streamflow and daily water-quality data were collected during the most recent phase of the study. The drainage area lies within the Blue Ridge Mountains Province and includes all of Buncombe, Henderson, Madison, and Transylvania Counties and a very small part of Haywood County, near Canton. (See figure 1.) The average altitude of the basin within North Carolina is between 2,500 and 3,000 feet above msl (mean sea level), but altitudes range from 6,419 feet along the drainage divide on the Buncombe-Yancey County line to 1,240 feet where the river enters Tennessee.

From its headwaters near Rosman, the French Broad River flows northeastward in a broad valley to its confluence with the Mills River near Fletcher. Downstream from this confluence the river course changes to a more north-northwesterly direction and the valley narrows. It is in this reach that the French Broad is joined by the Swannanoa River at Asheville. Although the topography of the basin is generally mountainous, Asheville lies in a central intermontane valley of moderate relief. Beyond Asheville, the French Broad River flows through the most rugged topography in the basin as it cuts through the core of the Appalachian Mountains in the Great Smoky Mountains region. Northwest of Asheville the French Broad is joined by Ivy Creek, approximately 2 miles upstream from the Geological Survey station at Marshall. The average stream gradient between Rosman and the Mills River is only about 3 feet per mile. From the Mills River confluence to the Tennessee state line, the gradient steepens to an average of about 12 feet per mile.

Although there are numerous ponds and lakes in the French Broad River basin, only three have a gross capacity equal to or exceeding 9,000 ac-ft (acre-feet). Lake Julian, upstream from Asheville, with a capacity of 9,000 ac-ft, is a cooling lake for a power company steam generating plant. Burnett Lake, in Buncombe County, has a capacity of over 23,000 ac-ft and serves as part of Asheville's municipal water supply. Ivy dam on Ivy Creek in Madison County, is owned by TVA (Tennessee Valley Authority) and forms a lake with a gross capacity of 43,600 ac-ft. The proposed Turkey Creek dam, to be located in Buncombe County and built by TVA, would form a lake with a gross capacity of 45,000 ac-ft. Because of the relatively small capacities of these existing and proposed reservoirs and their distances upstream from the sampling site at Marshall, their effects on the quantity and quality of streamflow at Marshall are probably negligible.

The basin is underlain by sparingly soluble igneous and metamorphic rocks that at shallow depths are characteristically broken by a network of fractures. These fractures may, in some places, extend downward to depths of a few hundred feet, but are most prevalent in the upper 25 to 50 feet of bedrock. Bedrock on the upper slopes of the ridges and peaks is usually covered by a thin layer of granular material in the form of soil and weathered rock, which becomes thicker on the lower slopes and in the valleys.

Most of the upper slopes, and many of the lower slopes, are covered with well-established forests which protect the land surface from erosion with a layer of fallen leaves and decaying organic matter. The valley floors, as well as much of the lower slopes, have been cleared of forest cover and are under cultivation or are used for pasture. However, most of the basin is covered by forests, with forest cover ranging from about 70 percent in Madison County to about 90 percent in Transylvania County. The remainder of the area is devoted primarily to crop and pasture land; but, as shown in table 1, there

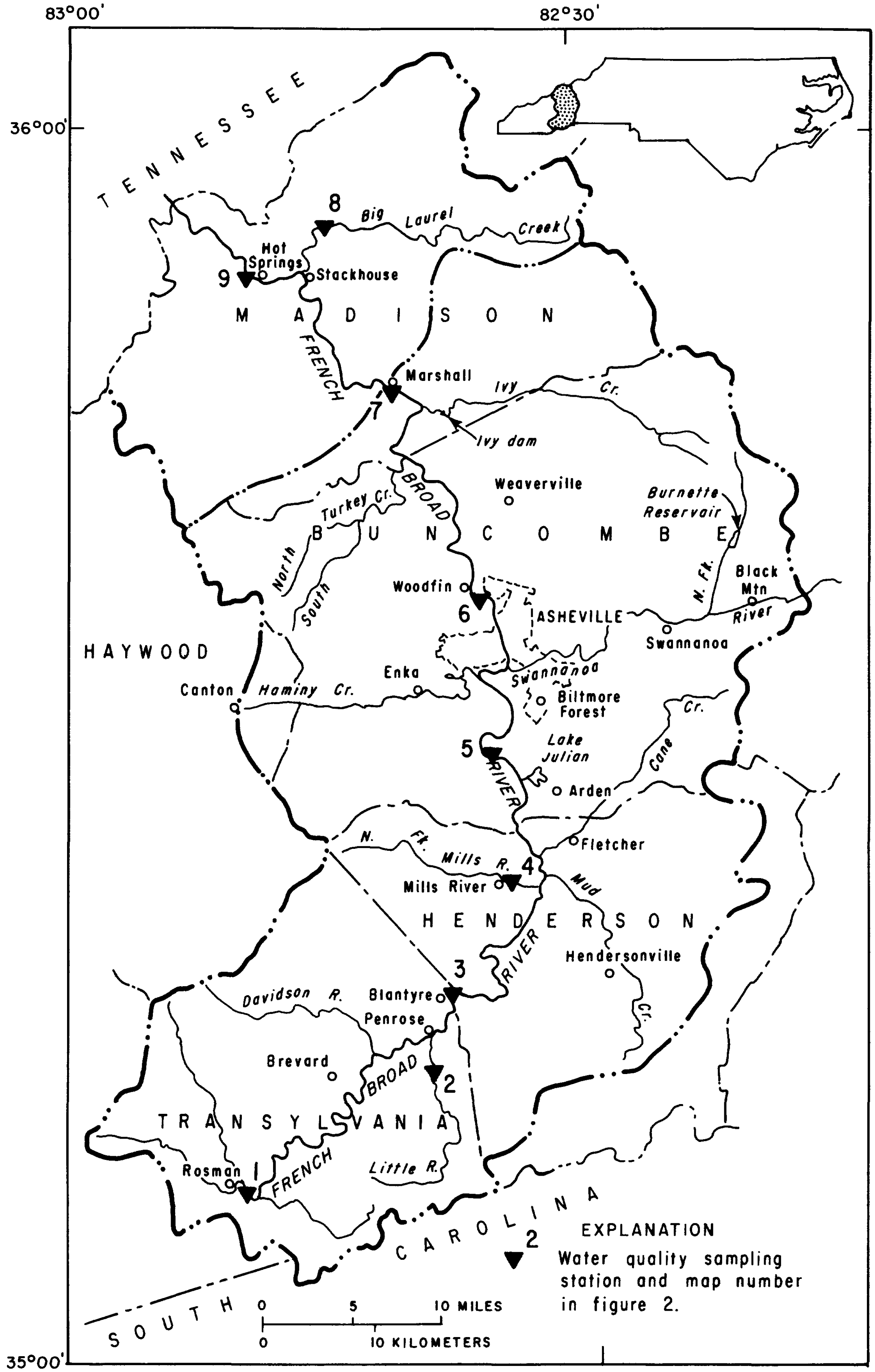
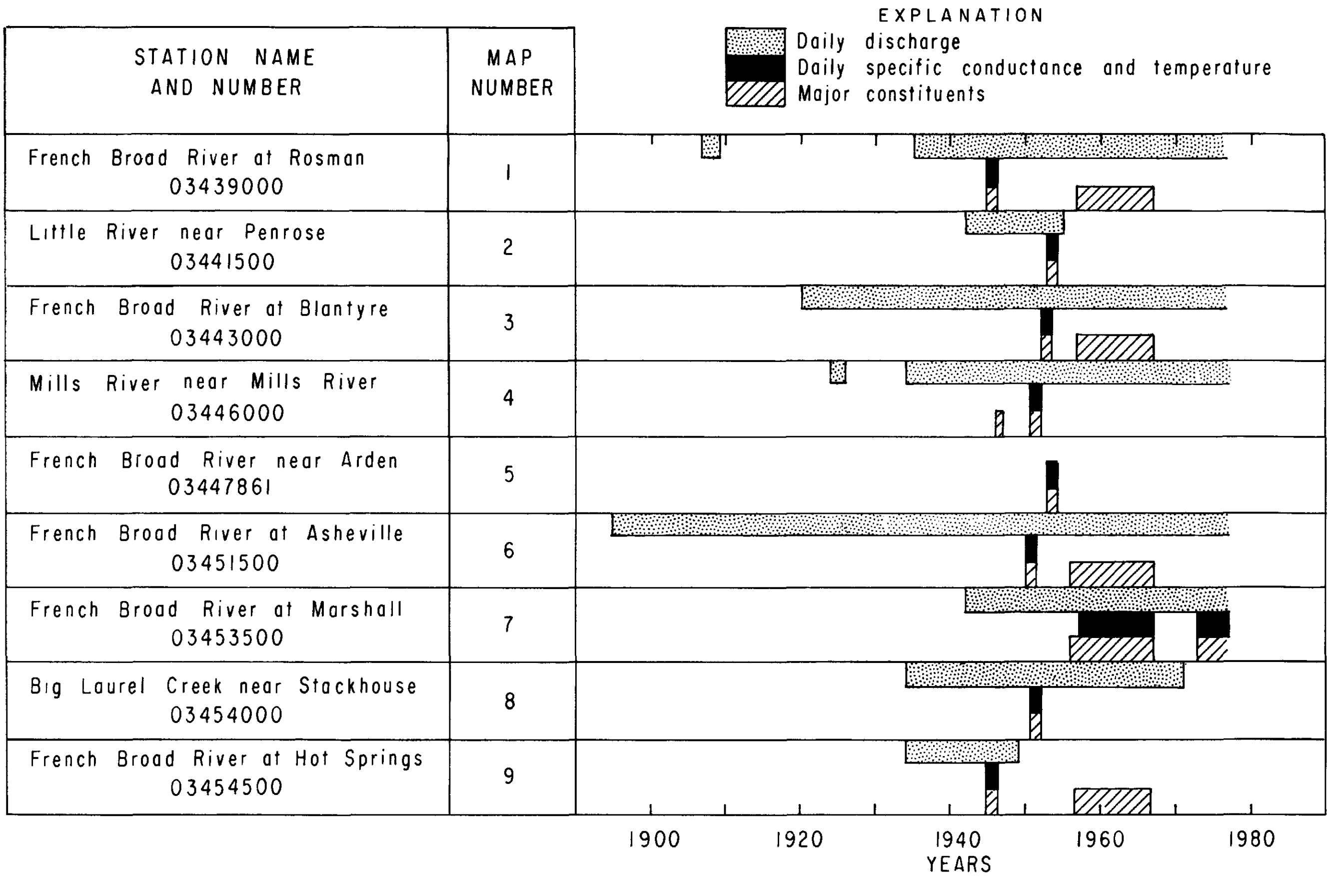


Figure 1. French Broad River basin in North Carolina, showing stations where water samples have been collected for one year or more, and the drainage area upstream from the station at Marshall, N.C.



STATION NAME AND NUMBER	MAP NUMBER
French Broad River at Rosman 03439000	1
Little River near Penrose 03441500	2
French Broad River at Blantyre 03443000	3
Mills River near Mills River 03446000	4
French Broad River near Arden 03447861	5
French Broad River at Asheville 03451500	6
French Broad River at Marshall 03453500	7
Big Laurel Creek near Stackhouse 03454000	8
French Broad River at Hot Springs 03454500	9

Figure 2. Period of data collection at stations in the French Broad River basin where daily data have been collected for one or more years.

are significant population centers in each of the counties in the basin.

Climate

Climate, which is strongly influenced by the mountainous topography, is the primary control of runoff in the French Broad River basin. In general, the higher altitudes receive more precipitation and have a lower mean annual air temperature than the lower altitudes. The area immediately around Asheville, which corresponds roughly to the center of the basin in North Carolina, has a mean annual temperature of 56°F, and mean daily range from 99°F to −7°F. The mean annual precipitation at Asheville is 38 inches, the lowest in North Carolina. Rosman, located in the upper headwaters in Transylvania County, has a mean annual precipitation of 77 inches, which is one of the highest in the State. On a seasonal basis, precipitation tends to be highest during winter and spring and lowest during summer and fall.

Streamflow in the French Broad River basin is derived from precipitation. Part of the precipitation falling on the land surface moves rapidly into streams either by running directly over the land surface as overland runoff or by moving through near-surface routes provided by the porous organic layer that blankets the land surface and by root holes, animal burrows, and other openings within a few feet of the land surface. Another part of the precipitation supports streamflow during dry periods by becoming ground-water recharge and percolating into the layer of weathered rock, bedrock fractures, and valley sediments. This ground water discharges slowly by seeping laterally into stream channels or to springs.

The seasonal variation of temperature is important in that it influences streamflow. An example is the low streamflow generally experienced in late summer and early fall. This is caused, in part, by the higher temperatures of summer, which increase evaporation and transpiration, thus reducing the water available for overland runoff and ground-water recharge.

The general decrease of temperature with increasing altitude is also an important factor in that it results in areal variations in evapotranspiration, and subsequently areal variations in streamflow. Because of generally lower temperatures at higher altitudes, the growing season is shorter than in nearby non mountainous areas.

Table 1. Population data for the four principal counties and their major municipalities in the French Broad River basin

County and largest town	[1]1940	[1]1950	[1]1960	[2]1970	[3]1976 (estimated)
Buncombe	109,000	124,000	129,000	145,000	151,000
Asheville	51,000	53,000	60,000	58,000	61,000
Henderson	26,000	31,000	33,000	43,000	49,000
Hendersonville	5,400	6,100	5,900	6,400	7,300
Madison	22,000	20,000	17,000	16,000	17,000
Marshall	1,200	980	930	980	1,000
Transylvania	12,000	15,000	15,000	20,000	21,000
Brevard	3,100	3,900	4,800	5,200	5,700

[1] U.S. Bureau of the Census, 1963.
[2] U.S. Bureau of the Census, 1971.
[3] North Carolina Division of State Budget and Management, 1977.

Consequently, the loss of water due to evaporation and transpiration by plants is lower on an annual basis at higher altitudes than at lower altitudes, resulting in higher rates of runoff from the higher areas.

Population and Industrial Development

The French Broad River is the most industrialized river basin in the mountain region of the State with about 30 percent of the employed population engaged in the manufacture of textiles, pulp and paper, leather goods, furniture and other wood products. Based on the countywide populations given in table 1, and prorated on the basis of the areas in each county drained by the French Broad, the population in the basin, above the sampling station at Marshall, is estimated to have been approximately 218,000 in 1970. This is an increase of 13 percent over the previous 10 years. In 1960, 41 percent of the inhabitants of the area above Marshall lived in communities, while the remainder were classified as rural residents. By 1970, 37 percent of the population lived in communities and 63 percent lived in rural areas. It is interesting to note that even though the population of the four counties comprising the basin has increased 40 percent since 1940, the increase in population of the major urban areas (table 1) has been only 24 percent. The large population centers of Asheville, Hendersonville, and Brevard are also the major industrial centers. A few of the smaller towns, such as Enka and Pisgah Forest, support "single industries" large enough to have a significant effect on the water quality of the area.

Only about 8 percent of the employed population in the four-county area is engaged primarily in agriculture. An additional estimated 30 to 40 percent are part-time farmers or rural residents. Tobacco is the principal cash crop in Madison and Buncombe Counties, and apples are the principal crop in Henderson County. Dairy farming, swine, and poultry production are also important agricultural activities in the area.

Water Use and Waste Disposal

Water in the French Broad River system is treated and used by municipalities for drinking water and by private industry for various uses such as cooling in manufacturing processes. Major municipalities and industries discharging effluent into the French Broad river system are listed in table 2 (North Carolina Division of Environmental Mangement, 1976). *Major* is defined as any community or industry discharging 1.0 million gallons per day or more into the river system. *Effluent* is defined as used water and it is not necessarily polluted water in the sense that its quality characteristics have been changed by the use so that it contravenes State or Federal waste-water standards.

Of the communities and industries listed in table 2, the major point source of effluent in the upper end of the basin is a large chemical company, Olin Corporation; while in the lower part of the basin, the major point sources are a large synthetics plant, American Enka, and the waste-water treatment facility for the Metropolitan Sewage District of Buncombe County. The sum of releases from municipal treatment facilities at smaller towns, such as Hendersonville and Brevard, and from some of the smaller industries in the basin represent a significant amount of effluents. Numerous nonpoint

Table 2. Sources of water supplies and points of waste disposal for municipalities and industries with waste-water discharges greater than 1.0 million gallons per day

Community or industry (location)	Source of water supply	Location of waste discharge	Water intake in millions of gallons per day	Volume of effluent in millions of gallons per day
Brevard (Transylvania Co.)	King Cr./Bushy Cr.	King Cr.	2.0	1.5
E. I. Dupont (Transylvania Co.)		Little River		2.0
Olin Corporation (Brevard)	Davidson R.	Davidson R.	26.5	27.3
Hendersonville Municipal (Henderson Co.)	Upper N. Fork Mills R./Bradley Cr.	Mud Creek	4.7	2.3
Cranston Print Works (Henderson Co.)	Cane Creek	French Broad R.	2.5	2.5
General Electric (Henderson Co.)	Hendersonville Water Dept.	Bat Fork Cr.	1.38	1.38
Metro-Buncombe Co. including:		French Broad R.		25.0
Asheville	Burnett Res.		22.5	combined discharge to Metro Sewage District
Biltmore Forest			<0.25	
Black Mt.			0.4	
Woodfin	Sugar Camp Fork Impoundment/Laurel Fork		0.8	
Weaverville	Ox Cr./Eller Cove		0.35	
American Enka (Buncombe Co.)	Hominy Cr.	Hominy Cr.	0.2 water dept. 8.0 Hominy Cr.	4.25
Carolina Power and Light Stream Station (Asheville)	French Broad R./ Lake Julian	French Broad/ Lake Julian (any overflow goes to French Broad R.		2.0 4.0 recycles
Hedrick Sand and Gravel, Grove Stone and Sand Division (Swannanoa)	N. Fork Swannanoa R.	N. Fork Swannanoa R.	3.0	3.0

Sources of data:

1. North Carolina Environmental Management Commission, 1976.
2. U.S. Environmental Protection Agency, National Pollutant Discharge Elimination System (NPDES) permits.
3. Jackson, N. M., Jr., 1974.

sources, such as agricultural operations and urban runoff, also affect stream quality.

The general increase in rural population and associated industrial growth coupled with a slower paced, but growing urbanization provides a basis for concern over the quality of water in the French Broad River basin. The following sections of this report will describe the quality of water in the French Broad river, as defined by the quality of water samples collected at Marshall, discuss its variability, the current status of pollution in the river, and the changes in quality that have accompanied the changes in population and industrialization over approximately the past 20 years.

WATER QUALITY

The quality of water in the French Broad River, as represented by samples taken at Marshall from 1974 to 1977, is satisfactory for most uses. None of the major dissolved constituents approach limits suggested for drinking waters (National Academy of Sciences, and National Academy of Engineering, 1972), and such defined properties as hardness, alkalinity, and color are all within acceptable ranges. The nutrients nitrogen and phosphorus were not observed to exceed drinking-water criteria, although they were sometimes present in amounts greater than recommended in eutrophication studies. Of the trace metals determined, chromium, lead, selenium, and zinc occasionally exceeded suggested limits for drinking water. Biologically the river met drinking water and aquatic environment criteria, except coliform bacteria were frequently far greater than the maximum limits recommended for bathing waters. Although there are no precise limits for allowable amounts of suspended sediment, it is likely that suspended matter is frequently high enough to interfere with fish propagation and other biological processes.

Variations in Water Quality

An understanding of the manner in which water quality varies is essential to its treatment and use. There are a number of important aspects of variation in water quality. Of the three most important, the most fundamental is a knowledge of the extremes within which constituents of interest to the user may be expected to range. Another is the correlation between changes in specific conductance and changes in the concentrations of various dissolved (ionized) water-quality constituents. A knowledge of relations between water-quality constituents and specific conductance can be an inexpensive and highly effective means of extending a small amount of data to a much longer priod of record. The third is the variation associated with changing streamflow, which is perhaps the single most important cause of water-quality variation. In the French Broad River, as in most streams, concentrations of constituents transported primarily in solution generally decrease at higher flows, whereas concentrations of materials that tend to be associated with suspended sediment increase with flow.

Data from individual analyses of periodic samples collected from the French Broad River at Marshall during 1974–77 for some 96 water-quality characteristics are reported in individual annual data reports of the U.S. Geological Survey, entitled "Water Resources Data for North Carolina." Selected data are grouped, and ranges and averages, where applicable, are summarized in table 3 and several other tables in the following sections of this report.

Major Dissolved Constituents

Concentrations of a number of significant constituents correlate sufficiently well with specific conductance so that, once a few concurrent measurements are made, concentrations of these constituents can be estimated with useful accuracy from a single measurement of conductance. For samples taken at Marshall, regression equations, correlation coefficients, and standard errors of estimate for the relation of major dissolved constituents to specific conductance are given in table 4. The regressions in table 4 are each based on no fewer than 264 data values; as a result, those regressions with correlation coefficients of 0.75 or greater are statistically valid at a significance level of better than 99 percent. Consequently, valid estimates of concentration can be expected from the equations given a measured value for specific conductance. Of the major dissolved constituents listed in table 4, sodium, sulfate, bicarbonate, and dissolved solids correlated well with specific conductance. An example of a good correlation is that between specific conductance and dissolved solids which is shown in figure 3.

The specific conductance of water in the French Broad River typically decreases as flow in the stream increases. The general characteristics of this non-linear inverse relationship are illustrated in figure 4. The concentrations of major chemical constituents having correlation coefficients greater than about 0.75 in table 4 can be expected to behave much like specific conductance in their relation to streamflow.

Suspended Sediment

Concentrations of suspended matter vary more with changes in streamflow than do materials in solution. Concentrations of suspended sediment, for example, have been observed to range from 3 mg/L (miligrams per liter) at a discharge of 1,020 ft^3/s to 10,800 mg/L at a discharge of 17,600 ft^3/s. The mean concentration for samples collected during the period 1974–77 was 926 mg/L.

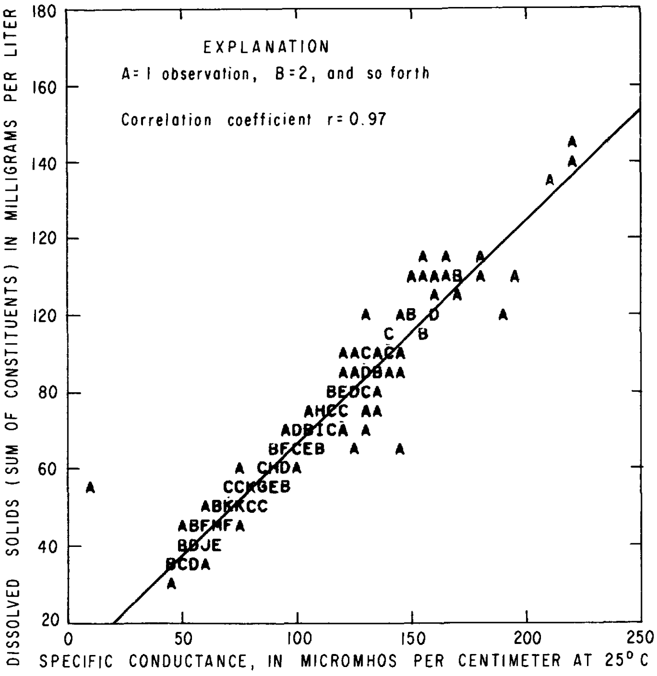


Figure 3. Relation between specific conductance and dissolved solids, French Broad River at Marshall, N.C., 1958–77 water years.

Table 3. Summary of chemical and biological constituents and physical properties of water in the French Broad River at Marshall, N.C., 1974–77 water years. (All units are milligrams per liter, except as noted.)

	Number of samples	Range	Mean
Major Dissolved Constituents			
Silica (SiO_2)	36	3.7–11	8.7
Calcium (Ca)	36	3.2–10	5.2
Magnesium (Mg)	36	0.2–2.0	1.1
Sodium (Na)	36	2.4–22	7.8
Potassium (K)	36	1.0–2.9	1.6
Bicarbonate (HCO_3)	39	9.0–35	18
Carbonate (CO_3)	32	0.0–0.0	.0
Alkalinity (as $CaCO_3^c$	39	7.0–29	14
Sulfate (SO_4)	36	5.1–42	14
Chloride (Cl)	36	0.9–5.8	3.3
Fluoride	36	0.0–1.2	.14
Dissolved solids (Residue at 180°C)	36	26–125	60
Dissolved solids (Sum of constituents)	36	30–112	52
Dissolved solids load (tons per day)	36	176–3680	812
Hardness (as $CaCO_3$)	36	11–32	18
Non-carbonate hardness (as $CaCO_3$)	36	0.0–9.0	3.5
Dissolved oxygen (O_2)	133	7.3–15.4	9.8
Carbon Dioxide (CO_2)	39	0.5–104	16
Physical Characteristics			
Specific conductance (micromhos)	Once daily	33–205	86
pH (pH units)	39	5.2–7.8	
Temperature (°C)	Once daily	0.0–26.0	13.2
Color (platinum-cobalt units)	35	0.0–600	57
Turbidity (JTU)	14	6–64	--
Biological Characteristics			
Total phytoplankton (cells per mL)	11	250–5,500	1,984
Periphyton biomass ash weight (gm/m^2)	10	.20–18	3.14
Periphyton biomass total dry weight (gm/m^2)	10	1.26–21	6.37
Total organic carbon (C)	30	3.0–44	11
Dissolved organic carbon (C)	27	2.5–20	6.6
Organic carbon in bed material (C) (gm/kg)	4	<0.1–6.7	--
Methylene blue active substance	30	0.0–0.3	0.04
Chemical oxygen demand	95	10–56	--
Biochemical oxygen demand, 5 day	101	0.2–4.9	1.9
Fecal coliform (colonies per 100 mL)	98	<10–12,000	[1]1100

[1] Log mean.

As shown in figure 5, suspended-sediment concentrations tend to respond simultaneously with discharge. The general relation between discharge and suspended sediment is shown in figure 6. The line of regression of figure 6 has been used in conjunction with flow-duration data for 1974–77 to estimate the annual suspended-sediment yields shown in table 5. The average annual suspended-sediment yield during the four-year period was 750 tons per square mile per year. It is important to note that a calculation of average sediment con-

Table 4. Summary of the results of the regression analyses relating the concentrations of dissolved chemical constituents to specific conductance, 1958–77 water years

Constituent	Concentration (milligrams per liter)			Simple regression equation	Correlation coefficient	Standard error of estimate (mg/L)	Specific conductance (microhmos at 25°C)		Number of samples
	Mean	Range	Standard deviation				Mean	Standard deviation	
Dissolved solids (DS) (sum of constituents) .	65	30–145	22	$DS = 7.46+0.586\,(SC)$[1]	0.97	5.5	98	36	264
Calcium (Ca)	4.4	2.2–9.8	1.0	$Ca = 2.53+0.0206\,(SC)$	.66	.60	101	35	299
Magnesium (Mg)	1.4	.20–2.9	.40	$Mg = 0.976+0.00402\,(SC)$	.34	.40	98	36	299
Sodium (Na)	12	2.4–36	6.2	$Na = -4.39+0.164\,(SC)$	.95	1.5	98	35	300
Chloride (Cl)	4.0	.9–16	1.7	$Cl = 0.631+0.0351\,(SC)$	.65	.13	98	35	306
Sulfate (SO_4)	19	2.8–58	10	$SO_4 = -7.20+0.269\,(SC)$	.93	3.0	97	35	297
Silica (SiO_2)	11	3.2–14	1.4	$SiO_2 = 8.86+0.0174\,(SC)$	.38	1.3	98	36	289
Bicarbonate (HCO_3) ...	20	8.0–43	5.3	$HCO_3 = 7.53+0.124\,(SC)$	.80	3.1	101	35	310
Potassium (K)	1.5	.20–3.9	1.6	$K = 0.513+0.0104\,(SC)$	.24	1.6	98	36	300
Dissolved solids (DS) (residue at 180°C).				$DS = 11.0+0.606\,(SC)$	.94	6.2	98	36	272

[1] SC is specific conductance.

centration based on this figure of suspended sediment yield gives an estimated average concentration of 347 mg/L. This value is much lower than the mean for actual samples (926 mg/L), suggesting that collection of sediment samples was somewhat biased towards periods of high flow.

Nutrients

The nutrients, nitrogen and phosphorus, are not present in large amounts in the water in the French Broad River. However, even in small amounts, they are highly significant because they affect biological processes. Three types of criteria pertain to nutrient concentrations. One involves toxic effects of ammonia on freshwater aquatic life, another concerns drinking-water supplies and toxic effects of nitrate and nitrite on humans, and the third involves the role of excess nitrogen and phosphorus in eutrophication of surface-water bodies.

Depending upon the level of oxidation, nitrogen may occur in solution in water in one or more forms. The most common forms, in order of increasing stability in most aerated waters, are ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). Various organic nitrogen-bearing compounds are also common, particularly in polluted waters, but no attempt to identify these was made in this investigation. Because of its toxicity to freshwater aquatic life, the U.S. Environmental Protection Agency (EPA) (1976) suggests a limitation of 0.02 mg/L of ammonia (as un-ionized ammonia, NH_3) for waters to be suitable for fish propagation.

Un-ionized ammonia is not measured directly but is calculated from the amount of dissolved ammonia. Ammonia gas and ammonium salts are quite soluble in water in the form of ammonium hydroxide. When ammonia dissolves in water, a chemical equilibrium is established that contains un-ionized ammonia (NH_3), ionized ammonia (NH_4^+), and hydroxyl ions (OH^-) according to the following simplified equation:

$$NH_3+H_2O \rightleftharpoons NH_4^+ + OH^-$$

The equilibrium of this equation is dependent upon temperature and pH. Under prevailing conditions in the French Broad, at a mean temperature of 13°C, and midrange pH of 6.5, the amount of un-ionized ammonia in aqueous solution is approximately 0.08 percent of dissolved ammonia (interpolated from table 3, EPA, 1976, p. 11). At a mean concentration of 0.10 mg/L dissolved ammonia (table 6) the un-ionized ammonia concentration is about 0.0001 mg/L, which is well below the recommended criteria level. On the other hand, if the most favorable conditions for ammonia (NH_3) formation were to occur simultaneously in the French Broad, with a pH of 7.8, temperature of 26°C and dissolved ammonia of 0.37 mg/L, the un-ionized ammonia, at 0.018 mg/L

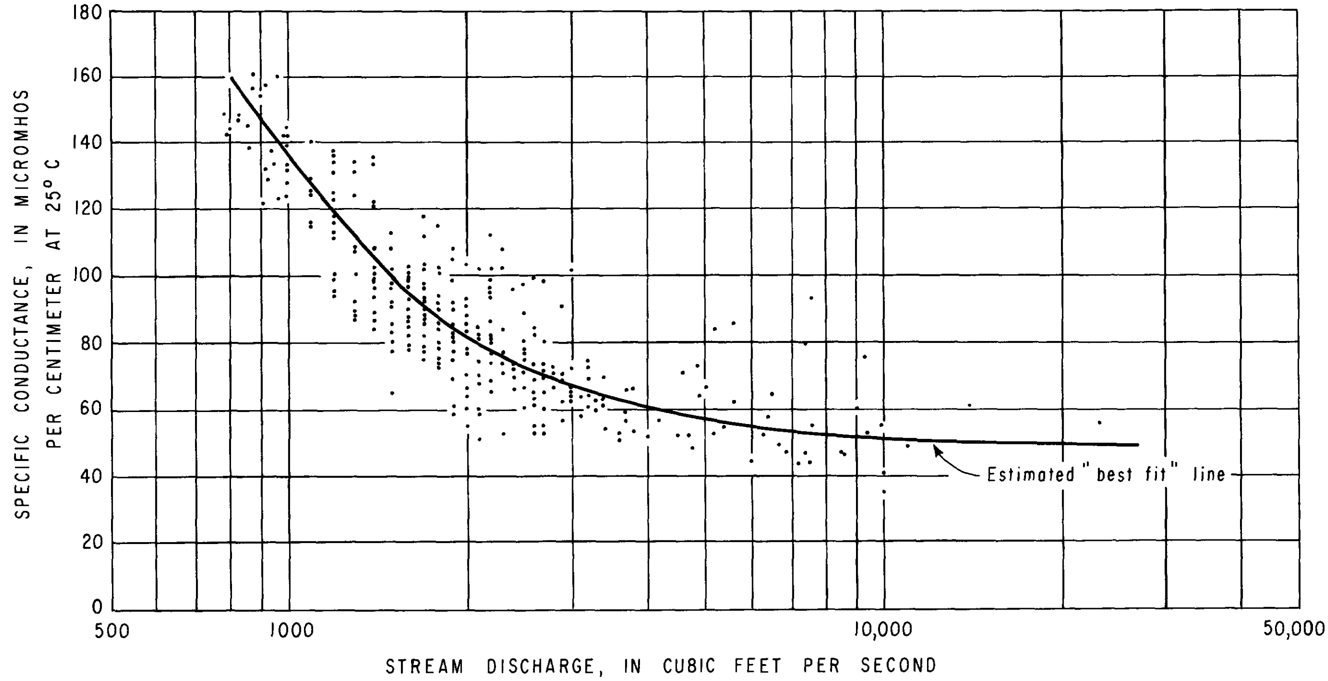


Figure 4. Relation of specific conductance to discharge for the French Broad River at Marshall, N.C., 1977 water year.

would be only slightly less than the recommended limit of 0.02 mg/L.

It has also been recommended (National Academy of Sciences and National Academy of Engineering, 1972) that total ammonia nitrogen (N) in public water-supply sources not exceed 0.5 mg/L. Concentrations of nitrite plus nitrate, reported as nitrogen, of less than 10 mg/L are suggested (EPA, 1976) for public water-supply sources because higher concentrations can cause serious and occasionally fatal poisonings (methemoglobinemia) in infants. Maximum observed concentrations of total ammonia nitrogen and nitrite plus nitrate nitrogen (table 6) during the period 1974-76 were below criteria levels.

It was first noted by Sawyer (1947) in Wisconsin that nuisance algal conditions could be expected in lakes when concentrations of inorganic nitrogen (NH_3+ NO_2+ NO_3 as N) as low as 0.3 mg/L are present in conjuction with as much as 0.01 mg/L of phosphorus.

Table 5. Average suspended-sediment yield in the French Broad river at Marshall, N.C., 1974–77 water years

Water year(s)	Average suspended-sediment yield, in tons per square mile
1974	760
1975	989
1976	703
1977	550
1974–77	750

Not only does the concentration of nitrogen and phosphorus have an important influence on algal growth, but as pointed out by the Technical Advisory Committee to the Secretary of the Interior (Department of the Interior, 1968), "The total nitrogen-total phosphorus ratio is also of importance. The ratio varies with the water, season, temperature, and geological formation, and may range from 1 or 2:1 to 100:1. In natural waters, the ratio is often near 10:1, and this appears to be a good guideline for indicating normal conditions." Weiss and Kuenzler (1976) support this observation by reporting that ratios of 10–12:1 are indicative of normal conditions in North Carolina lakes. The ratio of nitrogen to phosphorus can be used as an indication of the potential for excess growth of algae. If phosphorus is considered the limiting nutrient, a low ratio suggests that there is sufficient phosphorus for algae to utilize all the available nitrogen for growth, and a high ratio indicates that there is not enough phosphorus for algae to use all the available nitrogen.

Ranges and mean values for nutrient concentrations found at Marshall are shown in table 6. Mean concentrations of nitrogen species are below suggested criteria levels for drinking-water sources; however, the ratio of total nitrogen to total phosphorus for mean concentrations is low enough, at 7:1, to suggest that these waters are susceptible to nuisance algal growths given suitable light and temperature conditions.

Although much remains to be learned about the overall significance of the various forms of nitrogen and phosphorus in water it is expected that both the forms and the mode of transport will eventually be understood to be important in determining the significance of the two elements. Data given in table 6 show that nutrients are transported both in solution and in suspension (total material minus dissolved material equals suspended material). Higher concentrations occur during high flows when the nutrient-rich bottom materials are in active transport. No strong general correlation between stream discharge and nutrient concentrations has been observed (perhaps due partially to seasonal patterns produced by biologic activity and inexactness in some of the analytical methods); but, as shown in figure 7, the amount of nitrogen and its distribution in the aqueous matrix are definitely related to the amount of discharge. Similar patterns of distribution seem to prevail for phosphorus.

Trace Metals

Selected samples collected from 1974 through 1977 were analysed for iron, manganese, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, selenium, and zinc. Table 7 lists the ranges and mean concentrations found for these constituents, along with quality criteria based on EPA guidelines for drinking water. Chromium, lead, selenium, and zinc are the only trace metals to occasionally exceed drinking-water standards. It should be noted that most of these samples were collected during periods of high flow when suspended sediment concentrations were also high. Because all of the metals listed except arsenic, cadmium, selenium and mercury clearly tend to be transported in association with suspended sediment, means of total concentration shown in table 7 are probably biased toward higher values. At the low concentrations measured, the mode of transportation of

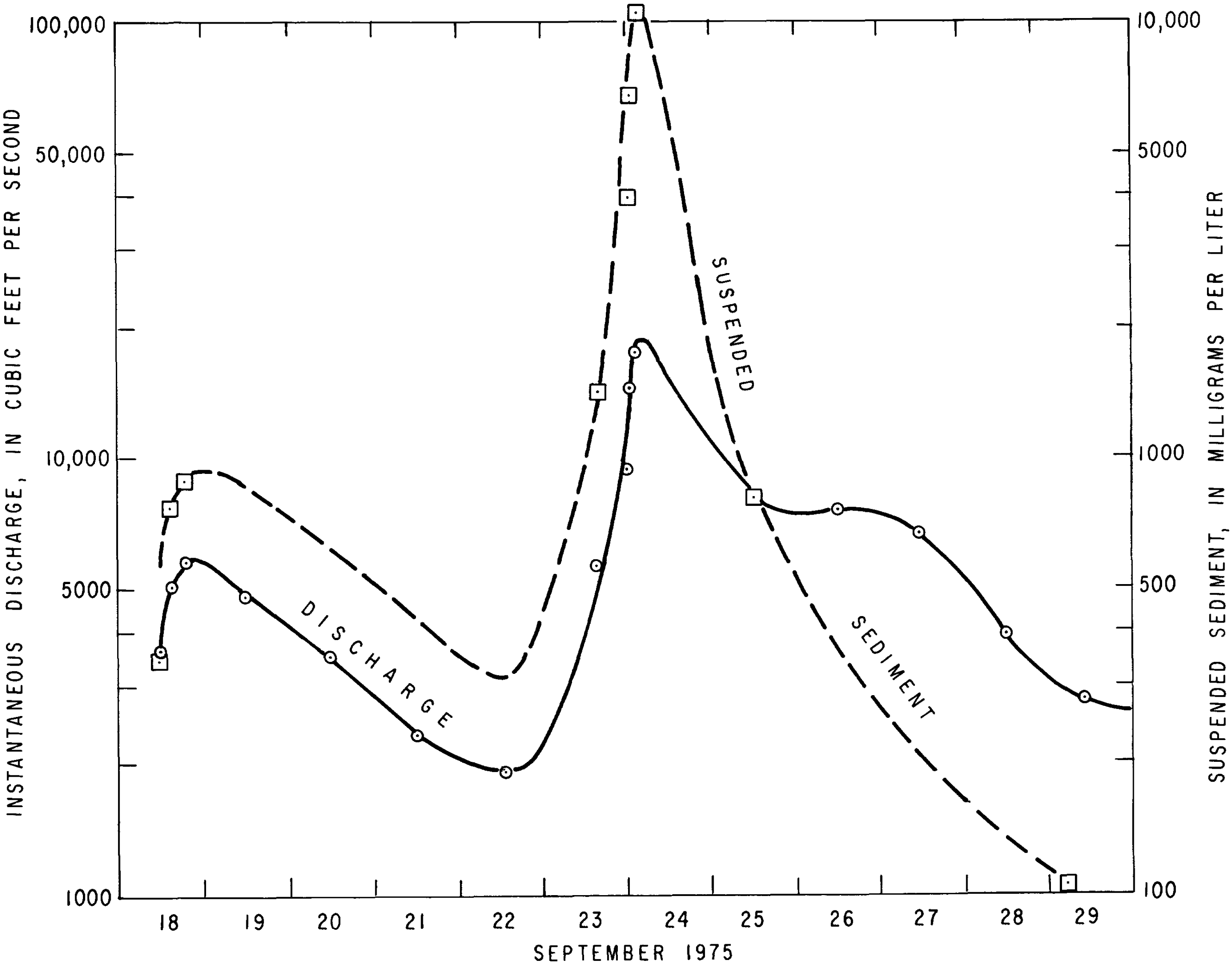


Figure 5. A comparison of changes in suspended-sediment concentration and stream discharge with time, French Broad River at Marshall, N.C., September 18–29, 1957.

Table 6. Mean values and ranges in concentrations of various forms of nitrogen and phosphorus in the French Broad river at Marshall, N.C., 1974–77 water years. (All values in milligrams per liter, except as noted.)

Constituent	Number of samples	Mean	Range	
			Minimum	Maximum
Total Nitrite plus nitrate (N)	32	0.60	0.28	2.4
Dissolved nitrite plus nitrate (N)	32	.46	.30	.84
Total ammonia nitrogen (N)	29	.12	.00	.42
Dissolved ammonia nitrogen (NH_4 as N)	29	.08	.00	.29
Dissolved ammonia (NH_4)	29	.10	.00	.37
Total organic nitrogen (N)	29	.71	.00	4.0
Dissolved organic nitrogen (N)	29	.26	.00	1.2
Total Kjeldahl nitrogen (N)	32	.83	.00	4.2
Suspended Kjeldahl nitrogen (N)	30	.54	.00	3.8
Dissolved Kjeldahl nitrogen (N)	32	.34	.10	1.2
Total nitrogen (N)	32	1.4	.66	4.8
Total nitrogen (NO_3)	32	6.3	2.9	21
Total nitrite plus nitrate in bottom deposits (mg/kg)	5	2.9	1.3	6.0
Total Kjeldahl nitrogen in bottom deposits (mg/kg)	5	200	8.0	560
Total phosphorus (P)	32	.22	.03	1.2
Dissolved phosphorus (P)	32	.07	.01	.48
Total orthophosphorus (P)	31	.10	.01	.48
Dissolved orthophosphorus (P)	31	.05	.00	.26
Dissolved orthophosphate (PO_4)	31	.15	.00	.80
Total phosphorus in bottom material (mg/kg)	4	142	100	240

arsenic, cadmium, selenium and mercury is not clearly defined. Arsenic and mercury apparently are carried in solution, selenium seems to be mostly in solution, and cadmium appears to be associated with the sediment.

Biological Characteristics

The systematic collection of biological data began at Marshall in the 1974 water year. The biological parameters analyzed were fecal coliform bacteria, 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and algal bioassays. Because dissolved oxygen availability influences the survival and diversity of aquatic life and is affected by the BOD and COD as well as temperature, oxygen and temperature are also discussed in this section.

Fecal coliform bacteria are those members of the coliform group found in the feces of various warm-blooded animals, and used as an indicator of bacterialogical pollution. According to U.S. Environmental Protection Agency (1976) cirteria, the number of fecal coliform bacteria in bathing waters should not exceed a log mean of 200 colonies per 100 mL (milliliters) based on a minimum of 5 samples in a 30-day period. At Marshall the log mean count for the 1974–77 water years was 1,100 colonies per 100 mL with a range from less than 10 to 12,000 colonies per 100 mL (table 3). Fifty-eight percent of the water samples analyzed exceeded the recommended limit. (Data furnished by North Carolina Department of Natural Resources and Community Development,, 1974–1977.) These high counts are usually the product of untreated sewage or animal wastes entering the river system. However, unless fecal streptococci and other bacterialogical pollution indicators are measured in connection with fecal coliform, it is impossible to distinguish whether the bacterial pollution is from human or animal sources.

Just as oxygen in the air is necessary for the respiration of air-breathing organisms, so too is dissolved oxygen necessary in water to support many forms of aquatic life. The saturation concentration of dissolved oxygen varies inversely with temperature, and as shown in figure 8, will range from 13.7 mg/L to 7.9 mg/L over the range of daytime water temperature that has been measured at Marshall (table 3). A minimum concentration of 5.0 mg/L of dissolved oxygen has been recommended (EPA, 1976) as a criteria level necessary for maintenance of a varied population of fish and other aquatic organisms, whereas 4.0 mg/L is cited as the minimum concentration that will support a variety of tolerant species. It should be noted, however, that dissolved oxygen levels below 5.0 mg/L will not necessarily result in fishkills, especially if the depleted oxygen levels last only for brief periods.

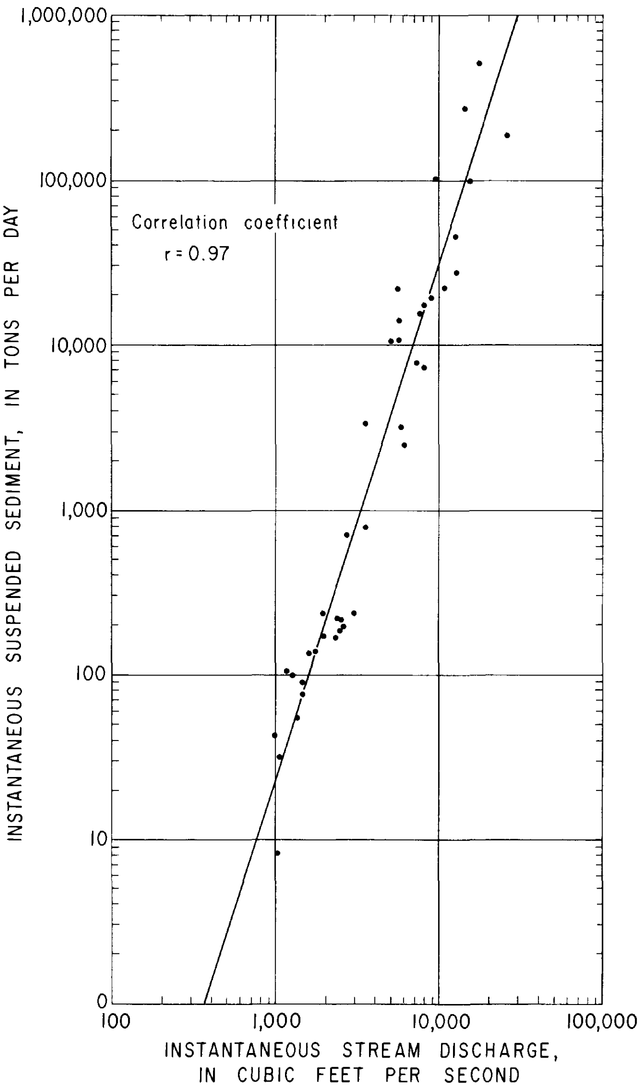


Figure 6. Suspended-sediment transport curve for the French Broad River at Marshall, N.C., 1974–77 water years.

Under natural conditions, water temperatures follow ambient air temperatures but are buffered from extreme values of air temperature by the slower heating and cooling rates of the water. During the summer months, high temperatures reduce the solubility of oxygen in water. Consequently, evaluation of dissolved oxygen levels in streams is important for the critical high temperature months. As shown in figure 8, the dissolved oxygen concentrations in the French Broad at Marshall are high year-round, remaining near or above the saturation level even at higher temperatures. The lowest reported dissolved oxygen concentration (table 3) (North Carolina Department of Natural Resources and Community Development) during the 1974–77 water years was 7.3 mg/L.

Biological uptake of oxygen dissolved in the stream, as measured by the BOD_5 test, is low, with a mean value of 2.0 mg/L. Available oxidizable organic material, measured by the chemical oxygen demand test (COD), is greater, with a range of 10–56 mg/L. Overall, the oxygen level tests characterize the French Broad at Marshall as a clean river.

A rough measure of biological productivity is given by the rate of periphyton growth on an artificial substrate. Discontinuous data (fig. 9) show that growth rates are generally low with a tendency for a seasonal variation in productivity with maximum growth rates occurring during the spring and summer months.

Algal bioassays (table 8) suggest a seasonal distribution of dominant groups with cyanophyta (blue-green algae) prevailing during the summer and fall months, while chrysophyta (diatoms) appear prominantly during winter and spring. The low algal cell counts and group distribution (table 8) indicate that algae are not a problem in the stream.

Man's Effects On Water Quality

Compared to many rivers, the quality of water in the French Broad River is very good. However, there is evidence that virtually every quality characteristic has deteriorated as man's activities in the basin have increased. Determining the precise amount of this deterioration, however, is difficult. A few chemical analyses of water from this river are available as early as the 1920's, but these are too few in number and there was already too much human activity by the 1920's to define undefiled water quality in the river. J. C. Ramage of the Southern Railway Company reported (Ray and Randolph, 1928) an analysis of a sample collected from the French Broad River at Marshall on May 3, 1923, at a discharge believed to be about 2,500 ft^3/s. It is interesting to compare Ramage's analysis with one by the U.S. Geological Survey on a sample collected April 12, 1976, at a similar discharge. (See table 9.) Differences in conventions of reporting results and refinements in analytical techniques make a rigorous comparison of the two analyses impractical. However, the overall impression is that, under low-to-medium high flow conditions, the quality of water in 1976 is similar to what it was in 1923, although the population and general development of the basin have certainly increased greatly since then. Ray and Randolph (1928) mentioned a number of industries, particularly several tanneries, that are no longer in operation. Thus, decreases in certain types of pollution sources, plus increased attention to waste treatment and disposal practices, have probably combined to minimize further deterioration in water quality over the past 50 years.

In the absence of data needed to make a direct evaluation of man's influence on the quality of North Carolina's larger rivers, Wilder and Simmons (1978)

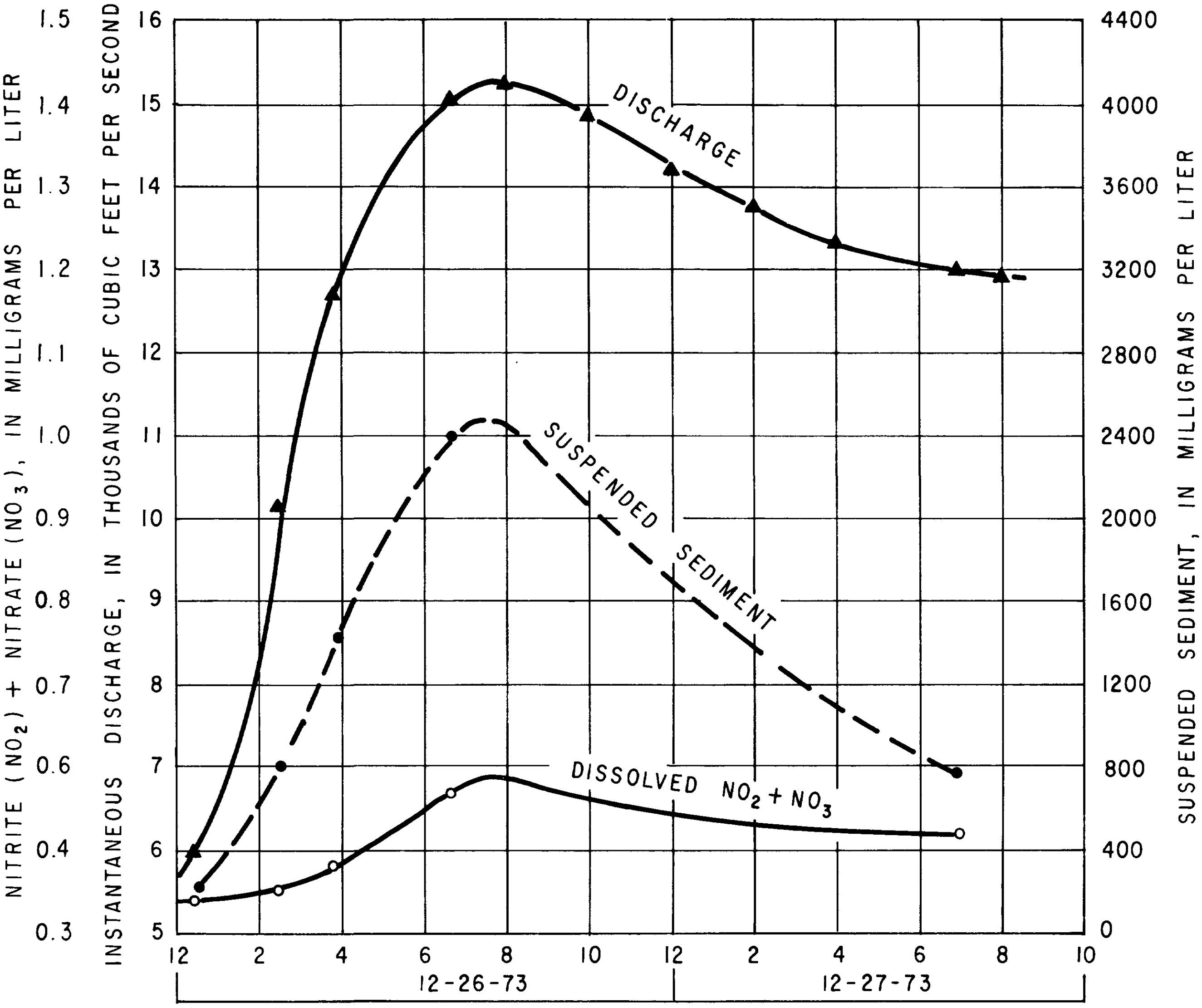


Figure 7. A comparison of changes in nitrite (NO_2) plus nitrate (NO_3) nitrogen, suspended sediment, and stream discharge with time, French Broad River at Marshall, N.C., December 26–27, 1973.

proposed that natural water-quality characteristics be estimated on the basis of the quality of water in environmentally similar unpolluted drainage areas. Such areas are usually in headwater areas and difficult to find, but 11 sites were found in the western part of the State which seem to represent unpolluted or baseline conditions except for pollutants brought in through the air and with precipitation (C. E. Simmons, U.S. Geological Survey, written commun., 1978). These baseline sites are shown in figure 10, along with a list of station names and locations. These sites were sampled an average of four times each during 1973–77 for the purpose of determining the quality of ground-water inflow to streams (low flow) and intense runoff following storms (high flow). A summary of these analyses, shown in table 10, indicates very little difference between the quality of water at low and high flows. This tendency toward sameness is undoubtedly a result of the sparingly soluble nature of the igneous and metamorphic rocks that underlie the area and the fact that ground-water recharge in the upland areas is shunted laterally through fractures in the rocks to points of discharge less than 1 mile (and commonly less than one-half mile) from their point of arrival at the water table (LeGrand, 1958, p. 179).

Table 10 also shows a comparison of water quality at baseline sites with samples taken from the French Broad River at Marshall during periods of distinct low flow and high flow. The differences between the two sets of samples are believed to closely approximate the quantitative effects of man's activities on water quality at Marshall.

The gross effects of man's activities on water quality can best be evaluated in terms of the mass transport of materials by the streams. The loads of sub-

Table 7. Trace metal concentrations and associated quality criteria for the French Broad River at Marshall, N.C., 1974–77 water years. Concentrations in micrograms per liter.

Trace metal	Number of samples	Range	Mean[1]	Quality criteria[2]
Dissolved arsenic	9	0–9	3	50
Total arsenic	9	0–10	4	50
Dissolved cadmium	9	0–3	1	10
Total cadmium	9	0–9	3	10
Dissolved chromium	34	0–14	2	50
Total chromium	34	0–90	21	50
Dissolved copper	34	0–9	3	1000
Total copper	34	0–230	26	1000
Dissolved iron	34	40–380	128	1000
Total iron	32	410–70,000	15,077	---
Dissolved lead	34	0–27	5	50
Total lead	34	0–250	54	200
Dissolved manganese	9	0–67	23	200
Total manganese	9	30–640	156	---
Dissolved mercury	9	0–0.5	0.1	2
Total mercury	9	0–0.5	0.1	2
Dissolved selenium	9	0–20	7	10
Total selenium	9	0–29	13	10
Dissolved zinc	34	0–70	14	5000
Total zinc	34	10–6900	327	5000
Dissolved cobalt	9	0–3	0	---
Total cobalt	9	0–49	12	---

[1] Those means based on 9 samples included 4 samples that were collected during high flow. Those means based on 32 and 34 samples included approximately 8 and 9 samples respectively that were collected during high flow.

[2] Criteria references:
National Academy of Sciences and National Academy of Engineering, 1972.
U.S. Environmental Protection Agency, 1976.

stances contributed by pollution can be estimated as described by Wilder and Simmons (1978), using the estimates of natural-quality concentrations (table 10) to calculate estimated natural loads. These natural-load estimates are subtracted from the actual loads determined from the samples collected at Marshall and the differences between the two are assumed to represent inputs resulting from man's activities. It should be emphasized that computation of representative transport loads requires both continuous streamflow measurements and water-quality measurements made with sufficient frequency to allow the determination of continuous concentration data. The frequency with which concentrations of transported materials must be measured varies with the variability of the constituent being measured, but the computation of usefully accurate loads usually requires at least daily values. As discussed earlier in this report, the only daily water-quality measurement made in this investigation is specific conductance. Thus, it is possible to estimate pollution loads only for those constituents that correlate meaningfully (correlation coefficient greater than 0.75) with specific conductance. (See table 4.) A summary of the amounts and sources of selected major dissolved constituents transported by the French Broad River at Marshall, calculated as described above, is shown in table 11.

The estimates of the effects of man on the quality of water at Marshall shown in table 11 are based on several assumptions (Wilder and Simmons. 1978), the most important of which is that natural quality of water in a large river is essentially the same as that in a small stream if their natural environments are the same. There

Table 8. Algal biossays, in percent of total cell count and the total cell count, for the French Broad River at Marshall, 1974–77 water years

	Date of sample and percent of total cell count										
	Apr. 15, 1974	June 14, 1974	Oct. 2, 1974	June 9, 1975	Oct. 1, 1975	Feb. 17, 1976	June 15, 1976	Aug. 20, 1976	Dec. 16, 1976	Mar. 28, 1977	May 23, 1977
Cyanophyta (Blue-green).	86	83	51	54	--	--	58	58	--	5	--
Chlorphyta (Green).	--	7	23	2	6	--	8	30	--	3	--
Chrysophyta (Diatoms).	--	9	18	44	94	97	32	12	99	92	92
Euglenophyta ...	--	--	--	--	--	2	--	--	--	--	8
Other	14	1	8	--	--	1	2	--	1	--	--
Total Cell Count	1,700	5,000	1.700	1,900	250	1.700	1,700	5,500	690	830	860

is, of course, no direct way of evaluating the validity of this assumption. For the French Broad River, however, some degree of the amount of confidence to be placed in the methodology used can be derived by comparing the results of the areal estimates derived from the baseline-quality network with results from a daily station operated on Cataloochee Creek near Cataloochee, N.C. (Shown as map number 56 in figure 10.)

At the station, Cataloochee Creek has a drainage area of 49.2 mi^2, all of which lies in a remote section of the Great Smoky Mountains National Park. On the basis of topography, geology and climate, the Cataloochee basin is hydrologically very similar to that of the French Broad basin at Marshall, and both lie entirely within Geochemical Zone I (fig. 10). Except for a one-lane access road and a sparse network of hiking trails and bridle paths, the Cataloochee basin is completely undeveloped; and activity within it is limited to this type of recreation, plus a small amount of overnight camping. Virtually all use of the basin occurs in the summer months. Although slight increases in nutrients and suspended materials were noted during peak-use periods, major dissolved chemical constituents were not noticeably affected.

With respect to major constituents, water in Cataloochee Creek should approximate natural quality in the French Broad River basin. The marked similarity between the chemical character of water in Cataloochee Creek and more general estimates based on miscellaneous samples from much smaller basins (0.74–18.6 mi^2) in the baseline-quality network is shown in figure 11.

An additional check on the adequacy of the baseline-quality network in furnishing valid information on natural quality at sites where such quality cannot be measured directly can be made by comparing natural loads for the French Broad River estimated by use of the baseline-quality network with those computed from daily measurements at Cataloochee. The results obtained for annual total dissolved solids are shown in table 12 as unit loads in order to facilitate comparison of the data. Comparisons based on actual loads can be misleading since, as with concentration, they are dependent upon the amount of streamflow. Because of differences in streamflow at the two stations, a more realistic means of comparing loads is by converting the actual loads to some equivalent unit value (in this case, unit load of dissolved solids in tons per million cubic feet of discharge). This technique is also useful for reducing the year to year effects of changing streamflow, for as will be seen in the Trends section of this report, significant trends can be masked by the "noise" of unusually wet or dry years.

The close agreement of the character and amont of natural dissolved matter estimated for the French Broad River at Marshall with that measured for a similar environment at Cataloochee offers encouraging evidence that the baseline-quality network is furnishing reliable baseline data for evaluating the effects of man's activities on water quality of the French Broad River.

To give the information shown in table 11 a somewhat broader perspective, historical data were used to calculate annual dissolved solids loads for the period of record at Marshall. The results, which are in table 13, show that during the periods 1958–67 and 1974–77, dissolved solids transport ranged from 131,000 tons/yr to 184,000 tons/yr, and that from 61 to 75 percent of this load was due to pollution. In general, pollution loads are greater during years of high total discharge even though concentrations of major dissolved constituents invariably decrease during high flows. The greater pollution loads during high-flow years probably reflect the influence of non-point source inputs on the quality of water in the river, because other factors being equal, point-source pollution input is probably largely independent of streamflow over a year's time.

The chemical character of inorganic pollution inputs to the river is illustrated in figure 12, which shows diagrams of natural water quality superimposed on diagrams of the average quality of high and low-flow samples from the river (table 10). These diagrams show that nonnatural inputs dominated most major dissolved ionic species, with the greatest increases occurring in sodium (Na), calcium (Ca), sulfate (SO_4), and bicarbonate (HCO_3).

Trends

A major concern in modern water-quality programs is the rate at which the quality of streams may either be deteriorating or improving. Thus, several investigations by both State and national agencies have the stated objective of detecting trends in stream quality. Detecting such trends, however, is difficult; and much of the effort currently being expended for this purpose may prove unsuccessful. Among the most troublesome problems encountered in detecting trends are the so-called "noise" effects of short-term variations caused by variations in environmental conditions, particularly variations in streamflow. In addition, the trends themselves also are not necessarily constant over long periods of time. This is often due to the fact that different aspects of water quality may change in response to factors not related to environmental conditions. For example, the discharge of manufacturing wastes may increase or decrease with changes in the economy.

If water-quality data were available over sufficiently long periods of time, natural trends caused by long-term changes in weather patterns would probably be detectable within them. However, uninterrupted water-quality records are seldom collected for periods lasting more than a few years, and any systematic variations during these periods almost certainly are caused by changes in man's activities. Thus, the research for trends can be made simpler by concentrating on man's effects on quality rather than on the combined effects of both man and nature. For the French Broad River at Marshall, selected water-quality data are available on a daily basis for 1958–67 and 1974–77. (See figure 2.) For the earlier period, only information concerning major dissolved inorganic constituents was collected, and comparisons of modern data with historical data must be based on measurements of these constituents.

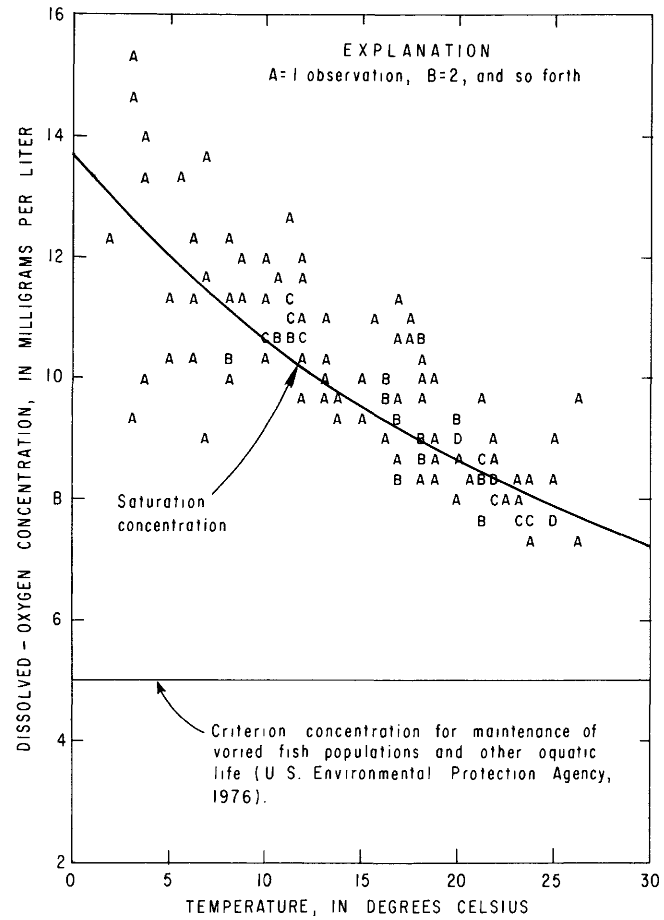


Figure 8. Dissolved oxygen concentration versus water temperature, French Broad River at Marshall, N.C., 1974–77 water years.

A first step in the search for trends is to deduce what factors are likely to have significantly influenced variations in water quality, and what the general influence of these factors might have been. In the French Broad River basin four factors are suspected to have dominated the water-quality of the river during the period of study:

1. Variations in stream discharge are known to cause short-term variations in constituent concentrations that, over periods as long as two years, may mask variations in water quality due to other causes. For example, increases in pollutant transport during years of high flow are believed to reflect in part, increases in the amounts of non-point source pollution.
2. The population of the basin has increased at an annual rate of slightly more than one percent. This increase should cause small increases in most major chemical constituents.
3. Manufacturing employment (and therefore industrial output) has increased steadily even if somewhat erratically on an annual basis. Unless other fac-

Table 9. Comparison of chemical analyses of water from the French Broad River at Marshall, N.C., 1923 and 1976

Dissolved constituent	Concentrations in milligrams per liter	
	[1]May 3, 1923 (discharge estimated at 2500 ft³/s)	April 12, 1976 (discharge = 2530 ft³/s)
Total dissolved solids	68	44
Dissolved solids sum	33.40	44
Silica (SiO_2)	.86	10
Iron (Fe)	1.08	0.89
Calcium (Ca)	6.92	4.2
Magnesium (Mg)	.54	.2
Sodium (Na)	2.20	7.0
Potassium (K)	.93	1.0
Carbonate (CO_3)	5.60	.0
Bicarbonate (HCO_3)	- -	15
Sulfate (SO_4)	11.90	11
Chloride (Cl)	2.68	2.8
Nitrate (NO_3)	trace	.32
Total hardness	19.55	11
Alkalinity	9.3	12

[1] Taken from Ray, C. E. and Randolph, E. E., 1928

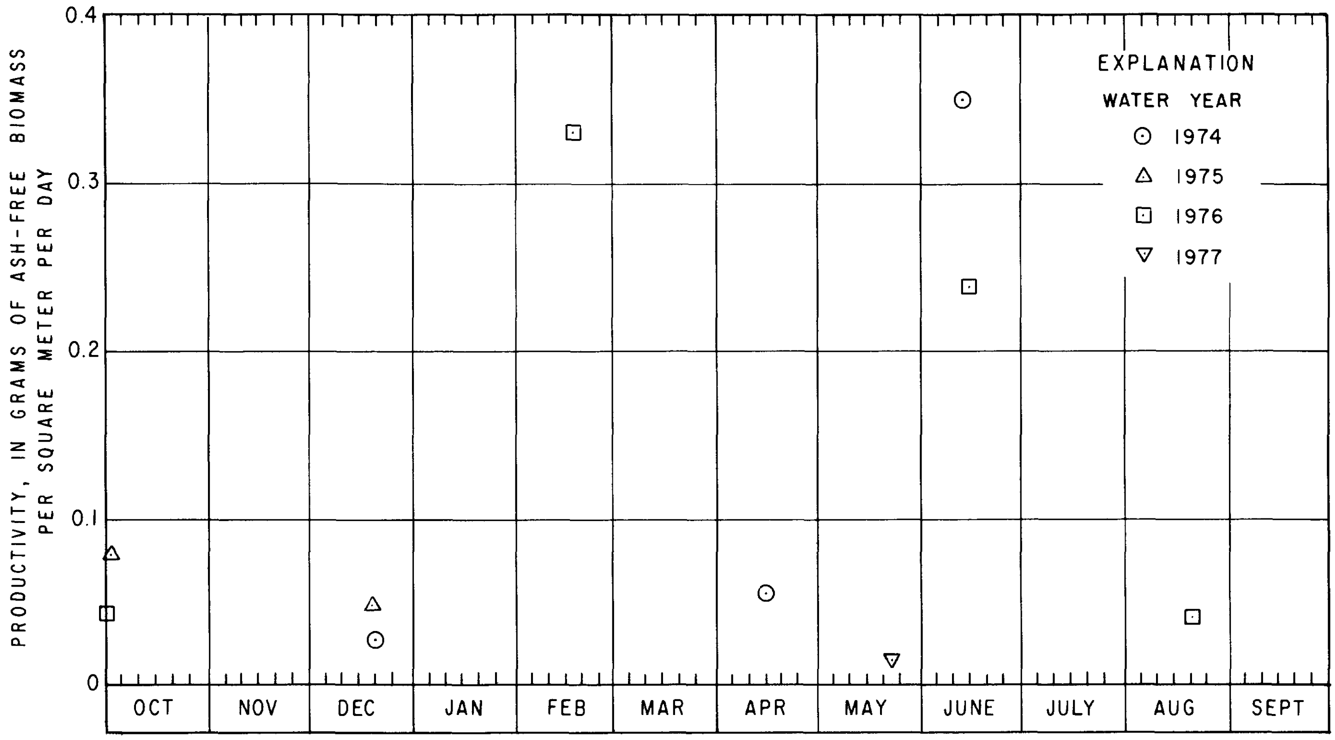


Figure 9. Periphyton productivity in the French Broad River at Marshall, N.C., 1974–77 water years.

Table 10. Comparison of water quality of samples from the French Broad River at Marshall, N.C., with samples from baseline-quality sites in the same area

	French Broad River at Marshall			Baseline quality sites			Range in percent attributable to pollution based on mean values[1]
	Mean value			Mean value			
	Low flow (<1800 ft^3/s)	High flow (>1800 ft^3/s)	Range of all samples	Low flow	High flow	Range of all samples	
Major dissolved constituents (milligrams per liter)							
Calcium	7.0	4.6	3.2–10.0	1.3	1.3	0.5–3.0	72–[2]81
Magnesium	1.2	1.1	.2–2.0	.6	.4	.3–0.9	[2]50–64
Sodium	14.0	5.8	2.4–22.0	1.5	.8	.4–2.2	86–[2]89
Potassium	1.7	1.6	1.0–2.9	1.0	.6	.3–1.9	[2]41–62
Bicarbonate	26.0	15.0	9.0–35.0	7.4	5.1	2.0–9.5	66–[2]72
Sulfate	24.0	11.0	5.1–42.0	2.2	2.2	.8–5.7	80–[2]91
Chloride	4.3	3.0	.9–5.8	0.9	.7	.0–2.0	77–[2]79
Fluoride	.1	.2	.0–1.2	0.1	0.1	.0–0.5	[2]0–50
Silica	10.0	8.2	3.7–11.0	8.1	6.6	3.5–9.4	[2]19–20
Dissolved solids	76.0	44.0	30.0–112.0	19.0	15.0	12.0–22.0	66–[2]75
Nutrients (milligrams per liter)							
Total nitrogen	1.2	1.5	0.66–4.8	0.19	0.30	0.0–0.92	80–[2]84
Organic nitrogen	.50	.79	.0–4.0	.11	.13	.0–0.29	[2]78–84
Nitrate nitrogen	5.2	6.8	2.9–21.0	.08	.17	.0–4.0	98–98
Ammonia nitrogen	.13	.11	.0–0.42	.0	.01	.0–0.01	91–[2]100
Total phosphorus	.16	.24	.03–1.2	.01	.01	.0–0.02	[2]94–96
Trace Metals (micrograms per liter)							
Total arsenic	0.33	5.2	0.0–10.0	0.1	0.0	0.0–1.0	[2]70–100
Total chromium	12.0	24.0	.0–90.0	10.0	10.0	1.0–[3,4]20.0	[2]17–58
Total copper	11.0	32.0	.0–230.0	4.0	4.0	.0–13.0	[2]64–88
Total iron	958.0	20,602	410–70,000	460.0	1800.0	20–[5]8600	[2]52–91
Total lead	41.0	58.0	.0–250.0	5.0	9.0	.0–[3,4]25	84–[2]88
Total mercury	.17	.12	.0–0.5	.10	.10	.0–0.50	17–[2]41
Total selenium	5.0	17.0	.0–29.0	.0	.0	.0–[3,4]0.0	100–100
Total zinc	58.0	424.0	10.0–6900.0	10.0	10.0	.0–[4]40.0	[2]83–98

[1] Some constituents have a higher percent attributable to pollution at high flow whereas others have a higher percent attributable to pollution at low flow.

[2] Low flow.

[3] Exceeded limits recommended in *Safe Drinking Water Act,* Federal Register, Dec. 24, 1975, in some samples.

[4] Exceeded limits recommended in *Quality Criteria for Water,* U.S. Environmental Protection Agency, 1976 in some samples.

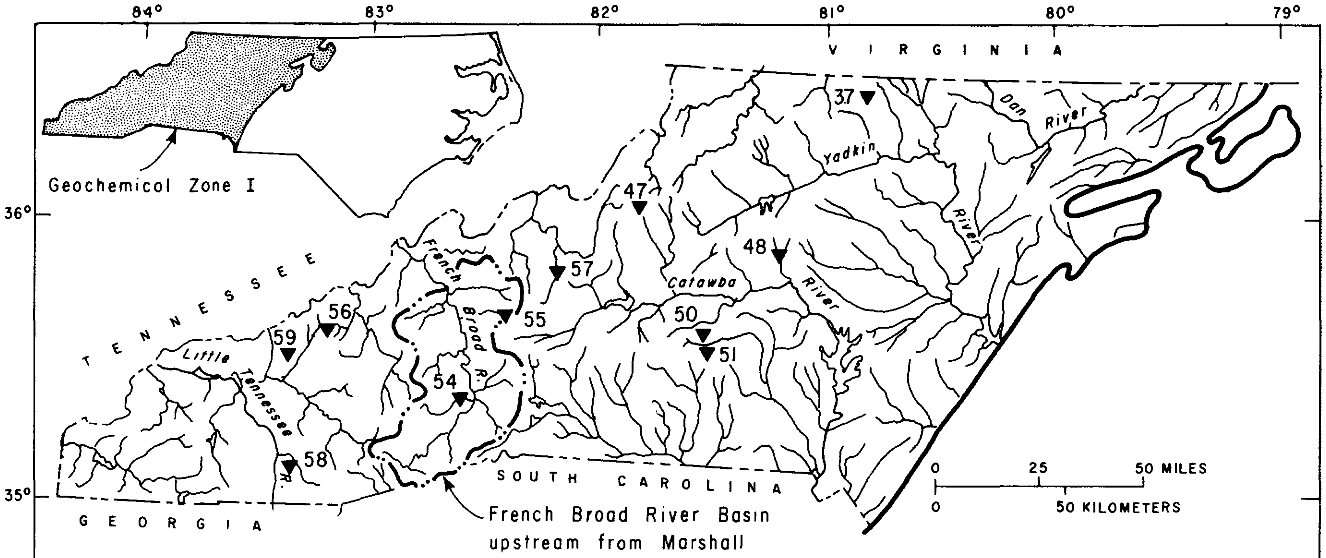
[5] No recommended limits.

tors such as changes in manufacturing processes or application of pollution abatement techniques are involved, there should be a general relation between manufacturing employment and point-source pollution input to the river.

4. Changes in waste-treatment facilities and manufacturing processes usually have an effect on water quality. During the most recent sampling period (1974–77) such changes apparently have resulted in improved water quality, and modification of previous trends. Although these changes are known to take place, there is presently no reliable

Table 11. Sources and average amounts of major dissolved constituents transported by the French Broad River at Marshall, N.C., 1974–77 water years

Constituent	Total load (tons/yr)	Natural load (tons/yr)	Pollution load (tons/yr)	Percent attributable to pollution
Sodium	22,900	3,630	19,200	84
Bicarbonate	49,500	19,100	30,500	62
Sulfate	37,200	6,340	30,900	83
Dissolved solids	147,000	51,300	95,800	65



EXPLANATION

MAP NO.	STATION NUMBER	STATION NAME	DRAINAGE AREA IN SQUARE MILES
37	02112401	Endicott Creek near Blevins Store	3.20
47	02140304	Wilson Creek near Gragg	0.74
48	02142122	Lower Little River Trib. near Taylorsville	2.60
50	02142988	Henry Fork Trib. near Pleasant	3.20
51	02143040	Jacob Fork at Ramsey	25.4
54	03445376	North Fork Mills River above Mills River	18.6
55	03450000	Beetree Creek near Swannanoa	5.46
56	03460000	Cataloochee Creek near Cataloochee	49.2
57	03463292	Locust Creek near Celo	1.80
58	03500741	Peeks Creek near Gneiss	2.00
59	03510815	Mingus Creek at Ravensford	4.70

Figure 10. Location of baseline water-quality sampling sites in Geochemical Zone I (from C. E. Simmons, U.S. Geological Survey, written commun., 1978).

Table 12. Comparison of natural dissolved-solids unit loads estimated for the French Broad River at Marshall, N.C., with unit loads calculated from daily measurements for Cataloochee Creek near Cataloochee, N.C.

Dissolved-solids Unit Loads (tons per million cubic feet of discharge)		
Water year(s)	French Broad River at Marshall (estimated from baseline-quality network)	Cataloochee Creek near Cataloochee
1974	0.57	0.61
1975	0.57	0.52
1976	0.54	0.55
1977	0.53	0.65
1974–77	0.55	0.56

way of documenting all these changes, or more particulary, assessing the impact of the changes.

A preliminary appraisal of the effects of these factors on chemical quality may be made by comparison of simultaneous plots of pollution loads of dissolved constituents and the three measurable factors thought to contribute to them. Figure 13 shows simultaneous time plots of stream discharge, manufacturing employment, population, and dissolved-solids pollution load. The general impression is that from 1958, when water-quality data collection began, through 1967, when data collection was suspended, dissolved pollution loads increased as did population and manufacturing. Pollution loads responded to variations in discharge also. A multiple-regression analysis for the period of record indicated that a major part of the variation in dissolved pollution loads was related to variations in discharge and manufacturing employment, with population playing a relatively minor role.

Figure 13 also suggests that from the resumption of sampling in 1974 through 1977 a decreasing trend in pollution loads was in progress. This trend is probably associated, at least in part, with the discontinuance of a major rayon-producing facility midway in the 1975 water year.

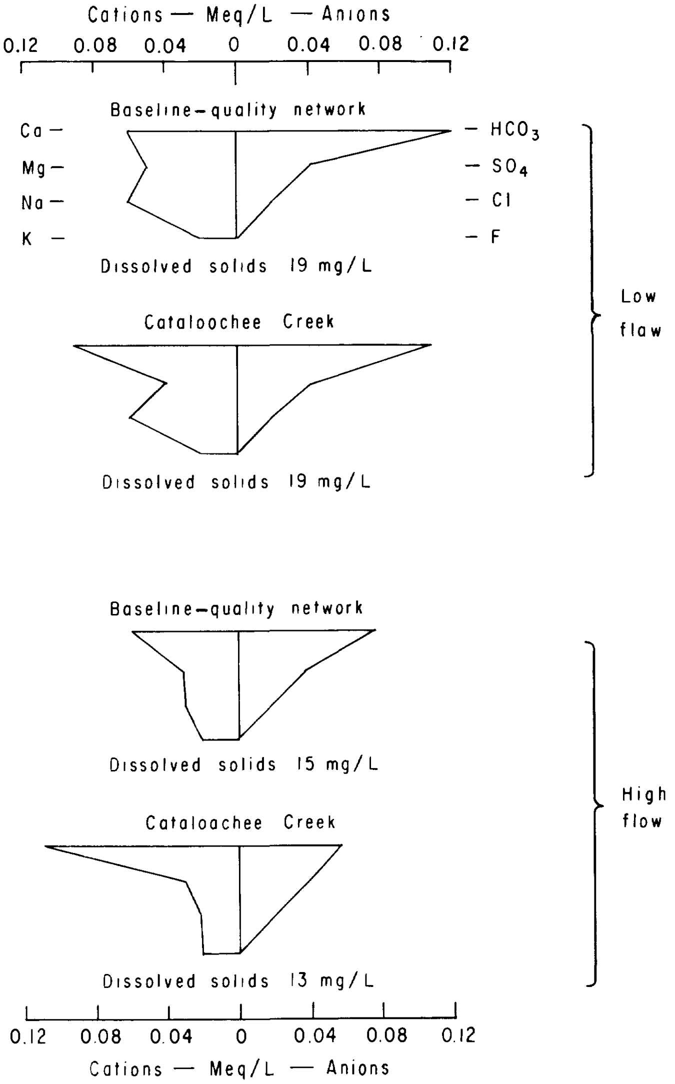


Figure 11. Natural chemical character and dissolved solids in the French Broad River basin as estimated from the baseline water-quality network compared to measurements at Cataloochee Creek near Cataloochee, N.C, 1974–77 water years (diagram pattened after Stiff, 1951).

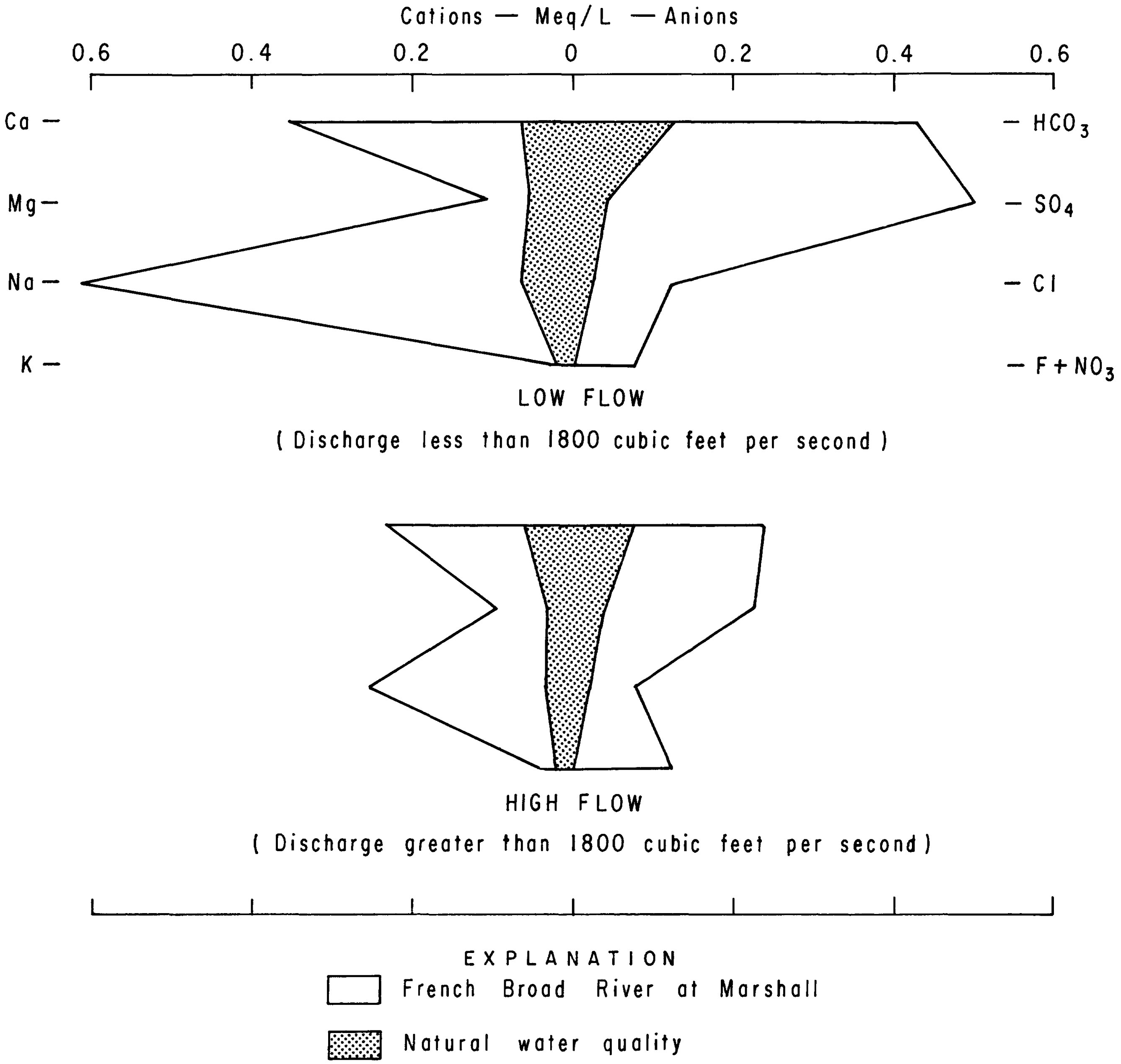


Figure 12. Differences in chemical character between estimated natural water quality and actual average quality for samples taken from the French Broad River at Marshall, N.C., during high and low flow (diagram patterned after Stiff, 1951).

Information on which chemical characteristics are most likely to contribute to trends is also helpful in establishing focal points for trend analyses. The chemical equivalents diagrams shown on figure 12 indicate that at high flows input of pollutants to the French Broad is fairly well balanced among the major chemical species. At low flows, however, sodium and sulfate increase greatly, suggesting that they are principal components of point-source pollution input. The increases in calcium and bicarbonate show them to be secondary pollutants.

To further explore the chemical character of man-made inputs to the river, the annual means for analyses of samples collected during low flow were plotted on a trilinear chemical equivalent diagram as shown in figure 14. This diagram indicates a time-related shift from a predominately sodium-sulfate-type pollution input in 1958 toward an input more evenly balanced between calcium, sodium, bicarbonate, and sulfate in 1977. Because of the discontinuity in data collection from 1967 to 1974, it is not possible to determine precisely when

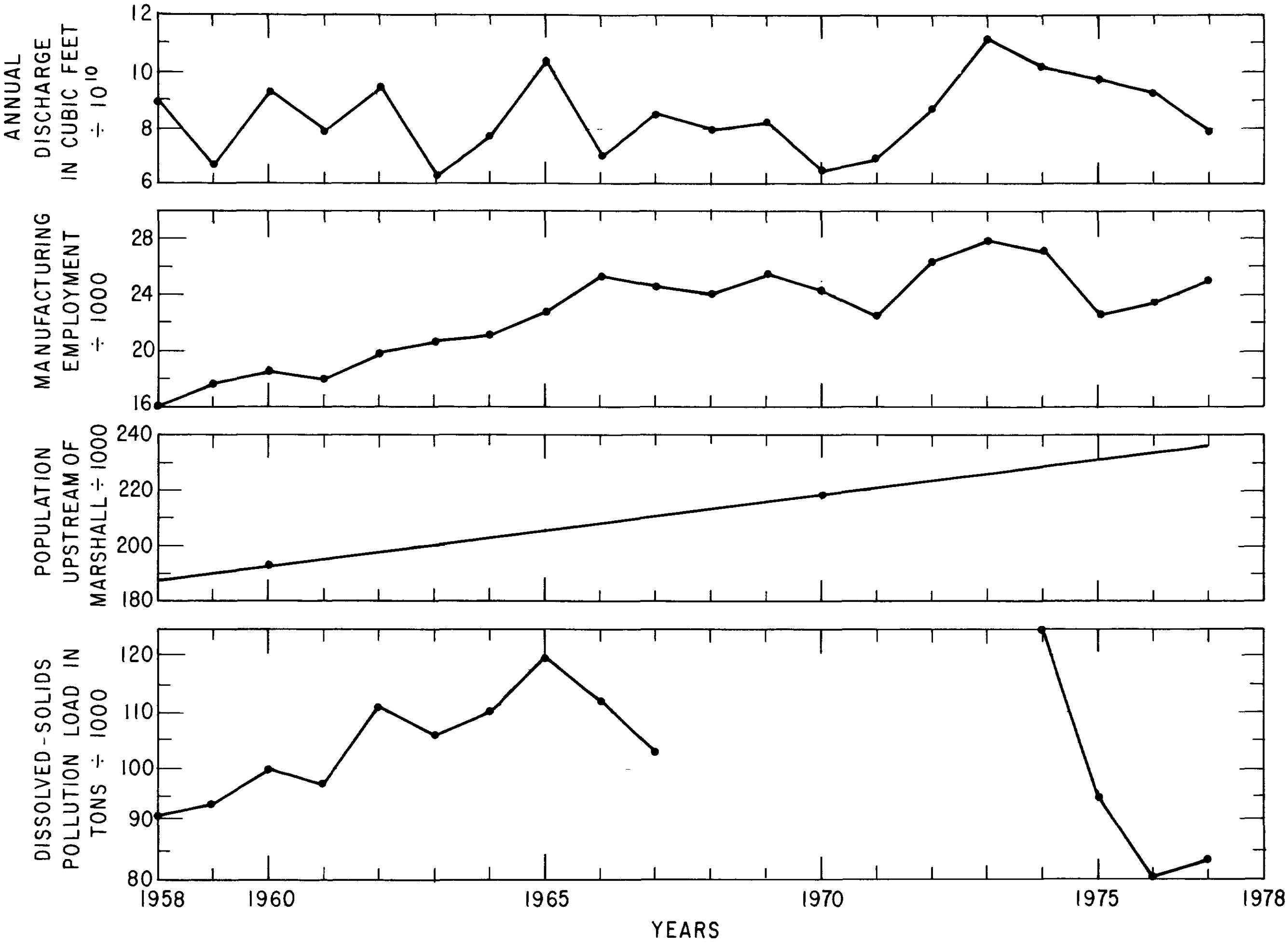


Figure 13. Stream discharge, manufacturing employment, population estimates, and dissolved pollution loads, French Broad River at Marshall, N.C., 1958–77 water years.

these shifts in chemical character began, but the transition seems to have been occurring when sampling was resumed in October 1973.

To investigate further, annual loads of the major conservative ionic species in solution (sodium, calcium, and sulfate) were regressed individually as dependent variables against both discharge and manufacturing employment as independent variables. Correlation coefficients resulting from these regressions are shown in table 14. From this table it seems apparent that during the earlier sampling period sodium varied primarily in response to variations in manufacturing employment, whereas calcium responded most sensitively to changes in discharge. Sulfate also was most responsive to discharge, but showed some response to manufacturing employment as well.

Although only four years of data are available for the most recent sampling period (1974–77), it is interesting to compare regression analyses for this period with those for the earlier period. Pollution loads of sodium and sulfate now seem to be about equally correlatable with discharge and manufacturing, while calcium is still dominated by discharge. The apparently decreased influence of manufacturing on sodium and sulfate is consistent with observations of changes in the chemical character of pollution input to the river discussed earlier.

A summary of trends in inorganic pollution input to the French Broad, as represented by a few inorganic constituents, is illustrated in figure 15 which shows average unit pollution transport, in tons per million cubic feet of discharge, for two 5-year periods during the earlier sampling period, and for the most recent 4-year period. It appears that even with continued economic growth the inorganic chemical quality of the river has improved, in most, but not all respects, since sampling was first discontinued in 1967. From information gathered from public officials and furnished by manufac-

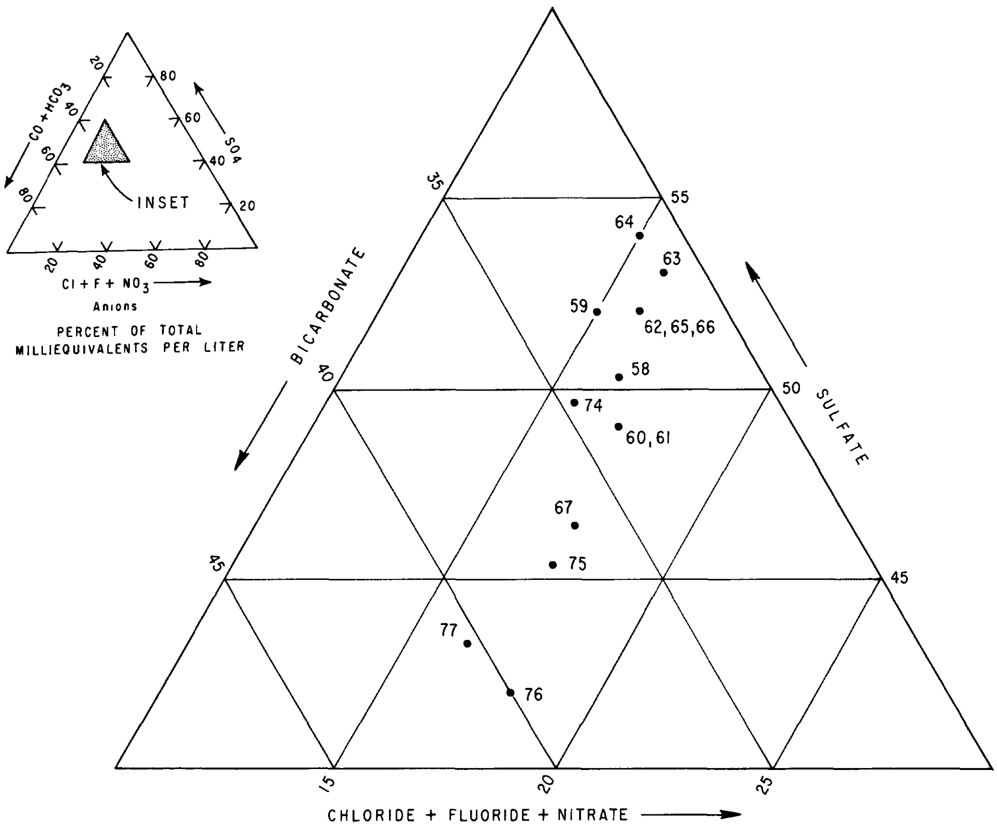


Figure 14. Trilinear diagrams of annual means for analyses of samples collected during low flow,

turers in the basin, it seems likely that this improvement is a result of both efforts to improve waste-treatment methods and efforts to clean up particularly so-called "dirty" manufacturing processes. There is, of course, no way of predicting with certainty what the future trends in the quality of water in the French Broad River will be. At present it appears that a noticeable level of improvement has been attained as the result of a lengthy and expensive effort on the part of public and private interests to return the river to a desirable water-quality condition.

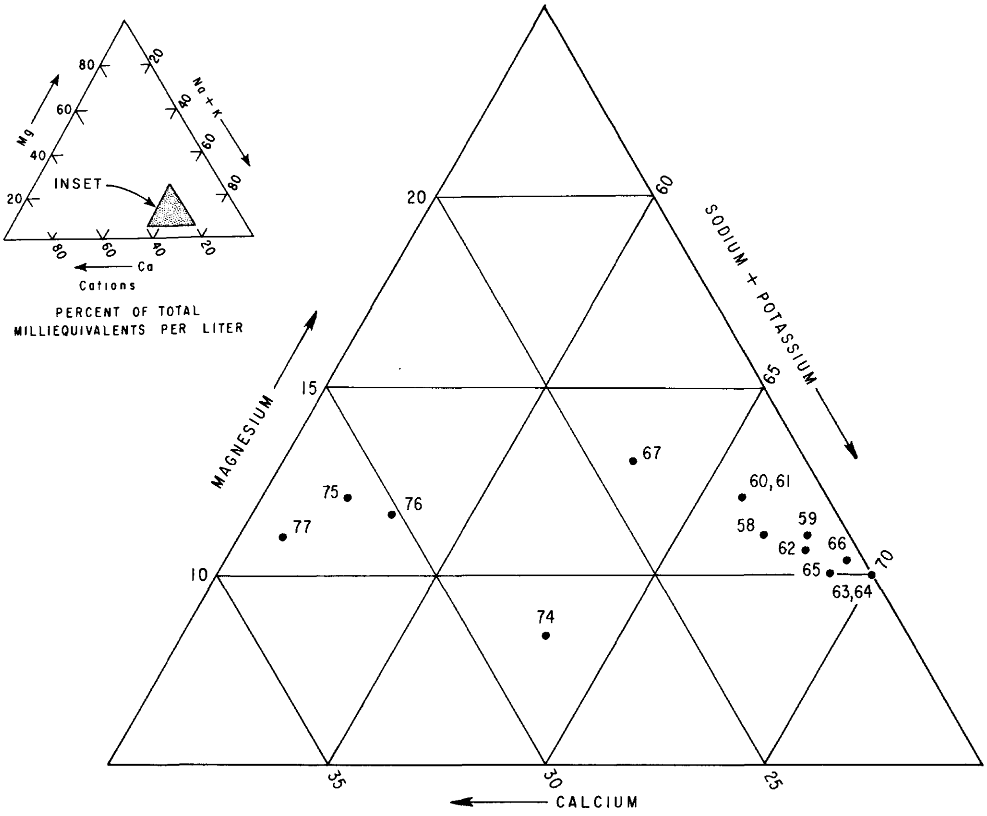
The results are encouraging because they show that the quality of water in our large rivers need not deteriorate continually in the face of economic growth. However, even during the most recent year for which records are available (1977 water year), 67 percent of the total dissolved material transported by the river was attributable to man's activities. (See table 12.) Therefore if, as seems certain, industrial growth in the basin continues, pollution abatement efforts must continue to keep pace. Otherwise, the French Broad River will enter another period of gradual degradation.

SUMMARY

An investigation of the quality of water in the French Broad River at Marshall, N.C., has defined variations in water quality, determined the degree to which the quality of water in the river is affected by man's activities, and analyzed trends in the chemical quality of the river during the period 1958–77. The French Broad River drains 1,667 square miles of the Blue Ridge Mountains Province in western North Carolina, an area of rugged topography with altitudes ranging from 6,419 feet along the northeastern drainage divide to 1,240 feet where the river enters Tennessee. The drainage area upstream from Marshall is 1,332 square miles.

The French Broad River is the most industrialized river basin in the mountain region of the State with about 30 percent of the employed population engaged in the manufacture of textiles, pulp and paper, leather goods, furniture and other wood products. Population in the basin above Marshall has increased 40 percent between 1940 and 1970 to approximately 218,000 inhabitants.

In general, the quality of the water in the French Broad River as represented by samples taken at Marshall is satisfactory for most purposes. None of the major dissolved constituents and nutrients, nor defined properties such as hardness, alkalinity and color, exceed limits suggested by the U.S. Environmental Protection Agency for drinking-water sources. Of the trace metals determined, only chromium, lead, selenium, and zinc occasionally exceeded approved drinking-water values. Dissolved ox-



French Broad River at Marshall, N.C., 1958–67, 1974–77 water years (diagram after Piper, 1944).

ygen concentrations are high year-round, remaining near or above the saturation level even at higher summer temperatures. Low levels of chemical oxygen demand (COD) and biological oxygen demand (BOD_5) characterize the French Broad at Marshall as a clean river. However, 58 percent of samples analyzed for fecal coliform bacteria during 1974–77 exceeded recommended limits for bathing waters.

Several variations of water quality have been identified and quantified. Of the three most important, the most fundamental has been to determine the extremes within which concentrations of constituents may be expected to range. A second has been to quantify variations in constituent concentration, in particular dissolved ionized constituents, by correlation with specific conductance. The third has been to identify the water-quality variations associated with variations in stream-flow. Changing streamflow is perhaps the single most important cause of water-quality variation.

Many major dissolved constituents in the river, particularly dissolved solids, sodium and sulfate, vary linearly with specific conductance. These relations have been quantified by linear regression analysis. However, the relation of specific conductance to streamflow is a non-linear inverse relation, and, as might be expected because of the way that dissolved constituents correlate with specific conductance, concentrations of dissolved constituents also follow a non-linear inverse relation to streamflow.

Suspended sediment concentrations generally increase with increasing streamflow and most trace metals clearly tend to be transported in association with the suspended sediment. At the low concentrations measured, the mode of transportation for arsenic, cadmium, selenium and mercury is not clearly defined. Arsenic and mercury are apparently carried in solution, selenium seems to be mostly in solution and cadmium appears to be associated with the sediment. No strong general correlation between stream discharge and nutrient concentrations has been observed.

Man's activities in the basin have resulted in deterioration of water quality in the French Broad River. By comparison with data from sites thought to represent natural conditions, it is estimated that at the time continuous water-quality monitoring began in 1958, 64 percent of the dissolved-solids load in the river at Marshall was due to pollution. Time-trend analysis shows that from 1958 to at least sometime in 1967 dissolved constituents carried in the river increased, coinciding with general increases in population and industrial employment. The total dissolved-solids load, along with the dissolved sodium, sulfate and calcium loads showed the

Table 13. Dissolved solids loads, French Broad River at Marshall, N.C., 1958–67, 1974–77 water years

	Measured at Marshall		Estimated from baseline-quality network		Loads			Unit loads		
Water year	A Total discharge (million cubic feet/yr)	B Total dissolved solids (tons/yr)	C Dissolved solids in ground water (tons/yr)	D Dissolved solids in overland flow (tons/yr)	E Dissolved solids in natural load (tons/yr) C+D	F Dissolved solids in pollution load (tons/yr) B−E	G Percent of total load from pollution (F/B)×100	H total unit load (tons/million cubic feet) B/A	I Natural unit load (tons/million cubic feet) E/A	J Pollution unit load (tons/million cubic feet) B−I
1958	89,360	143,000	40,800	10,400	51,200	91,800	64	1.60	0.57	1.03
1959	66,010	131,000	30,100	7,700	37,800	93,200	71	1.99	.57	1.43
1960	92,720	153,000	42,200	10,700	52,900	100,100	65	1.64	.57	1.07
1961	79,150	142,000	36,100	9,200	45,300	96,700	68	1.80	.57	1.23
1962	94,040	165,000	42,900	10,900	53,800	111,200	67	1.76	.57	1.19
1963	62,670	142,000	28,600	7,300	35,900	106,100	75	2.26	.57	1.69
1964	77,380	154,000	35,200	9,00	44,200	109,800	71	2.00	.57	1.43
1965	104,140	180,000	47,500	12,100	59,600	120,400	67	1.72	.57	1.15
1966	69,270	152,000	31,600	8,000	39,600	112,400	74	2.19	.57	1.62
1967	84,620	152,000	38,600	9,800	48,400	103,600	68	1.79	.57	1.22
1974	101,570	184,000	46,300	11,800	58,100	125,900	68	1.81	.57	1.24
1975	96,800	150,000	44,100	11,200	55,300	94,700	63	1.55	.57	0.98
1976	92,270	130,000	37,200	13,000	50,200	79,800	61	1.41	.54	0.87
1977	78,440	125,000	20,800	20,800	41,600	83,400	67	1.59	.53	1.06

Table 14. Correlations of major dissolved ionic species with stream discharge and manufacturing employment for the French Broad River at Marshall, N.C., 1958–67, 1974–77 water years

Independent variable	Dependent variable correlation coefficients					
	1958–67			1974–77		
	Sodium	Calcium	Sulfate	Sodium	Calcium	Sulfate
Stream discharge	0.16	0.92	0.92	0.74	0.94	0.72
Manufacturing employment	.77	.29	.61	.73	.43	.71

most dramatic increases. By 1966, 74 percent of the total dissolved load could be attributed to pollution. The exact time that conditions in the river began to improve is not certain because water quality monitoring was discontinued between 1968 and 1973; however, since 1974 the amount of inorganic constituents has decreased dramatically in spite of increased population and industrial growth. New waste-water treatment facilities and improved industrial technology apparently have combined to curb pollution and reverse the earlier trend. In 1977 water quality had returned at least to levels of 1958. It appears that a noticeable level of improvement has finally been attained as the result of a lengthy and expensive effort to return the river to a desirable water-quality condition.

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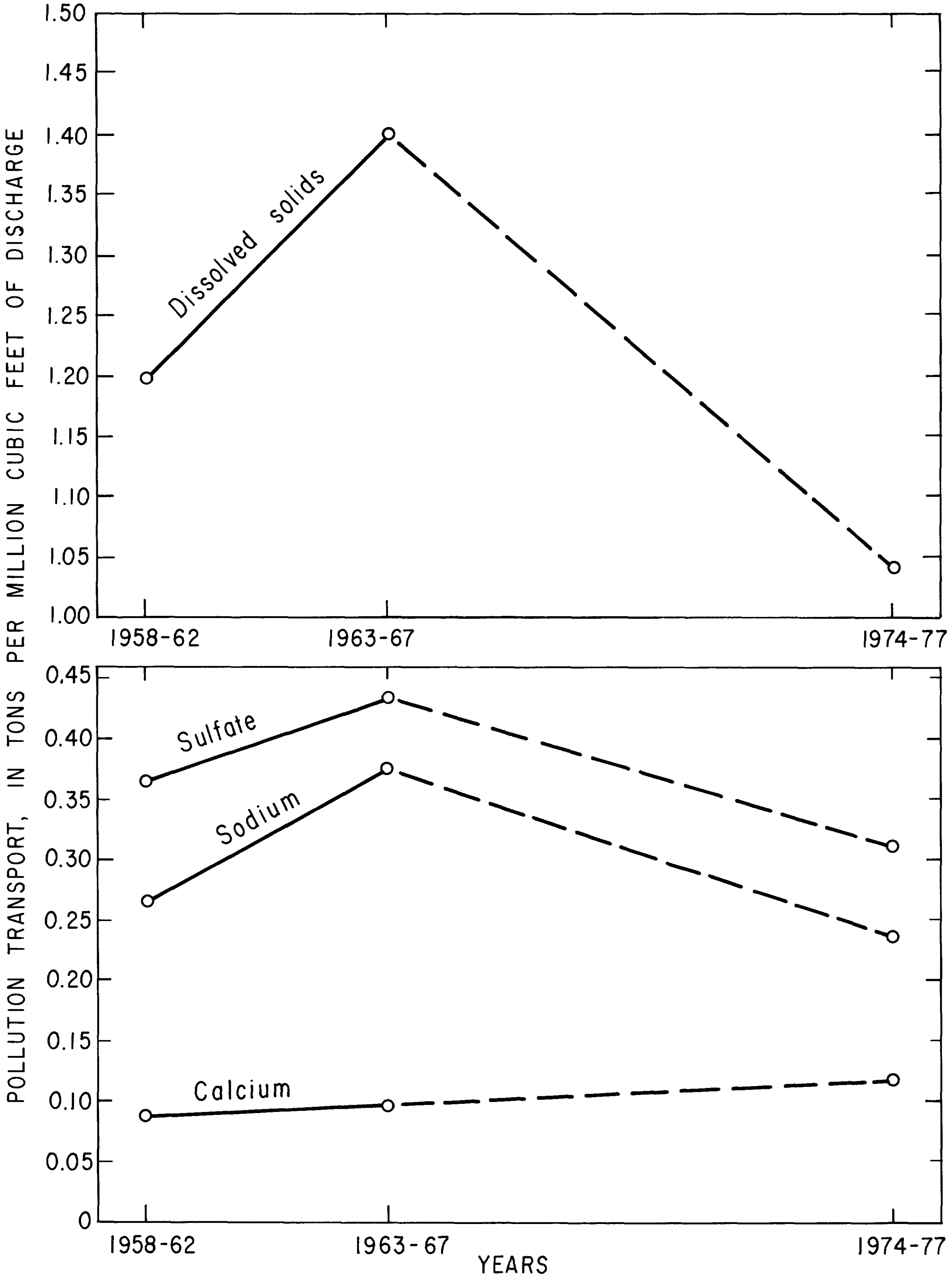

Figure 15. Inorganic pollution transport for selected consituents, French Broad River at Marshall, N.C.

Chapter D

Water Quality of the Neuse River, North Carolina—Variability, Pollution Loads, and Long-Term Trends

By DOUGLAS A. HARNED

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2185

WATER QUALITY OF
NORTH CAROLINA STREAMS

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Water Quality of the Neuse River, North Carolina – Variability, pollution loads, and long-term trends

By Douglas A. Harned

ABSTRACT

Interpretation of water-quality data collected by the U.S. Geological Survey for the Neuse River, North Carolina, has identified water-quality variations, charactrized the current condition of the river in reference to water-quality standards, estimated the degree of pollution caused by man, and evaluated long-term trends in concentrations of major dissolved constituents.

Two sampling stations, Neuse River near Clayton (02087500) and Neuse River at Kinston (02089500) have more than 12 years of water-quality data collected during the period from 1955 to 1978. The Clayton station provides information on the upper fourth of the basin (1,129 mi²) which includes several urbanized areas, including Raleigh, N.C., and part of Durham, N.C. The Kinston station provides information from the predominantly rural midsection of the basin (2,690 mi²). A network of temporary stations on small rural streams in the Neuse River and adjacent basins provide an estimate of baseline or essentially unpolluted water quality.

Overall, the water quality of the Neuse River is satisfactory for most uses. However, dissolved-oxygen, iron, and manganese concentrations, pH, and bacterial concentrations often reach undesirable levels. Concentrations of cadmium, and lead also periodically peak at or above criterion levels for domestic water supply sources. Nutrient levels are generally high enough to allow rich algal growth.

Sediment concentrations in the Neuse are high in comparison to pristine streams, however, the impacts of these high levels are difficult to quantify. Sediment and nutrient concentrations peak on the leading edge of flood discharges at Clayton. At Kinston, however, the discharge and sediment concentration peak almost simultaneously.

Changes in algal dominance, from genera usually associated with organically enriched waters to genera that are less tolerant to organic enrichment, indicate improvement in water qualiy of the Neuse since 1973. These changes, along with a reduction in total organic carbon concentrations, coincide with activation in 1976 of a new waste-water treatment plant for the Raleigh metropolitan area.

The amount of dissolved inorganic pollution in the Neuse was determined by subtacting estimated natural loads of dissolved constituents from measured total loads. Pollution makes up approximately 50 percent of the total dissolved material transported by the Neuse.

Two different data transformation methods allowed trends to be identified in constituent concentrations. Both methods recomputed concentrations as if they were determined at a constant discharge over the period of record. Although little change since 1956 can be seen in many constituents, increases of over 50 percent are shown for potassium and sulfate concentrations. These long-term rises indicate the increasing impact that man has had on the Neuse River, in spite of improved waste-water treatment in the basin. The increase in sulfate is probably largely due to increased long-term imputs of sulfur compounds from acid precipitation.

INTRODUCTION

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

The Geological Survey's study has three major goals:

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

Identification of the presence of dissolved and suspended materials in stream waters, and knowledge of how the amounts of these materials change with stream conditions is critical to any evaluation of stream contamination. It is also important to separate pollution, defined here as any substance that is present in the stream as a result of man's activities, from the natural water quality of the stream. Finally, the evaluation of long-term trends in water quality provides a historical perspective on the changing character of the stream.

Purpose and Scope

The purpose of this report is to present the results of analyses of water-quality data for the Neuse River collected near Clayton and at Kinston from 1956 to 1977. The results of this study are organized in a manner designed to allow comparison to results produced from studies, currently in progress, of eight other North Carolina basins. First, a basin description gives characteristics which have important relationships to water quality. These characteristics include population and land-use distributions, physical features of the basin such as topography and geology, industrial and municipal waste-disposal points, and on going programs of stream-channel modification for flood-control or navigation purposes. Second, a summary of water-quality analyses gives an overview of the condition of the river. Next, an accounting of pollution and baseline water quality reveals the effect man has had on the stream. Finally, water-quality changes throughout the total data-collection period allow an examination of past and projected trends in pollution of the Neuse River.

The methodology used in evaluating long-term trends receives special emphasis in this report. This is because this methodology is to be used in similar studies on other large rivers in North Carolina.

Data Collection

Data from two key locations on the Neuse, near Clayton and at Kinston (fig. 1), allow characterization of water-quality variation, pollution loads, and historical changes in quality in the river.

The station near Clayton (Neuse River near Clayton, 02087500) provides information about the Piedmont reach of the Neuse, an area where water quality is of particular concern because of expanding water-supply needs. Chemical data for the Neuse River were collected near Clayton during the 1944, and 1964–67 water years. Data collected from 1956 to 1958 at a station 9.9 miles downstream from Clayton (Neuse river near Selma, 02087530) has been merged with the Clayton data for the purpose of analysis in this report. Samples collected during these years were analyzed for major ions, dissolved solids, hardness, specific conductance and pH. An expanded program of water-quality data collection at the Clayton station began in 1973. Periodic measurements of organic substances, nutrients, toxic materials, suspended materials, metals, and biota are now also part of the ongoing study.

The sampling station at Kinston (02089500) provides water-quality data at a point within the Coastal Plain reaches of the Neuse River. This station is part of the National Stream Quality Accounting Network (NASQAN) of the U.S. Geological Survey. NASQAN is a program devised to monitor water quality in major river basins across the United States.

Chemical data were collected from the Kinston station during the 1950, 1955–56 and 1958–67 water years. The current program of monthly water-quality data collection at Kinston began in 1973. This station measures the output from a major portion of the Neuse River basin which is, in turn, the input to the downstream estuary system.

Two other sampling stations, Neuse River near Falls (02087183) and Neuse River at Goldsboro (02089000), were employed to fill gaps in daily specific conductance record of the Clayton and Kinston stations. The periods of data collection for the major stations employed in this study are shown in figure 2.

Nine stations located in undeveloped tributary basins give a measure of water quality under as near natural conditions as is possible for the basin. With a measure of baseline water-quality conditions, the effect of man can be defined. The methods employed to evaluate baseline water quality are discussed in detail in the pollution section. The locations of these baseline water-quality stations are shown in figure 1.

Recent Water-Quality Studies

Recent studies have reemphasized the importance of the Neuse River as a water-supply source (Putnam and Lindskov, 1973), and a recreational and ecological resource (North Carolina Department of Natural and Economic Resources, 1975a; Hobbie and Smith, 1975). The first complete Area-wide Waste Treatment Management Plan in the nation, the pilot of many such plans mandated by section 208 of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), encompasses much of the upstream area of the Neuse River basin (Triangle J Council of Governments, 1977). This plan instigated a number of detailed water-quality studies designed to evaluate problems of point-source pollution, such as the end-of-the-pipe effluents of industry and of municipal treatment plants, and nonpoint source pollution, such as rainwater washoff of pollutants from construction sites and urban areas. According to the triangle J Council of Governments (1976), the majority of tributary streams in the upper Neuse Basin are water-quality limited. That is, additional measures

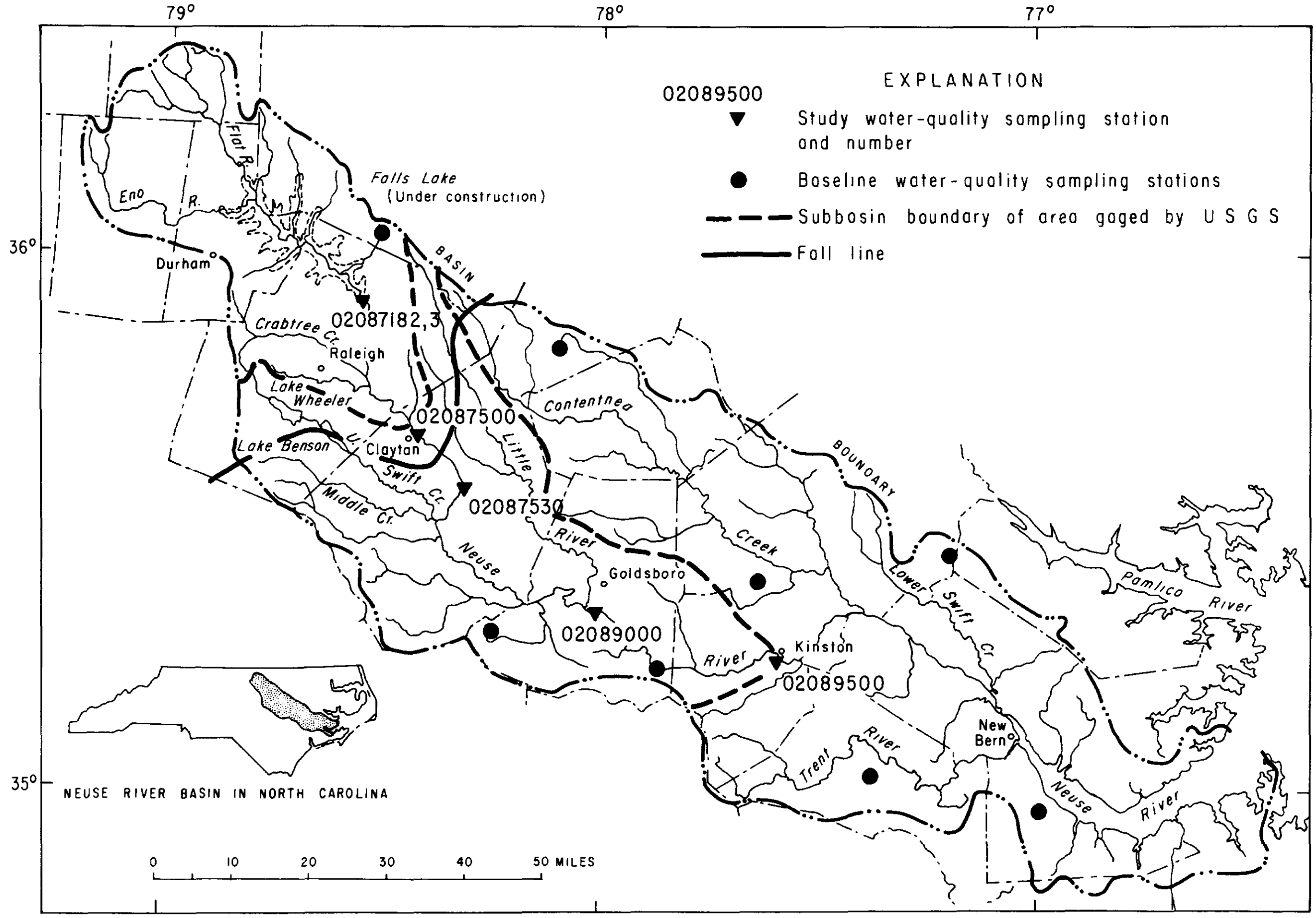

Figure 1. Locations of water-quality sampling stations used in the Neuse River basin study.

beyond secondary treatment of municipal sewage and best-practicable-technology treatment of industrial waste water will be required to return the streams to fishable and swimmable conditions.

A major flood-control and water-supply reservoir is under construction on the upper Neuse River west of Falls, N.C. The environmental impact statement for this project is an exhaustive catalogue of the environmental effects of the reservior (U.S. Army Corps of Engineers, 1973). Optimal use of the reservior for recreation and water supply hinges on acceptable water quality. Furthermore, this reservior will directly impact water-quality variation, pollution loads and trends in the Neuse River. Current water-quality and pollution loads and trends are particularly interesting in light of the changes that will result from the filling of this reservior.

An intensive one-year water-quality survey of the Neuse River was recently completed by the N.C. Department of Environmental Management and Community Development (Tedder and others, 1980). This study which was initiated in response to requests from citizens of New Bern, N.C. is a compilation and summary of 1979 water-quality data for the Neuse River for many chemical and biological water-quality measures. (Author's note: this report was published after completion of the U.S. Geological Survey study, and therefore is not used as a data source for the U.S.G.S. study).

ACKNOWLEDGMENTS

R. S. Taylor of the N.C. Department of Natural Resources and Community Development, provided valuable insight and information about the history of the operation of the Raleigh waste-water treatment plant. Charles C. Daniel III developed the discharge-normalization technique for this study. Joseph S. Riggsbee provided valuable assistance with computer programming.

J. R. Flowers, Jr., of Clayton, N.C., measured daily specific conductance and water temperature for 1974–75. B. R. Creech, of Selma, N.C., took daily conductance and temperature measurements for 1976–78.

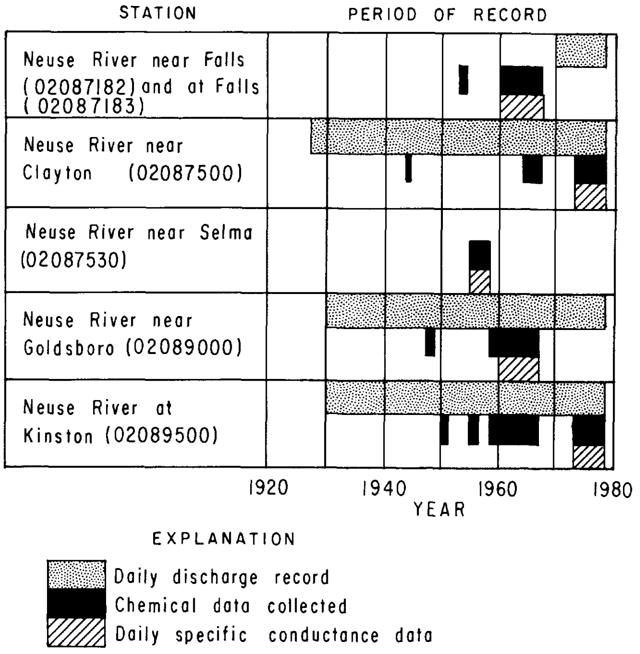

Figure 2. Period of record for water-quality sample collection, and discharge measurement at stations used in the Neuse River study.

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

Catherine E. Harrington and Karen Miles-English typed the manuscript. John Teel drafted the illustrations.

BASIN DESCRIPTION

The Neuse River drains 5,710 mi$_2$, about 12 percent of the total land area of North Carolina. The drainage basin lies within both the Piedmont and Coastal Plain provinces in the eastern part of the state (fig. 1). Beginning at the confluence of the Eno and Flat Rivers in Durham County, the Neuse flows southeast for 222 river miles, emptying finally into Pamlico Sound.

Important tributaries of the Neuse River include the Eno River (drainage area 253 mi^2), the Flat River (169 mi^2), Crabtree Creek (143 mi^2), Upper Swift Creek and Middle Creek (283 mi^2), Little River (323 mi^2), Contentnea Creek (849 mi^2), Lower Swift Creek (322 mi^2), and the Trent River (519 mi^2).

The streamflow-measuring and water-sampling station near Clayton (fig. 1) gages a basin area of 1,129 mi^2, which includes the Eno and Flat Rivers and Crabtree Creek. The Kinston station, downstream from Clayton (fig. 1) gages an area of 2,690 mi^2, including the drainage area of the Clayton station and the Little River.

Climate

The climate of the Neuse River basin is temperate, characterized by moderate winters and humid summers. Average monthly temperatures usually peak in July around 77°F (25°C) and drop to lows near 43°F (6°C) in January (U.S. Army Corps of Engineers, 1964). The mean annual air temperature in the basin is 59°F (15°C).

Precipitation is greatest near the coast, decreasing in the inland direction. At New Bern, near the mouth of the Neuse River, annual precipitation averages 56 inches within a range of 41 to 70 inches (U.S. Army Corps of Engineers, 1964). Near the headwaters of the basin, annual precipitation recorded at the Raleigh-Durham Airport station averages 44 inches with a range of 35 to 52 inches. Rainfall is usually greatest during the summer months of June, July, and August, and may be especially intense during thunderstorms and hurricanes. Annual snowfall at the New Bern and Raleigh-Durham Airport weather stations averages 4 inches and 7 inches, respectively.

Topography

The Neuse River basin lies within two physiographic provinces. The basin west of Clayton is in the Piedmont province. The eastern half of the basin lies within the Coastal Plain. The Fall Line (fig.1) is the border between these two areas.

Deeply eroded valleys and rolling hills characterize the Piedmont where altitudes range from about 770 feet along the drainage divide where it passes through central Orange and Person Counties to about 160 feet along the flood plain of the Neuse near Clayton. Local relief in the Piedmont part of the basin is on the order of 150 feet. The stream channel slope of the Flat and Eno Rivers is approximately 15 feet per mile. The channel slope of the Neuse River from the confluence of the Flat and Eno Rivers to Clayton is approximately 2 feet per mile.

Southeast of Clayton, the Piedmont topography changes gradually to the flatlands of the Coastal Plain. The river slope in this eastern region is around 1 foot per mile. Swampy areas are common, flood plains are broad, and streams are sluggish in this area.

Geology

Billingsley, Fish, and Schipf, (1957), and Simmons and Heath (1979) summarize the relation between geology and water-quality for the Neuse River basin.

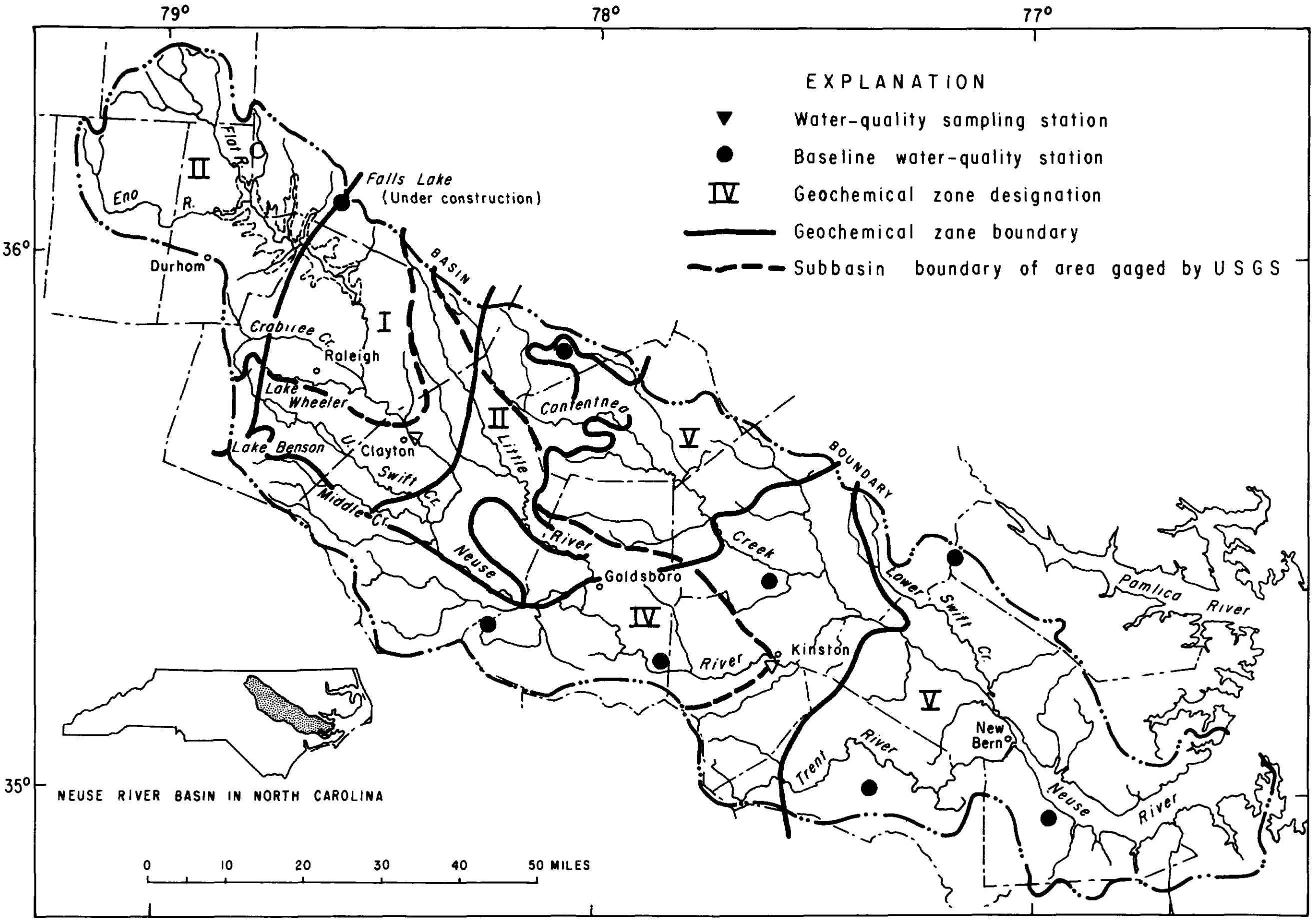

Figure 3. Geochemical zones of the Neuse River basin (Simmons and Heath, 1979).

Simmons' geochemical zones for the Neuse River basin, which are based on surficial geology and a grouping of similar water-quality analyses from samples collected at natural water-quality network sites (fig. 1), are shown in figure 3. The four geochemical zones in figure 3 closely correspond to ground-water provinces defined for the Neuse basin by Billingsley, Fish, and Schipf, (1957).

Rocks of geochemical zones I and II are generally crystalline. Granite is the rock type predominate in geochemical zone I (fig. 3). Zone II rocks are mainly massive slates and compact shales in the western part of the basin and massive slates and schists in the midsection of the basin. The surface water of zone II, particularly in the shale areas, is more mineralized than that observed for zone I. Water is generally soft in both zones, but may be locally hard and alkaline in some shale areas of zone II.

Rocks of geochemical zone IV are sedimentary in origin and composed predominately of sand, clay and marl. Much of the land surface is underlain by a layer sand, causing surface water in this region to be relatively low in dissolved solids compared to the other zones.

Limestone and shell beds with surface sands and clay characterize zone V. The soluble limestones and shells increase the mineralization of water in this region. Surface and ground water in this zone is generally hard.

Streamflow

At Clayton the average daily discharge for 49 years of record is 1,181 ft^3/s with a range from 22,900 to 44 ft^3/s. This average discharge is approximately 1.0 $(ft^3/s)/mi^2$ of drainage area. At Kinston the average discharge for 46 years of record is 2,889 ft^3/s, with a range of 26,000 to 124 ft^3/s. This average discharge is approximately 1.1 $(ft^3/s)/mi^2$ of drainage area.

Although the greatest amount of precipitation usually comes during summer, the lowest streamflow also occur during this period. Summer temperatures and plant growth increase evaporation and transpiration (use of water by plants) to a point where much of the summer rainfall never reaches the streams.

Kinston lies just above the region of the Neuse River basin where tides influence streamflows. Tidal influences, which complicate data analysis, were avoided by location of the station at Kinston.

Population

The 1970 population of the parts of the 17 counties that lie within the Neuse basin was 709,900 or 14 percent of the total population of North Carolina. (North Carolina Department Water and Air Resources, 1972). This represents an increase of 10 percent over the 1960 population (636,000). The largest cities bordering on or lying within the basin are: Raleigh (projected 1979 population 121,577), Durham (95,438), Goldsboro (26,810), Kinston (23,309), and New Bern (14,660) (U.S. Department of Commerce, 1971). In addition, there are 57 towns and villages in the basin with populations between 1,000 and 8,000.

The distribution of 1970 population by major subbasins is shown in figure 4. Approximately 40 percent of the Neuse River basin population (284,000 people in 1970) reside upstream from Clayton. Almost 70 percent (497,000 people in 1970) of the total basin population reside upstream from Kinston. The area upstream from Clayton, which includes Raleigh and Durham, has the fastest growing population in the basin, showing an increase of approximately 70 percent from 1960 to 1970. The basin area between Clayton and Kinston, however, showed practically no increase in population during the 1960-70 period.

Water Use And Waste Disposal

All points of major minicipal and industrial wastewater discharge in the Neuse basin are catalogued by the North Carolina Department of Natural and Economic Resources (1975b). According to their figures, one hundred sixty sources discharge approximately 170 ft^3/s of waste-water within the basin. This compares to the natural 7-day, 10-year minimum low flow at Kinston of 210 ft^3/s. Sixteen of these sources account for nearly 150 ft^3/s or 88 percent of wastewater discharge (table 1). The locations of these 16 major effluent sources and the percentages of total effluent discharge by sub basin are shown in figure 5. A comparison of population distribution by sub basin (fig. 4) and sub-basin waste-water discharge (fig. 5) reveals a general correspondence of wastewater discharges to population. However, one discrepancy appears; the Weyerhaeuser plant in Craven County uses particularly large amounts of water relative to the county population. In the Neuse River basin upstream from Kinston, waste-water discharge is dominated by municipal waste-water treatment plant effluent which is largely a function of population.

Upstream of Clayton, 45 ft^3/s or 83 percent of the total waste-water discharged into the Neuse and its tributaries originates from 26 municipal waste-water treatment facilities. Two of these plants, the Durham Northside plant and the Raleigh Neuse River plant, discharge approximately 35 ft^3/s or 77 percent of the total point-source waste water discharged into the Neuse above Clayton.

In the segment of the basin between Clayton and Kinston, 14 ft^3/s or 95 percent of the total 15 ft^3/s of waste water discharged into the Neuse and its tributaries originates from 10 municipal waste-water treatment facilities. The Goldsboro waste-water treatment plant alone discharges 9 ft^3/s or 59 percent of the total effluent discharged into the Neuse in the basin area between Clayton and Kinston. Industrial and private sources account for the remaining waste-water discharge.

Recent water-pollution legislation has induced most of the major municipalities within the Neuse River basin to upgrade their waste-treatment facilities. Raleigh's Neuse River waste-water treatment plant serves as an example of this trend. This plant employs an advanced three-stage treatment process designed to remove 98 percent of organic materials and suspended solids in the waste when operated properly. Upgraded waste treatment, if matched to the needs of the growing population in an ongoing process, should maintain or improve water quality of the Neuse River for many major pollutants. However, current waste-water treatment practice does not remove all materials of concern, including nutrients and many dissolved materials. Thus, coinciding with increases of population, increases of these pollutants probably will appear in streams.

Hydrologic Modifications

Approximately 48 man-made lakes and ponds (excluding small farm ponds) are scattered throughout the Neuse watershed. Five of these impoundments make up 57 percent of the 4,657 total acres of water surface are (Fish, 1968). Of these five large lakes, three are water-supply reservoirs, and two are power-plant cooling ponds. Lake Wheeler (500 acres) and Lake Benson (440 acres), both impoundments on Swift Creek, are water-supply reservoirs for Raleigh. Lake Michie (507 acres) on the Flat River, is the reservoir for Durham. Quaker Neck Lake (600 acres) and Lee Lake (600 acres), both in Wayne County, serve as cooling ponds for Carolina Power and Light Company.

Of 13 reservoir projects proposed by the U.S. Army Corps of Engineers (1964) only the Falls Lake project has been funded. The Falls Lake dam will be located near the village of Falls and the main body of the reser-

Table 1. Major municipal and industrial wastewater discharges of the Neuse River basin (from North Carolina Department of Natural and Economic Resources, 1975b)

Map location (fig. 5)	Facility	Effluent discharge (ft^3/s)
1	Northside Waste-water Treatment Plant (Durham)	13
2	Liggett and Myers (Durham County)	1.55
3	Burlington Industries (Durham County)	1.55
4	Neuse River Treatment Plant (Raleigh)	29.3
5	Smithfield Municipal Treatment Plant	1.7
6	Burlington Industries (Wake County plant)	3.7
7	Goldsboro Municipal Treatment Plant	8.5
8	Kinston Municipal Treatment Plant	7.8
9	E. I. Dupont (Kinston)	5.9
10	Carolina Power and Light (Wayne County)	2.5
11	Nello Teer Quarry (Princeton)	2.3
12	Wilson Municipal Plant No. 1	3.9
13	Wilson Municipal Plant No. 2	4.5
14	Farmville Municipal Plant	2.2
15	Weyerhaeuser (Craven County)	54.3
16	New Bern Municipal Plant	5

voir will be in Durham County and northern Wake County. The lake will be 22 miles long, extending upstream from the dam at Falls into the Flat and Eno Rivers. When completed, the 13,000 acre reservoir will increase the total water surface area of lakes and reservoirs in the Neuse basin by a factor of three. This impoundment will have a profound environmental impact on the Neuse River from the head of the lake to Pamlico Sound. The impoundment will trap sediment, while an increase in carrying capacity will result in channel scouring down stream from the damsite. A change in downstream sediment particle size may result from this altered sedimentation-scouring scenario. Some downstream bank erosion and draining of swampy areas within the flood plain may occur. Changes in water quality will result from the altered stream regimen. Pollutant constituents associated with sediment will be affected, and dissolved oxygen levels will reflect new reaeration and biological relationships in and downstream from the lake.

Since 1896 the U.S. Army Corps of Engineers has modified 310 miles, or 21 percent of the approximate 1,500 miles of river channel in the Neuse basin (U.S. Army Corps of Engineers, 1977). These channel modifications include: cleaning, snagging, deepening and straightening of channels, excavation of new channels and other construction. Currently, 1979, flood-protection schemes are proposed for an additional 75 river miles.

The U.S. Soil Conservation Service has also played a major role in alteration of tributaries of the Neuse. Four major stream channelization projects have been completed, and four other channel modification projects have been approved or are underway (North Carolina Department of Natural and Economic Resources, 1976).

Channelization, and other stream modifications, directly impact a wide range of environmental variables. Stream realignment, or clearing and snagging activities cause temporary increases in suspended sediment concentrations and turbidity. Channelization is generally undertaken to alter the flow regime to facilitate rapid land drainage. Hydrogeologic effects of channelization include reduced surface ponding, increased water velocities, and rapid peaking of discharge during floods. Sediment carrying capacity increases with increased flow velocity. Problems of erosion and increased sediment concentrations are often encountered in both urban and rural areas where extensive channel modification is employed to improve drainage efficiency. Both temporary and longterm effects of stream modification are reflected by changes in stream-centered animal and plant populations.

WATER-QUALITY VARIATION

The quality of water in the Neuse River is satisfactory for most uses. However, several water-quality parameters indicate problems, and certain constituents occur at undersirable levels.

Measurements at Clayton and Kinston of specific conductance, temperature and turbidity show no out-

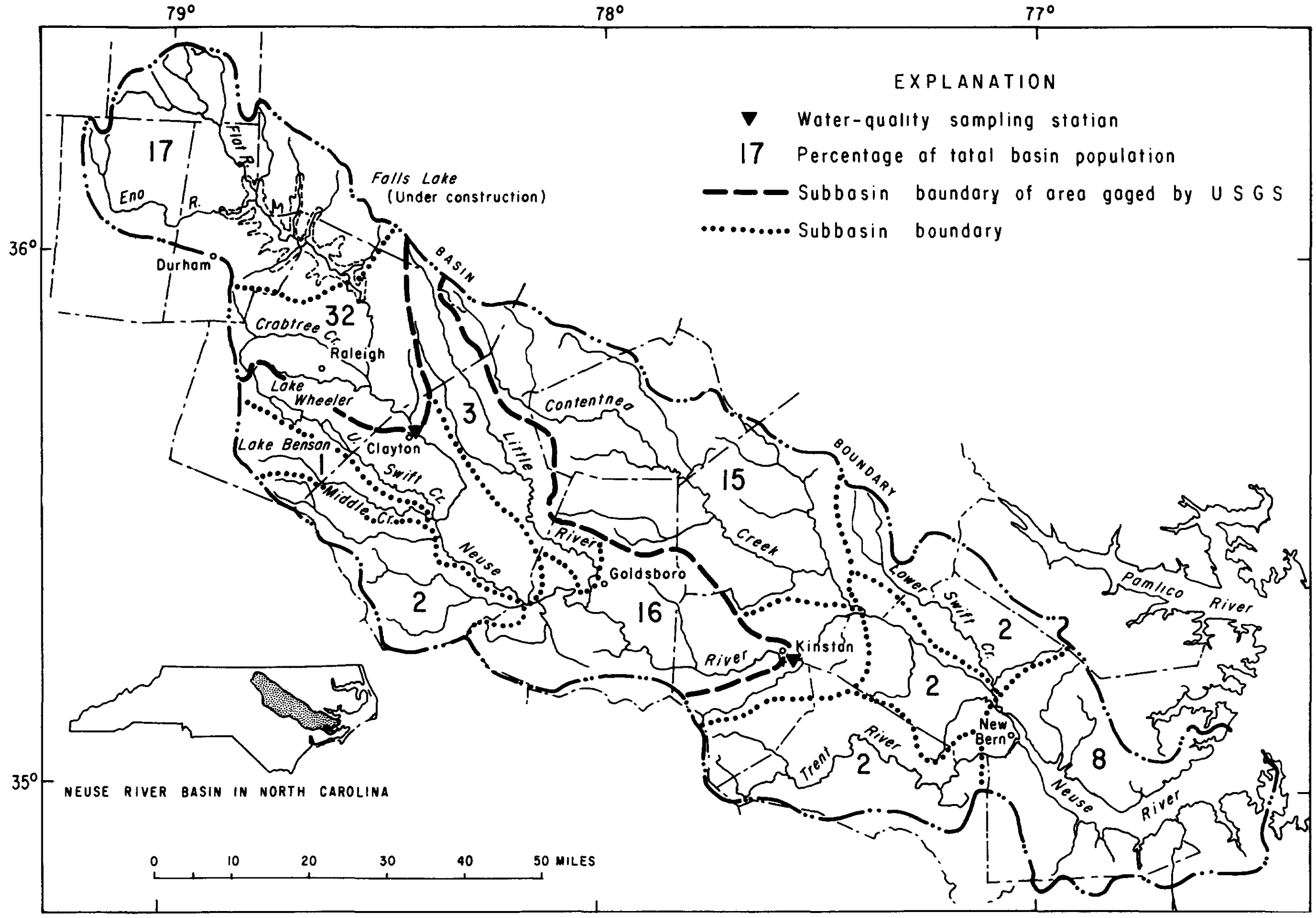

Figure 4. Percentage of total Neuse River basin population (1970), by subbasins.

standing extreme values. However, pH and dissolved oxygen levels are often lower than the optimal ranges suggested by the U.S. Environmental Protection Agency (EPA, 1976) for protection of freshwater aquatic life.

Suspended-sediment concentrations at Clayton show a response to flood flows characterized by a rapid peaking at the beginning of a flood, followed by a recession. This response is characteristic of discharge-sediment and discharge-pollutant relationships often observed for streams in urbanized areas. At Kinston, suspended-sediment concentration is more independent of discharge than at Clayton. This is principally due to increased basin size and lower relief that results in dilution and lower flow velocity.

The predominate cations in Neuse River water are potassium and sodium, and the dominant anion is bicarbonate. The major ionic constituents occur at concentrations that are satisfactory for most uses of the water.

Trace metals generally occur in low concentrations at both stations. Only iron and manganese concentrations are consistently above levels suggested for domestic water supply. Cadmium, and lead concentrations periodically rise above EPA (1976) criteria levels.

Nutrient levels are usually higher than the lower limits required for algal growth. Recently (July 1979), large algal blooms have appeared in the segment of the Neuse River downstream from the construction site of the Falls reservoir, and upstream from Clayton (S. Howe, U.S. Geological Survey, personal commun., July 15, 1979). Eutrophication has been recently identified as a problem in the downstream segment of the Neuse near New Bern (Tedder and others, 1980). Currently, eutrophication is not a major concern in the segment of the Neuse upstream from Kinston, however, future problems may arise in the Falls reservoir.

High ammonia and total organic carbon concentrations at Clayton are indicative of stream pollution. High total organic carbon concentrations also occur at Kinston, indicating organic carbon enrichment of the stream.

The biological data available for Clayton and Kinston characterize the Neuse River as eutrophic and organically enriched with some degree of fecal contamination. Fecal coliform and fecal streptocci bacteria occur at levels exceeding the recommended criteria (EPA, 1976) for bathing waters. Coliform levels at

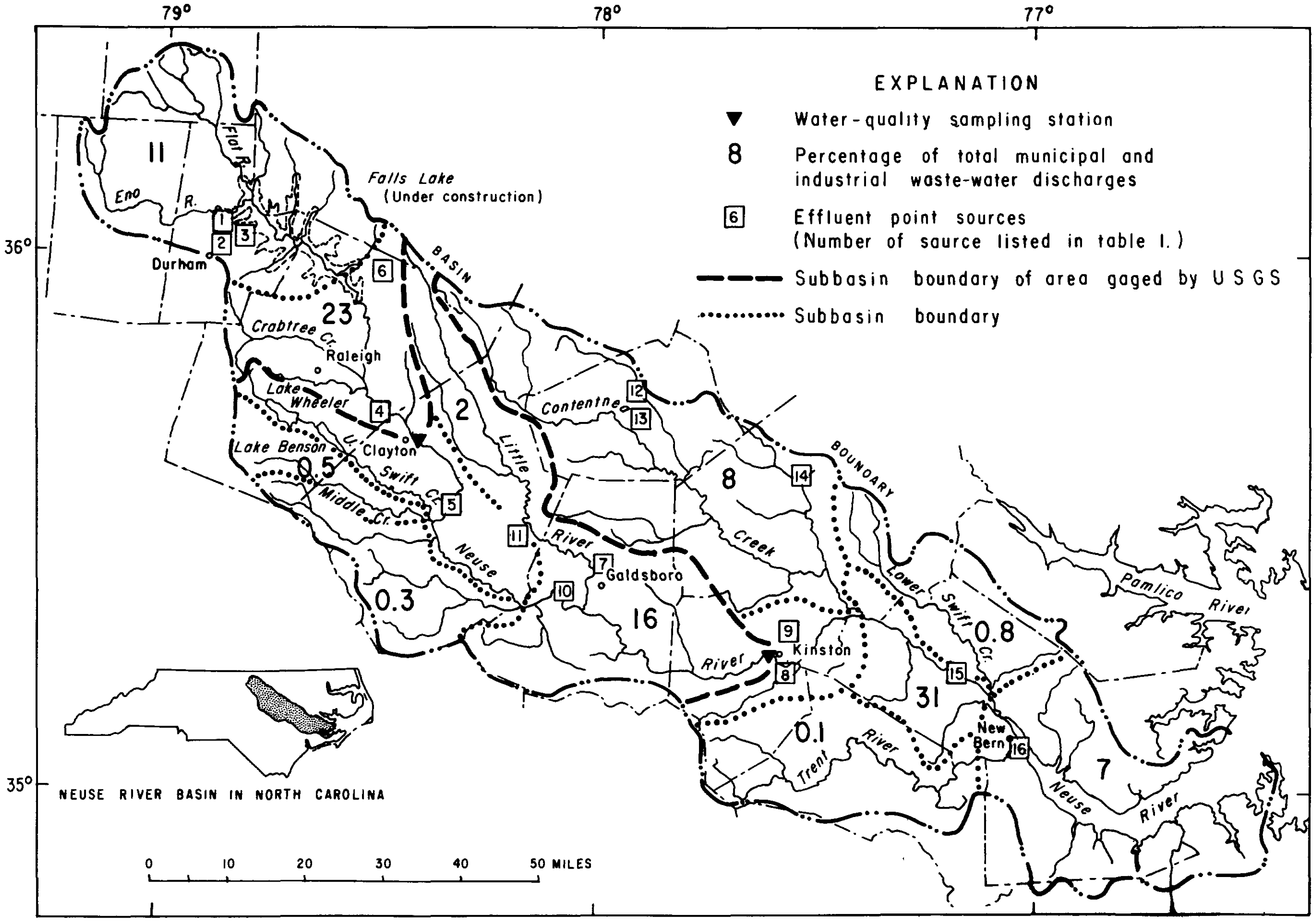

Figure 5. Percentage of total municipal and industrial waste-water discharges for the Neuse River basin, by subbasins.

Kinston are especially high. Interestingly, five-day biological oxygen demand tests indicate that levels of organic contamination are frequently higher at Clayton than at Kinston.

Changes in dominance of algal genera in the Neuse in 1976 correspond to the opening of the Neuse River Waste-water Treatment Plant, a new facility designed to serve the Raleigh metropolitan area. These observations suggest improvement in the water quality of the Neuse River following the activation of this treatment plant.

Physical Characterisitics

Dissolved oxygen and water temperature

Oxygen, while plentiful in the atmosphere, is often in limited supply in water. During summer months, high temperatures reduce the solubility of oxygen in water. Subsequently, evaluation of dissolved-oxygen levels in streams is important for the critical high-temperature months.

Water temperatures follow ambient air temperatures, but are buffered from extreme values of air temperature by the slower heating and cooling rate of the water. This is demonstrated by the plot of 1976 water and air temperatures shown in figure 6. Water temperature statistics are given in table 2.

The saturation of dissolved oxygen varies inversely with temperature. For a summer-month water temperature range of 18°–27°C the predicted saturation of dissolved oxygen will be 9.5 to 8.0 mg/L. However, at Clayton the 1974–76 daytime mean dissolved-oxygen level for this range of temperatures was 4.8 mg/L. At high daytime water temperatures, observed levels are substantially lower than saturation levels (fig. 7). This difference is in part accounted for by the presence of oxygen-demanding materials, often predominated by organic pollution, in the stream. (See Biological Characteristics).

A value of 5.0 mg/L of dissolved oxygen is commonly promulgated as a target criterion level necessary to maintain a varied fish population, while 4.0 mg/L is cited as the minimum concentration necessary to permit persistence of sizable tolerant species populations. However, dissolved-oxygen levels below 5.0 mg/L will

Table 2. Summary statistics of physical characteristics, Neuse River near Clayton and at Kinston

	CLAYTON			KINSTON			
	Mean 95 percent confidence limits	Range	Number of samples	Mean 95 percent confidence limits	Range	Number of samples	Criteria (EPA, 1976)
Discharge (ft^3/s)	1181 -	44-22,900	Continuous monitor 51 years	2889 -	124-26,000	Continuous monitor 48 years	-
Temperature (°C)	17 16–18	1–28	114	19 18–20	5–29	104	-
Dissolved Oxygen (mg/L)	6.6 6.1–7.0	1.4–12.0	113	8.1 7.8–8.4	5.1–13.0	100	Freshwater aquatic life: 5 mg/L minimum
pH (pH units)	6.3[1] -	5.5–7.5	115	6.3[1] -	5.5–8.1	73	Domestic water supply: 5–9 Freshwater aquatic life: 6.5–9
Suspended Sediment (mg/L)	179 86–272	3–1330	45	29 26–32	12–78	55	-
Turbidity (JTU)	20 -	4–46	24	12 -	1–30	38	-

[1] Calculated from mean hydrogen-ion concentration.

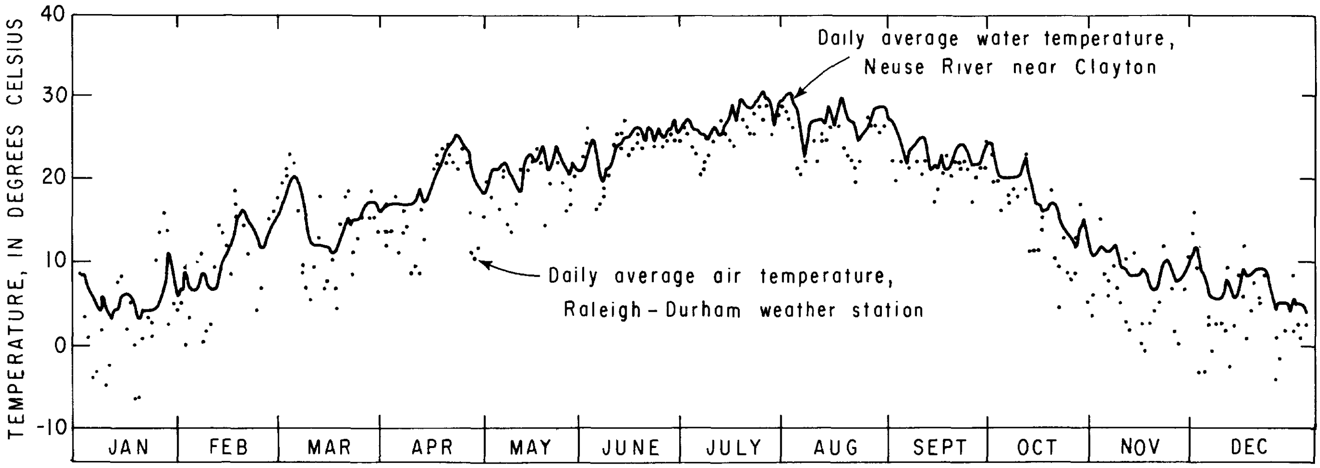

Figure 6. Air and water temperatures, 1976.

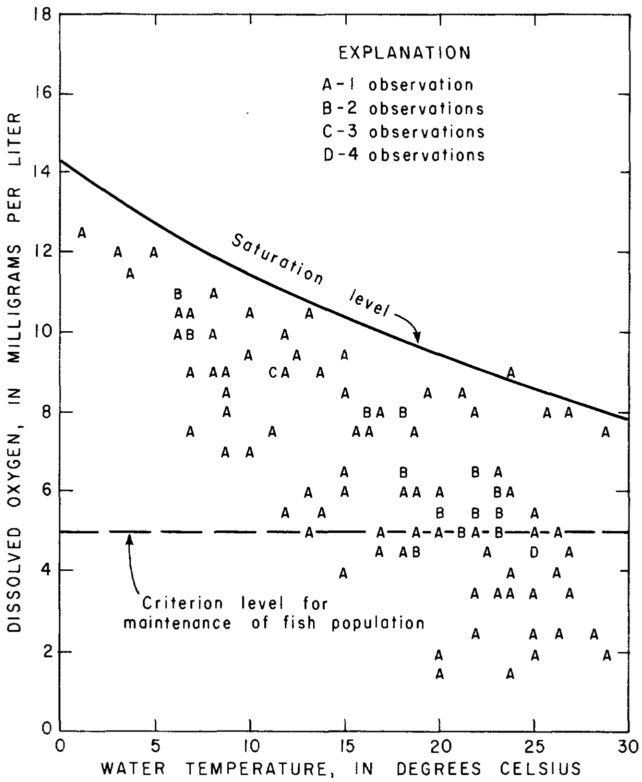

Figure 7. Dissolved-oxygen concentrations versus water temperatures for the Neuse River near Clayton, 1974–77 water years.

not necessarily cause fishkills, especially if the depleted oxygen levels occur only for brief periods.

The observed summer daytime dissolved-oxygen levels at Clayton hover very closely to the minimum criterion level, and periodically decrease to lower values (fig. 7). During the period of high summer temperatures, dissolved-oxygen concentrations are less than 5.0 mg/L in approximately 60 percent of the samples, occasionally decreasing to as low as 2 mg/L. These low dissolved-oxygen values are the net result of a combination of factors including high summer temperature, low rates of reaeration due to low discharge, and waste-water effluent. Dissolved-oxygen statistics for Clayton are given in table 2.

In contrast to the low concentrations observed at Clayton, daytime dissolved-oxygen levels at Kinston are generally high (table 2). Dissolved-oxygen levels at or above satuartion are common at the Kinston site (fig. 8). These observed high dissolved-oxygen values probably are due to presence of extensive algae growths during summer months. (See Biological Characteristics). However, oxygen from algae photosynthesis is only produced during daylight hours. At nightfall in water containing large concentrations of algae, high dissolved-oxygen levels fall continuously as photosynthesis ceases and plant and animal respiration uses the available oxygen (Hines and others, 1977). Although there is no data available for nighttime summer dissolved-oxygen levels, it is very likely, in light of the summer algae concentrations, that respiration oxygen demands at both Clayton and Kinston depress the daytime dissolved-oxygen buildup.

The oxygen level in a stream can be deduced from the fish population found in the stream. Not surprisingly, fish found in the main channel of the Neuse River (Fish, 1968) are predominantly species with tolerance for low dissolved-oxygen concentrations: sunfish (approximately 35 percent of fish caught), catfish (33 percent), and carp or shad (11 percent each depending on location). These fish counts were evaluated by creel census,and therefore may not reflect the true composition of the fish community.

Future improvement in dissolved-oxygen concentrations may be a result of the current trend to upgrade waste-water treatment plants. Improved waste-water treatment will reduce the amount of oxygen-

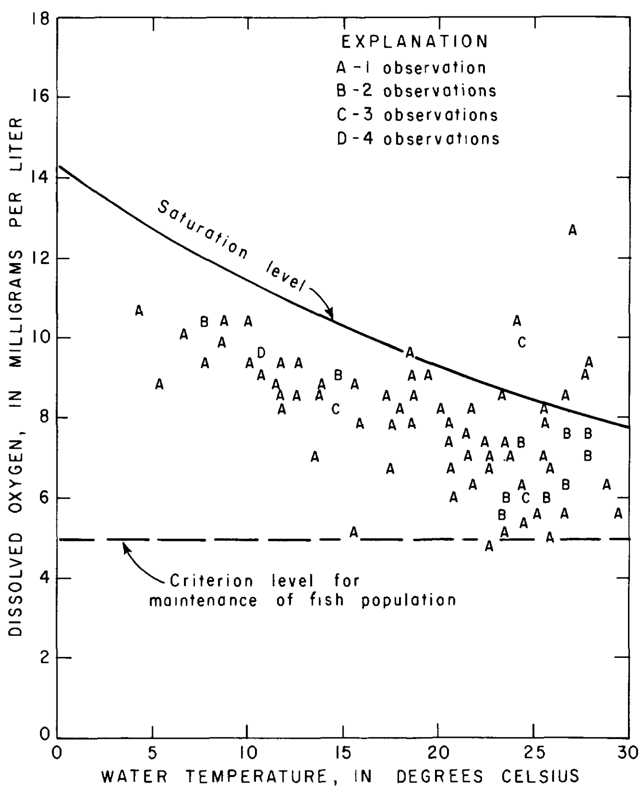

Figure 8. Dissolved-oxygen concentrations versus water temperatures for the Neuse River at Kinston, 1974–77 water years.

demanding organic material introduced into the river, in turn lowering the recurrance of periods of low dissolved-oxygen concentrations. However, increases in population may offset the progress accomplished through effective waste-water treatment by causing increases in volume of treated waste water that is introduced into the stream systems. In particular, areas immediately downstream from treatment plant discharge points will continue to be highly impacted by depressed dissolved-oxygen concentrations.

pH

The distribution of pH values observed for Clayton is similar to the Kinston distribution. The mean-hydrogen ion concentration for Clayton is not statistically different from the mean concentration for Kinston, both of which give a pH of 6.3. The pH data for both stations ranges between 5.5 and 9.4; however, the majority of values fall within a range of 5.7–7.5. The U.S. Environmental Protection Agency (1976) recommends a pH range of 6.5–9.0 for protection of freshwater aquatic life. Neuse River pH values were below this range in approximately 50 percent of the samples. These low values indicate a slight acidity which is not likely to directly harm freshwater aquatic life, but may act synergistically with other materials, causing detrimental effects. The toxicity of lead to fish, for example, changes with pH.

Suspended sediment

Sediment is the solid material of stream discharge. Sediment consists of any erodable material that is not in solution in the stream. This material includes soils, leaf litter and similar organic debris, sewage or industrial sludge, and particulate fallout from material suspended in the atmosphere. Nutrients, metals such as lead, and organic materials, including many pesticides, are readily sorbed by sediment particles.

Sediment is extremely important in the ecology of streams. Sediment provides animal habitats and nutrients to many organisms. Rapid changes in suspended-sediment concentrations may choke fish or filter-feeding organisms. Suspended sediment also reduces light available to water-plants or algae.

Sediment is often a problem for man. Reservoirs, locks, and navigation channels can be clogged with sediment. Sediment may also be a problem in fisheries, and industrial or domestic water use. Finally, high suspended-sediment levels reduce aesthetic values of rivers and lakes.

At Clayton, unusually high sediment concentrations generally are associated with storms. Suspended-sediment statistics are given in table 2. Suspended-sediment concentrations for a storm monitored at Clayton are shown in figure 9. In general, the change in suspended-sediment concentration with floodflows near Clayton is characterized by a rapid peaking of concentration with the beginning of a flood, followed by a recession. This flushing effect, in which sediment concentration on the rising phase of the streamflow hydrograph is greater than on the falling phase, is in part due to the decrease of the erosive action of streamflow during the recession. However, the availability of erodible material also plays an important role. A small storm may be sufficient to cleanse the stream of material immediately available for erosion. If another storm occurs soon after the first, suspended-sediment concentrations will be correspondingly lower. This may in fact be the relationship displayed in the double-peaked hydrograph of figure 9.

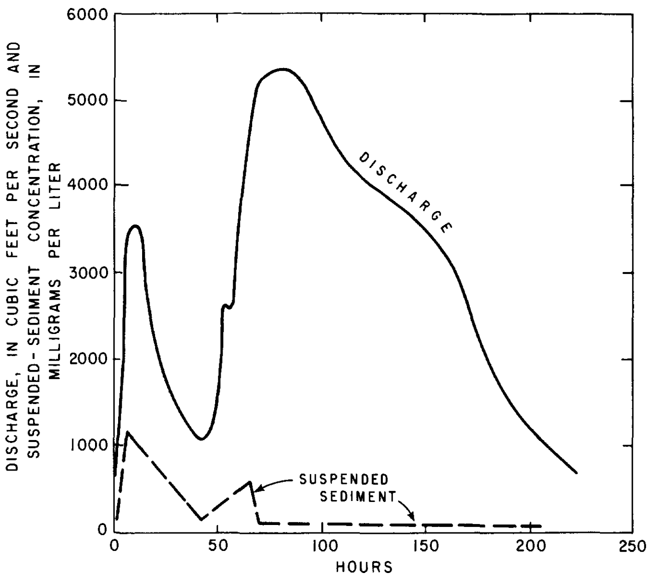

Figure 9. Hydrograph showing relationship of discharge and suspended-sediment concentration for the storm of August 4, 1974, near Clayton.

The recession in suspended-sediment concentration is exponential as illustrated by the curves shown in figure 9. Similar exponential declines during floods often characterize the concentrations of other materials associated with sediment. Stormwater runoff from urban areas is often heavily laden with sediment. This nonpoint-source pollution is a growing problem in most urban areas (American Public Works Association, 1969).

Plots of suspended sediment concentration against discharge give the relation shown in figure 10 (Clayton) and figure 11 (Kinston). The correlation coefficient for the Clayton relation is high (r=0.86) and the F value indicates a significant (at the 95 percent probability level) relation of suspended-sediment concentration to discharge. However, the low correlation of the Kinston relation (r=0.37) and the nearly constant suspended-sediment concentrations observed there, suggest a relative independence of sediment concentration from

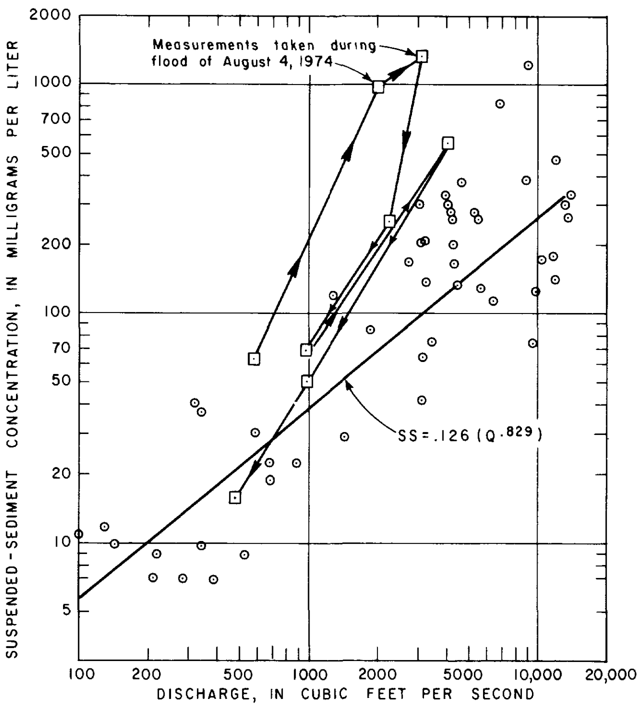

Figure 10. Stream discharge (Q) versus suspended-sediment concentration (SS) for 1973–76, Neuse River near Clayton.

discharge. A hysteresis effect in figure 10, caused by the suspended-sediment-concentration recession, is apparent for the plotted points of the flood of August 1974 (see fig. 9).

At Kinston, the apparent independence from discharge of suspended-sediment concentrations is principally a result of the basin size and relief. The areal rainfall distribution over a large watershed is usually nonuniform. Consequently, although a heavy rainstorm at Clayton may have a considerable impact on water quality, the effect will be dampened by the time the flood crest reaches Kinston. Water flowing past the Kinston station which came from a rainstorm above Clayton has been mixed with surface water from other tributaries. The lower stream bed slope at Kinston also plays an important role in the difference in suspended-sediment concentrations observed at the two stations. A lower slope reduces the river flow velocity, which in turn reduces the stream's sediment carrying capacity.

Turbidity values are also lower at Kinston than at Clayton, corresponding primarily to the lower suspended-sediment concentrations at Kinston. This difference between two stations in capacity to transmit light through water may be an important reason for the larger algal cell concentrations found at Kinston than at Clayton. (See Biological Characteristics). Turbidity statistics for both stations are given in table 2.

Although environmental impacts of high suspended-sediment concentrations are numerous, no national standards have been promulgated. However, some guidelines for turbidity are available (EPA, 1976). Turbidity levels at both stations are at satisfactory levels for use of the water in domestic supplies with standard treatment. Less demanding industrial uses, such as paper pulp processing, could use Neuse River water from either location without treatment.

The aesthetic problems of sediment are rarely addressed in water-quality standards or guidelines. The crystal-clear waters reported by early explorers of North Carolina (North Carolina Department of Natural Resources and Community Development, 1979), are now, for the most part, murky with suspended sediment.

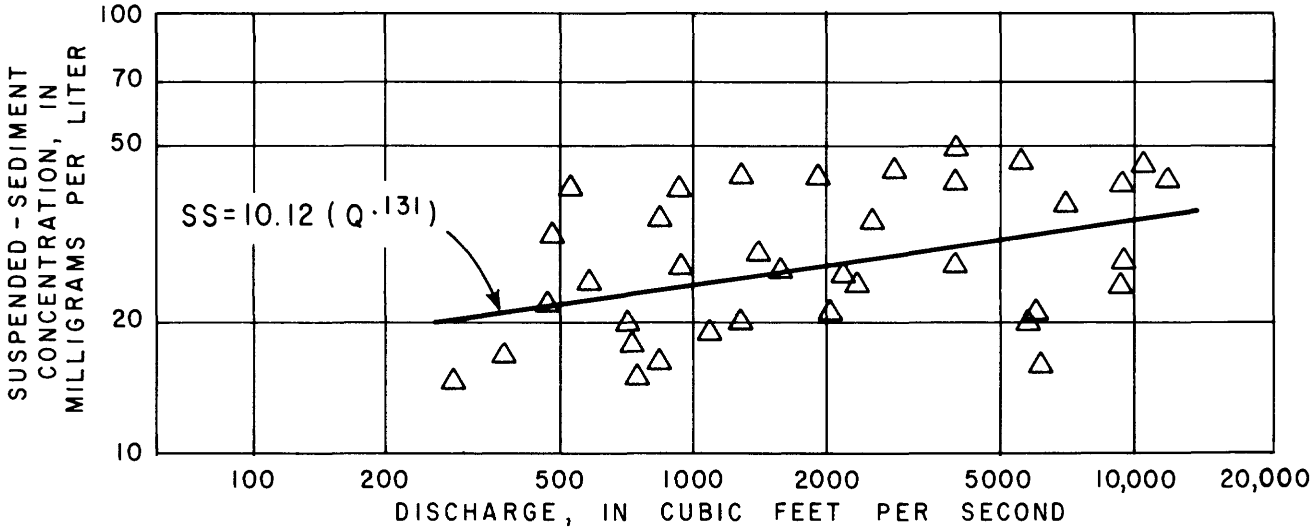

Figure 11. Stream discharge (Q) versus suspended-sediment concentration (SS) for 1973–76, Neuse River at Kinston.

The full aesthetic impact of sediment on the Neuse River is undefinable.

Major Dissolved Substances

Mean values for all major dissolved substances characterize the Neuse River water at both Clayton and Kinston as chemically average or lower than average for natural surface waters of the United States (Todd, 1970). A summary of mean values for major dissolved materials and related statistics for the samples collected at both Neuse stations during the 1974–77 water years is given in table 3.

In instances where criteria values for recommended maximum constituent concentrations for domestic use have been defined (EPA, 1976), Neuse River water at both stations meets the most stringent recommendations (table 3).

Cation-anion diagrams (Stiff, 1951) give a graphic representation of the ionic composition of water samples. Composite diagrams, each representing the mean of all samples taken in the 1974–77 water years, for both Neuse stations are shown in figure 12. The cation-anion diagrams for the two stations are quite similar. At both stations, sodium and potassium are the dominant cations, and bicarbonate is the dominant anion. The only sizable difference in ionic composition between the stations appears to be a higher overall concentration of sodium and potassium at Clayton.

Specific conductance, a measure of the ability of water to carry an electric current, gives an approximate expression of the amount of ionic material dissolved in water. Dissolved material concentrations are diluted by floodflows, so specific conductance usually varies inversely with discharge.

Specific conductance statistics given in table 3, show Kinston to have lower values than Clayton, indicating an overall water-quality improvement in dissolved consitutents downstream from the urbanized upper basin. A comparison of the frequency distributions of specific conductance values for the two stations (fig. 13) illustrates this difference in water quality. Daily specific conductance values at Clayton are greater than the maximum value recorded at Kinston 25 percent of the time. The lower conductance values observed at Kinston are primarily a result of dilution by streamflow from rural areas of the wastes originating from the urban areas upstream from Clayton.

Conductivity is also correlatable with several specific ion concentrations. Correlations between specific conductance and dissolved constituent concentrations are high, usually with coefficients (r) above 0.80. The regression lines for these relations, shown in figure 14 for Clayton and figure 15 for Kinston, can be used to predict concentrations of certain dissolved constituents if specific conductance is known. (See POLLUTION). Interestingly, the slopes of the regression lines drawn for Clayton data (fig. 14) are similar to those found for Kinston (fig. 15), an indication that the chemical quality of water at Kinston is much like that of Clayton.

Arithmetic plots of discharges versus dissolved-constituent concentrations show a decrease in concentration with increased discharge. Power curves can be fitted to these plots and yield reasonably high correlation coefficients. Power curves have the general form:

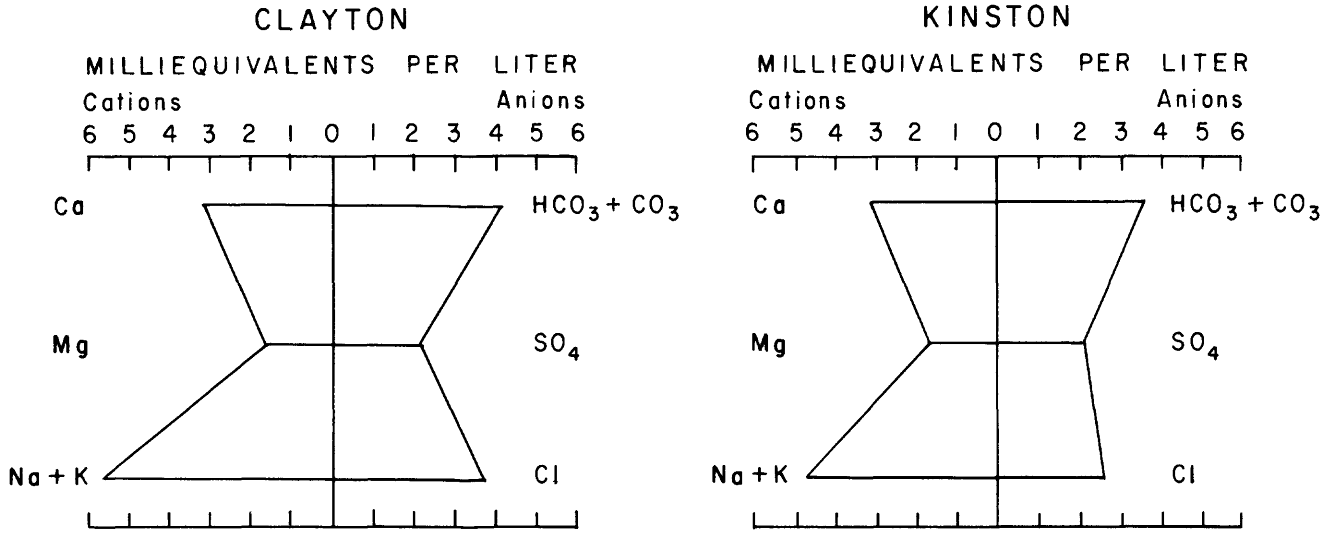

Figure 12. Cation-anion diagrams for the Neuse River near Clayton and at Kinston. Each diagram represents the mean of all samples taken in the 1974–77 water years.

Table 3. A summary of statistics for major dissolved substances for samples collected from the Neuse River near Clayton and at Kinston, 1974–77 water years

	CLAYTON			KINSTON			
Constituent mg/L	Mean 95 percent confidence limits	Range	Number of samples	Mean 95 percent confidence limits	Range	Number of samples	Criteria (EPA, 1976)
Silica (SiO_2)	12 10.9–13	4.9–19	48	9.3 8.6–10	3.1–14	45	-
Calcium (Ca)	6.1 5.5–6.7	3.3–12	48	5.6 5.2–6.0	3.2–8.8	45	-
Magnesium (Mg)	1.9 1.7–2.1	0.9–3.3	48	1.7 1.6–1.8	1.1–2.5	45	-
Sodium (Na)	11 9.1–14	2.6–37	48	8.4 7.4–9.4	3.5–17	45	-
Potassium (K)	2.7 2.4–3.0	1.5–6.4	48	2.6 2.4–2.8	1.7–4.0	45	-
Bicarbonate (HCO_3)	25 22–29	9–70	48	20 17–23	7.0–40	46	-
Sulfate (SO_4)	9.8 8.8–10.8	6.3–24	48	10.2 9.5–10.9	7.2–15	45	Upper limit for domestic use: 250 mg/L
Chloride (Cl)	12 10–15	2.7–41	48	8.9 8.0–9.8	3.6–17	45	Upper limit for domestic use: 250 mg/L
Fluoride (F)	0.3 0.2–0.4	0.1–0.8	48	0.2 0.17–0.23	0–0.5	45	-
Dissolved Solids Residue at 180°C)	83 73–93	34–190	47	71 76–67	39–99	45	-
Hardness (as $CaCO_3$)	23 21–25	13–44	48	21 20–22	13–32	45	Category: soft water
Specific Conductance (micromho)	120 8–233	45–280	92	97 34–160	48–184	81	-

$$C=bQ^{\mathrm{m}} \qquad (1)$$

or in logarithmic form:

$$ln\, C=\ln(bQ^{\mathrm{m}})=\ln b+m\ln Q \qquad (2)$$

where C is constituent concentration, Q is discharge, $\ln b$ is the y-intercept, and m is the slope. This relation for the Neuse River is illustrated by the plot for dissolved solids shown in figure 16.

Trace Elements

Minute concentrations of a variety of elements occur naturally in surface waters. Industrial and municipal effluents frequently contain metals in low concentrations. Certain trace elements such as mercury, lead, arsenic, and cadmium can be highly toxic to both humans and wildlife. Even minute concentrations of these toxic substances are of concern because higher concentrations are frequently accumulated in aquatic organisms feeding in contaminated waters. Other elements, including iron and manganese, may cause undesirable water taste, or produce scaling, particularly in hot water systems.

A summary of trace element analyses from 1974–77 (table 4) indicates low-level contamination of the Neuse River at both Clayton and Kinston. However, only iron and manganese concentrations are consistently higher than criterion levels suggested for dometic water supply (EPA, 1976). Iron concentrations are higher than the criterion level in 28 percent of the samples taken at Clayton and 39 percent at Kinston. Manganese concentrations are higher than the criterion level in all samples taken at Clayton and in 88 percent of the samples collected at Kinston. The geology of the region is the primary cause for these high iron and manganese concentrations.

Other trace element concentrations periodically rise above the EPA (1976) domestic raw water supply criteria levels. Cadmium concentrations were above the criterion level for domestic water supply in 22 percent of the Clayton samples and 17 percent of the Kinston samples. Concentrations in 25 percent of Clayton lead analyses, and 20 percent of Kinston lead concentrations were also above domestic water supply criteria levels.

Wilder and Simmons (1978) reported a strong correlation between suspended-sediment concentrations and total concentrations of lead and manganese for the Neuse River at Clayton. Relations of this kind demonstrate the role of sediment in controlling surface-water metal concentration. Sediments effectively remove dissolved metals from the water of rivers by adsorption of the metals onto the sediment particles. However, if the supply of dissolved metals in the river is reduced, metals are

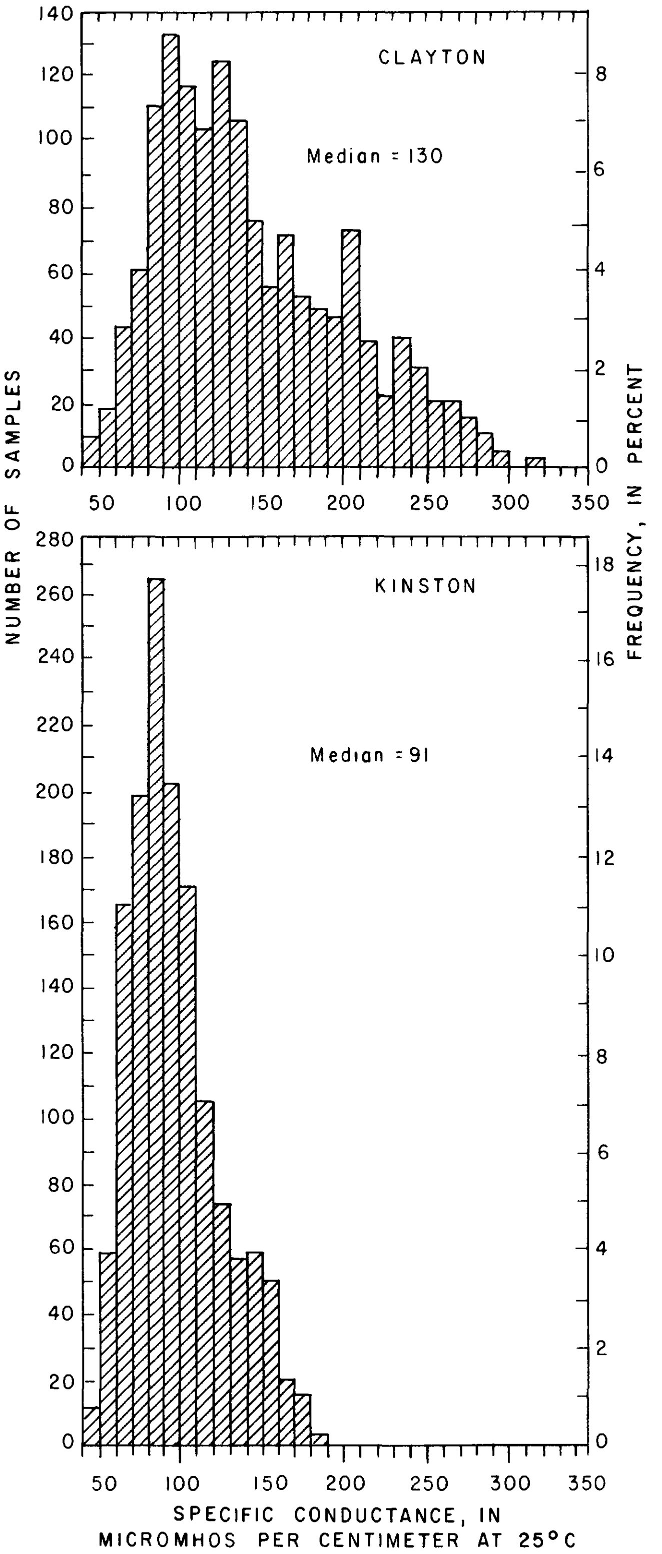

Figure 13. Frequency distribution of daily specific conductance values, Neuse River near Clayton and at Kinston, 1974–77 water years.

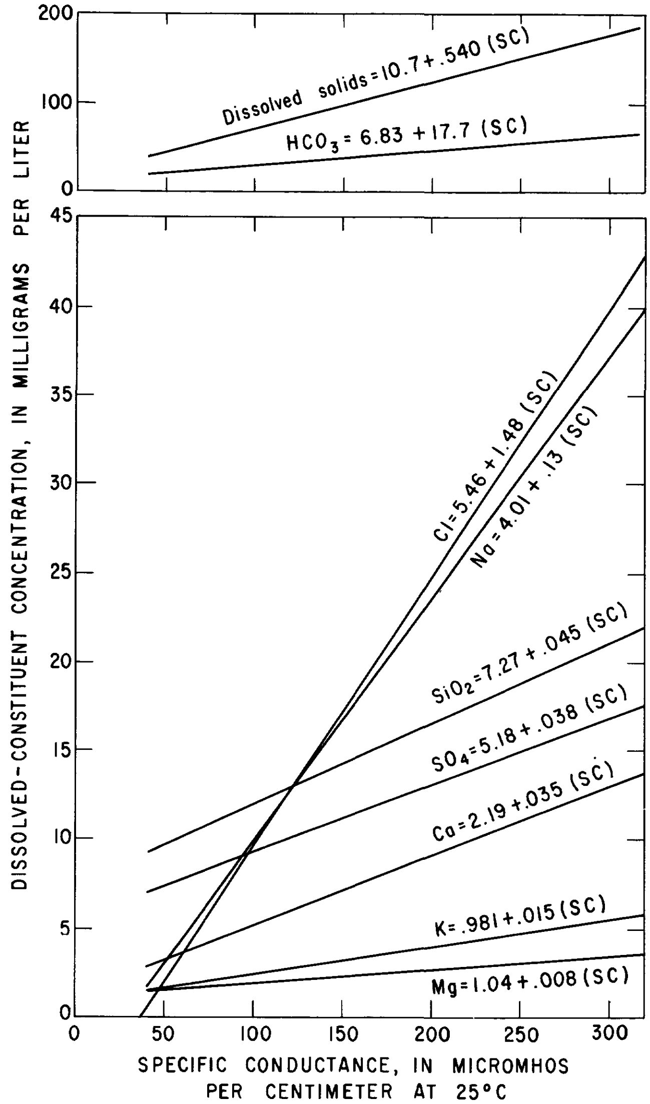

Figure 14. Regression lines of dissolved-constituent concentration versus the known range of specific conductance, Neuse River near Clayton, 1974–77 water years.

released from the sediments in order to maintain chemical equilibrium (Wershaw, 1976).

Overall, ambient concentrations for toxic elements in the Neuse River at both stations are low. However, little is known about toxic element concentrations in bottom sediments or in aquatic organisms found in the Neuse River.

Nutrients

Carbon, nitrogen and phosphorus are primary chemical elements required by algae for growth. These nutrients are therefore of primary interest in identifying causes of nuisance growths or blooms of algae.

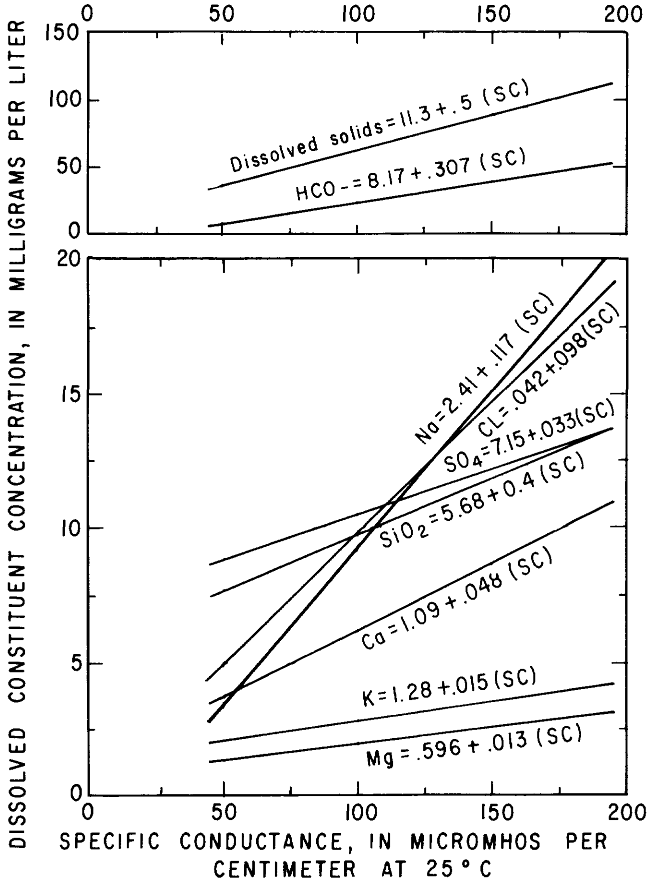

Figure 15. Regression lines of dissolved-constituent concentration versus the known range of specific conductance, Neuse River at Kinston, 1974–77 water years.

The enrichment of a body of water with nutrients, the process of eutrophication, is normally associated with increases in algal populations. The accumulation of organic matter caused by growth and decomposition of algae in turn provides habitats and ample food supplies for bacteria and other aquatic organisms. Increased biological respiration from algae, and from organisms associated with the algae, causes an increased oxygen demand which reduces available dissolved oxygen. These effects are usually most pronounced in lakes and estuaries, where accumulation of nutrients may result in particularly high concentrations of algae.

The U.S. Geological Survey has periodically measured total and dissolved organic carbon, total and dissolved organic and ammonia nitrogen, dissolved orthophosphate and total phosphorus at both Neuse stations since 1973. Measurements of total phosphate and

Table 4. A summary of total trace-element concentration statistics for the Neuse River near Clayton and at Kinston, 1974–77 water years

Trace Element (µg/L)	CLAYTON			KINSTON			Criteria (EPA, 1976)
	Mean 95 percent confidence limits	Range	Number of samples	Mean 95 percent confidence limits	Range	Number of samples	
Arsenic (As)	5.1 2–8.2	0–30	22	4.8 0.9–10.5	0–50	23	Upper limit for domestic water supply: 50µg/L
Cadium (Cd)	7.9 0.7–15	0–50	23	5 -1.1–11	0–50	24	Upper limit for domestic water supply: 10 µg/L, for fish: 4µg/L
Cobalt (Co)	14 1.5–27	0–100	21	12 -1.7–26	0–100	23	-
Copper (Cu)	17 12–22	2–70	38	9.3 5–14	2–40	24	Upper limit for domestic water supply 1000 µg/L
Iron (Fe)	320 280–360	110–950	34	290 240–340	90–480	22	Upper limit for domestic water supply: 300 µg/L
Lead (Pb)	40 13–67	2–500	38	24 38–10	0–100	24	Upper limit for domestic water supply: 50 µg/L
Manganese (Mn)	430 190–670	70–2200	22	120 80–170	20–450	23	Upper limit for domestic water supply: 50 µg/L
Mercury (Hg)	0.3 0.2–0.4	0–0.5	29	0.2 0–0.4	0–2.2	22	Upper limit for domestic water supply: 2 µg/L for fish: 0.05 µg/L
Zinc (Zn)	76 3.9–148	0–1400	38	30 17–44	4–140	24	Upper limit for domestic water supply: 5000 µg/L

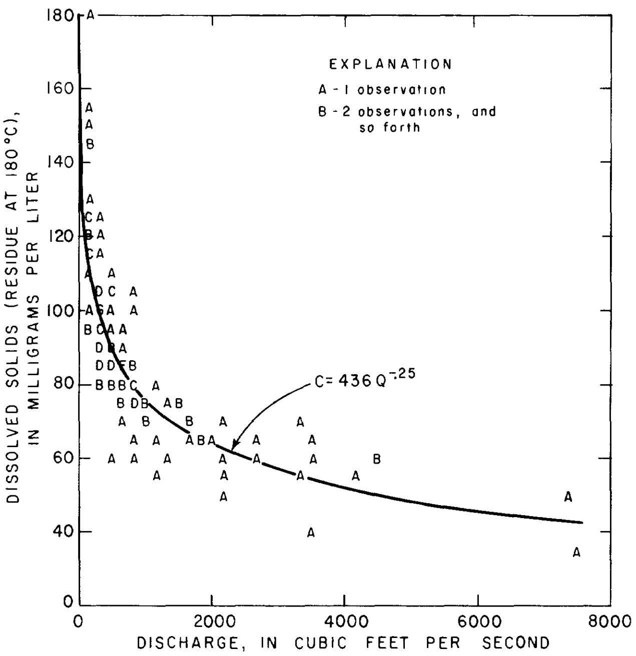

Figure 16. Relation of discharge (Q) and dissolved-solids concentration (C) of the Neuse River near Clayton, 1956–67 water years.

nitrates are also available for certain periods previous to the more intensive sampling program begun in 1973. Table 5 is a summary of nutrient analyses.

Carbon

A range of 5 to 15 mg/L TOC (total organic carbon) is characteristic of unpolluted streams in this region (Weiss and others, 1973). One-fourth of the samples collected at Clayton and half of the samples collected at Kinston during the 1974–77 water years have TOC values of 15 mg/L or greater. Dissolved organic carbon concentrations are approximately 85 percent that of the total organic carbon concentrations. These results indicate that the Neuse River at both Clayton and Kinston is moderately enriched with organic carbon, often with concentrations greater than Weiss' upper limit for unpolluted streams. Furthermore, there is no distinct difference between the distribution of TOC concentrations at Clayton and that at Kinston.

There is some evidence that total organic carbon concentrations in the Neuse River have decreased significantly since 1976. This improvement in water quality corresponds to the activation of the Neuse River Waste-water Treatment Plant in December 1976. (See Water Use and Waste Disposal).

Nitrogen

Ammonia is a reduced form of nitrogen that is oxidized by aquatic aerobic bacteria to nitrite and nitrate. In addition, ammonia nitrogen is used by algae in preference to these other forms of nitrogen. Because of the transiency of ammonia nitrogen, the presence of substantial concentrations (greater than 0.5 mg/L as N) is considered indicative of contamination by human or animal wastes, or fertilizer (Weiss and others, 1973). At Clayton 27 percent of the samples had total and dissolved ammonia nitrogen concentrations greater than 0.5 mg/L (as N), while at Kinston all samples had less than 0.2 mg/L total and dissolved ammonia nitrogen. The high ammonia levels at Clayton are probably due to upstream point-source nutrient inputs, including waste treatment plants for Raleigh and Durham.

The low total ammonia concentrations measured at Kinston are due in part to the natural in-stream oxidation of ammonia to nitrite and nitrate. However, total nitrite plus nitrate concentrations measured at Kinston are also lower than Clayton values. These lower concentrations reflect, to a large extent, the uptake of the nitrogen by algae (see Biological Characteristics). The frequency histograms given in figure 17 illustrate the reduced Kinston levels.

A value of 0.5 mg/L total nitrogen (as N) has been suggested by the National Technical Advisory Committee (1968) as a threshold value of algal growth in impounded waters. The total nitrogen levels at both Neuse stations (median values of 2.0 mg/L at Clayton, and 1.4 mg/L at Kinston) are usually higher than this threshold (fig. 18).

Mean annual nitrogen (NO_2+NO_3, and ammonia + organic) concentrations at Clayton have increased significantly since the activation of the Neuse River Wastewater Treatment Plant in December 1976. No significant changes in nitrogen concentrations are apparent at Kinston for this period. The increases evident at Clayton are probably a result of the location of the new plant closer to the Clayton station.

Phosphorus

Phosphorus is the other major nutrient essential to algal growth. The National Technical Advisory Committee (1968) cites 0.05 mg/L total phosphorus (as P) as the limiting level for algae growth for streams entering impoundments. Total phosphorus levels at both Neuse stations are almost always greater than this limiting concentration (fig. 19) with median values at 0.56 mg/L at Clayton and 0.23 mg/L at Kinston.

Mean annual total phosphorus concentrations at Clayton have increased significantly (two-tailed *t*-test of means, at a 95 percent probability level) since the relocation of the waste-water treatment plant closer to the station. No significant recent changes in phosphorus concentrations are evident at Kinston.

Table 5. A summary of nutrient statistics for samples of the Neuse River near Clayton and at Kinston, 1974–77 water years. All values are in milligrams per liter

	CLAYTON				KINSTON			
	Mean	95 percent confidence limits	Range	Number of samples	Mean	95 percent confidence limits	Range	Number of samples
Total organic carbon	14	10.2–18	5–58	34	12	9.1–15	4.1–27	20
Dissolved organic carbon	9.2	8–10.4	2.8–20	39	12	8.8–15.2	1–19	12
Total ammonia nitrogen (as N)	.51	.3–.7	0–1.9	43	.07	.03–.11	.02–.27	13
Dissolved ammonia nitrogen (as N)	.4	.3–.5	0–1.7	39	.05	.04–.06	0–.16	11
Dissolved ammonia nitrogen (as NH_4)	.52	.3–.7	0.–2.2	39	.06	.01–.11	0–.21	11
Total organic nitrogen (as N)	.84	.7–1	0–3.4	43	.66	.50–.82	.06–1.1	13
Dissolved organic nitrogen (as N)	.52	.4–.6	.16–1.3	39	.52	.61–.43	.35–.76	11
Total nitrite+ nitrate (as N)	.92	1.2–.7	.08–4.5	44	.48	.56–.40	0–1.1	47
Total Kjeldahl nitrogen (as N)	1.4	1.1–1.7	.06–4.9	44	.79	.70–.88	.1–1.4	47
Total nitrogen (as N)	2.4	2.–2.8	.33–6.1	44	1.3	1.2–1.4	64–2.1	47
Dissolved ortho-phosphate (as PO_4)	1.4	.8–2	0–8	42	.28	.17–.39	.06–.55	12
Total phosphorus (as P)	.71	.5–.9	.07–2.7	43	.23	.21–.25	.07–.38	47

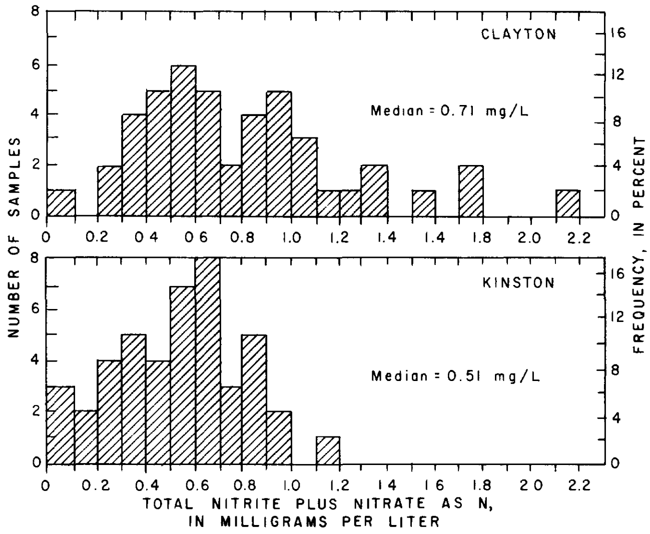

Figure 17. Frequency histograms for total nitrite plus nitrate (as N) of the Neuse River near Clayton and at Kinston, 1974–77 water years.

Nutrient relations

The total nitrogen/total phosphorus ratio is a means used to evaluate nutrient conditions in surface waters. The National Technical Advisory Committee (1968) cites a ratio of 10:1 as indicative of normal conditions in lakes. A similar ratio is reported by Weiss and Kuenzler (1976) for North Carolina lakes. The ratio of median total nitrogen to median total phosphorus is 3.5:1 at Clayton and 6:1 at Kinston. These results may indicate a potential for excess algae growth at both stations, however, it is difficult to compare Neuse River nutrient concentrations to conditions measured for lakes.

The amounts of nitrogen and phosphorus in the Neuse River are ample to supply algal growth. The reach of the Neuse above Clayton is particularly rich in these nutrients. Not surprisingly, much concern has been voiced over projected nutrient levels in the Falls reservoir (U.S. Army Corps of Engineers, 1973) that will be located along the upper reach of the Neuse downstream from the Durham waste-water treatment plant outfall. Construction of the Falls reservoir has coincided with the growth of algal blooms downstream from the dam site and upstream from Clayton. Construction has increased sediment loads below the dam site, in turn increasing the re-solution of nutrients associated with sediment. High nutrient levels, combined with warm summer temperatures, and low streamflow have promoted the growth of algal blooms.

Reduced nutrient levels measured downstream at Kinston coincide with considerable in-stream algal growth that has used some of the nutrients in the water (See Biological Characteristics). Currently algal growths are reported to be of growing concern in the Neuse River estuary (Tedder and others, 1980). Future problems are projected as increased nutrient loading exceeds the estuary's ability to assimilate nutrients without excess algal growth (Hobbie and Smith, 1975).

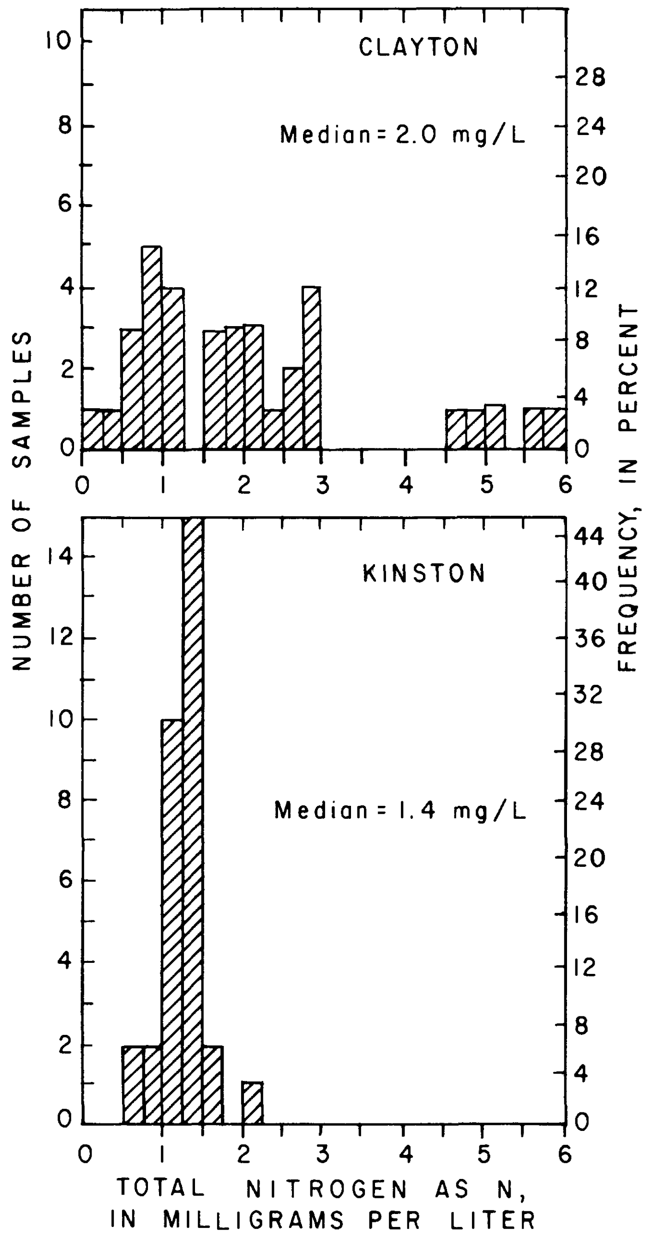

Figure 18. Frequency histograms for total nitrogen (as N) of the Neuse River near Clayton and at Kinston, 1974–77 water years.

Nitrogen is frequently cited as the limiting nutrient in the Neuse River and estuary system (U.S. Army Corps of Engineers, 1973; Triangle J Council of Governments, 1976; Hobbie and Smith, 1975). That is to say that more nitrogen would be required before algal growth used up the available phosphorus. Therefore, nitrogen

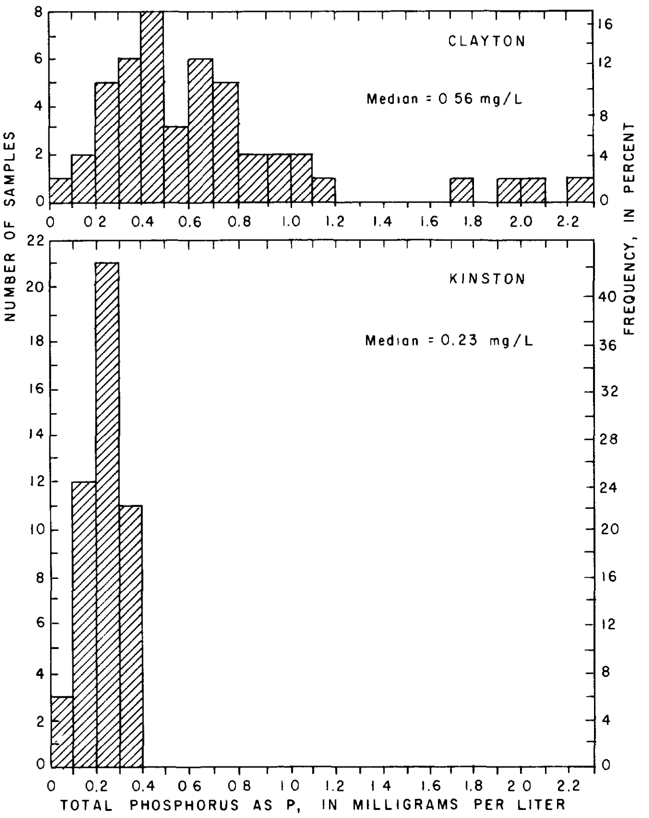

Figure 19. Frequency histograms for total phosphorus (as P) of the Neuse River near Clayton and at Kinston, 1974–77 water years.

reduction is the most likely goal for nutrient management. However, when nutrient-management control options are discussed, reductions in both nitrogen and phosphorus are usually recommended.

Variation in nutrient concentration is greatly influenced by discharge. Concentrations of dissolved nutrients plotted against discharge show dilution relations similar to that illustrated for dissolved solids and discharge (fig. 16). Furthermore, total nutrient concentrations respond during flow floods in a manner similar to sediment response. The total nitrogen and total phosphorus concentrations during the flood of August 4, 1974 (fig. 20) show a pattern of response comparable to that of sediment. The dissolved nitrogen and phosphorus concentrations are diluted by the floodflows, but nutrients associated with suspended material are greatly increased during the first peak in discharge. The net result is a flushing effect similar to that observed for Clayton suspended sediment data (fig. 9).

Biological Characteristics

Biological monitoring is a direct means of assessing water-quality impacts in streams. Measurements of physical and chemical parameters give instantaneous levels of the materials in the waters of a stream. When reviewing these instantaneous values, special attention must be paid to complicating factors, such as discharge, that may make the values unrepresentative. In contrast, biological measures, such as algal assays, directly provide information on the short-term impacts of water quality in a stream. Finally, the variation found in the Neuse River in many of the physical or chemical parameters is too much to conclude a statistically significant change. Biological measures also exhibit substantial variation, but provide an alternate source of information about the study system to that provided by physical and chemical tests.

The systematic collection of biological data at Clayton and Kinston began in late 1973. Samples are collected near Clayton several times a year, and at Kinston monthly. Colony counts of fecal coliform bacteria and algal bioassays are performed for selected samples for both stations, and fecal streptococci bacteria colonies are counted for selected Kinston samples. The five-day biochemical oxygen demand (BOD_5) is determined for each sample from both stations.

Bacteria

Fecal coliform bacteria are those members of the coliform group found in the feces of various warm-blooded animals, and are used as indicators of bacteriological pollution. Fecal coliform statistics for both stations are given in table 6. The fecal contamination levels at both stations exceed the recomended

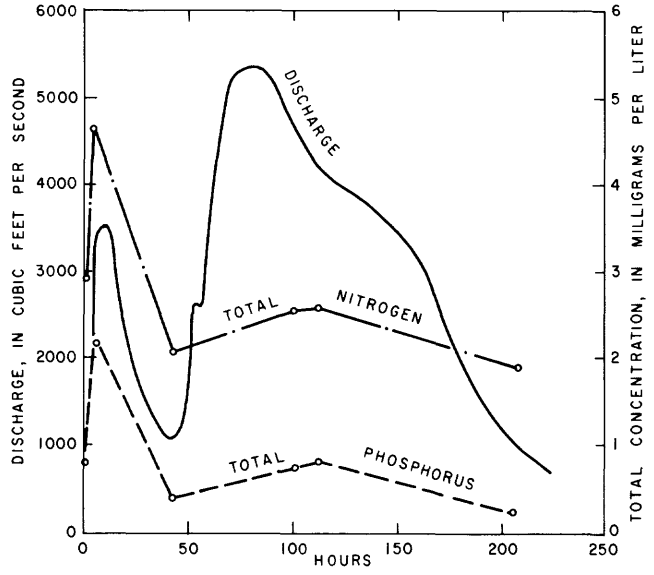

Figure 20. Hydrograph of discharge, total nitrogen, and total phosphorus concentration for the storm of August 4, 1974, Neuse River near Clayton.

Table 6. Summary statistics for biological analyses, Neuse River near Clayton and at Kinston, 1974–77 water years.

	CLAYTON			KINSTON			
	Mean 95 percent confidence limits	Range	Number of samples	Mean 95 percent confidence limits	Range	Number of samples	Criteria (EPA, 1976)
Five-day biochemical oxygen demand (mg/L)	3.3 3–3.6	1.3–8.3	80	2.4 2–2.6	0.5–6.8	65	-
Fecal coliform (colonies per 100 mL)	161[1] -	20-12,000	81	352[1] -	20-40,000	91	Bathing waters: should not exceed 200 per 100 mL
Fecal streptococci (colonies per 100 mL)	- -	-	-	276[1] -	68-10,000	12	-
Periphyton (Total dry weight g/m^2)	13 -	6.9–21	4	15 -	1.9–26.9	5	-
Photoplankton count (cells/mL)	4100[1] -	200-55,000	10	8300[1] -	180-220,000	26	-

[1] Geometric mean.

criterion for bathing waters (EPA, 1976). Kinston especially shows high fecal coliform levels.

Fecal streptococci also are organisms used to indicate fecal pollution from warm-blooded organisms. Although there are no criterion levels currently recommended for fecal streptococci, they supply a backup indicator to fecal coliform results. The fecal streptococci statistics (table 6) observed for Kinston samples corroborates the evidence of substantial bacterial contamination given by fecal coliform counts.

The fecal coliform-fecal streptococci ratio is sometimes used to help identify the origin of bacterial contamination (Geldreich, 1966). Ratios greater than 4.0:1 indicate contamination primarily of human origin, while ratios less than 0.6:1 indicate animal origin. Kinston fecal coliform to fecal streptococci ratios for low-flows (discharges less than 1,000 ft^3/s) tend to fall between these values, indicating combined human-animal origin of the coliform bacteria.

Biochemical oxygen demand

The biological uptake of oxygen by organisms for metabolism can be measured by the five-day biochemical oxygen demand test (BOD$_5$). Therefore, a stream's BOD$_5$ helps to evaluate the amount of organic material in the stream being used by organisms. A range of 1 to 8 mg/L is common for moderately contaminated streams (Nemerow, 1974). BOD$_5$ values at both stations fall within this range. Fifty percent of the Clayton values are less than 3 mg/L, while 50 percent of the Kinston values are less than 2 mg/L. Clayton has higher levels more frequently than Kinston.

Algae

Algae are simple plants that are ubiquitous in surface waters. In nutrient-enriched waters massive growths, or blooms, of algae may cause objectionable odors, impair water uses, and decrease aesthetic values of the body of water. Algae do not presently often cause such problems on the Neuse River. However, algal assays of samples collected near Clayton and at Kinston provide a direct means of evaluation of effects of current nutrient concentrations. In addition, certain assemblages of dominant algal species serve as biological indicators of stream pollution in the Neuse.

Knowledge of algal growth levels are of particular interest in studies of lakes, estuaries and slowly moving rivers. Algae often play an important role in the oxygen balance of slowly moving water. High daytime dissolved-oxygen levels can largely be a function of photosynthetic activity. However, night-time respiration of the algae and decomposition of algal debris by microorganisms can deplete available oxygen and recycle nutrients into solution.

Rates of algal growth are highly dependent on temperature and the amount of sunlight, in addition to the availability of nutrients. Changes in growth of algae are as dramatic as the changes in the seasons. Not surprisingly, there is a distinct seasonal variation in algal cell counts at both Neuse stations. This variation is particularly apparent at Kinston (fig. 21). Algal cell counts are extremely high during summer months, reflecting the nutrient enrichment of the Neuse River (see Nutrients). Total cell counts at Kinston suggest that algae may play an important role in the oxygen balance of the lower reaches of the Neuse River.

Algal cell counts are also affected by streamflow. Floodflows often flush drifting organisms and phytoplankton downstream (Slack, 1974). This flushing may cause catastrophic changes in organism populations. One such turnover is documented at Kinston in figure 21. A precipitous drop in algal cell count, from 50,000 cells/100 mL to 600 cells/100 mL, a five-fold decline in total algal cells in the river, corresponds to the flood of July 1975. Phytoplankton and nutrient loads flushed during high flows may seed algal blooms downstream and in the Neuse River estuary.

Annual distributions of the three predominant algal genera during 1974–76 at Clayton indicate a dominance of Chrysophyta (diatoma) much of the summer, fall and winter. The diatom genera that prevail include: *Synedra, Nitzschia, Navicula* and *Melosira.* Dominance of Chlorophyta (green algae) or Cyanophyta (blue-green algae) begins in February and lasts through midsummer. Blue-green algae genera that prevail during this period include *Anacystis* and *Lyngbya.* The dominant green algal genus that appears at Clayton in early summer is *Scenedemus.* All of these genera, excluding *Synedra*, contain indicator species that are commonly associated with organically enriched waters (Nemerow, 1974).

Three complete water years of algal cell counts and identification are available at Kinston. The dominant assemblage of organisms has changed from year to year

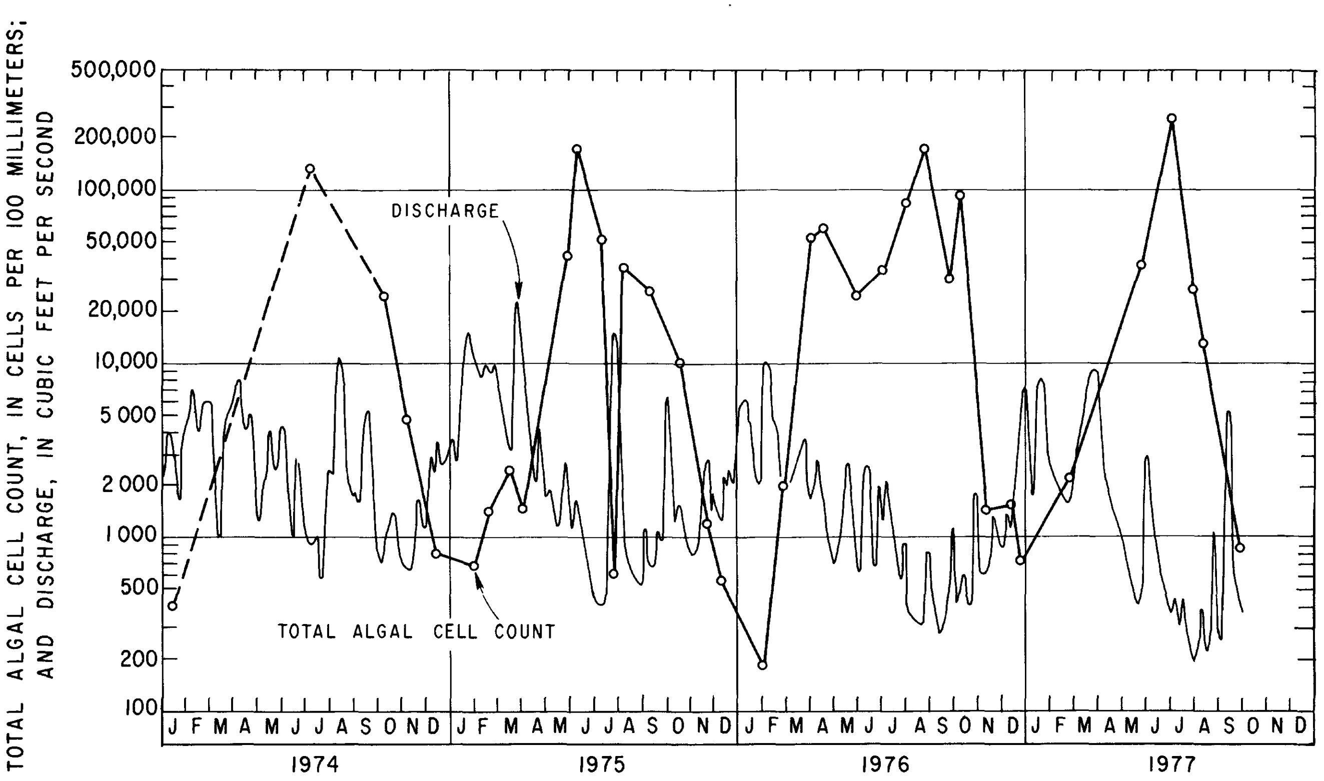

Figure 21. Algal cell counts and discharge for the Neuse River at Kinston.

Table 7. Major algal division dominance represented by the percent of time over the water year in which each division is dominant, Neuse River at Kinston

DIVISION	Percent of year dominant		
	1975	1976	1977
Cyanophyta (blue-green algae).	52	35	15
Chlorophyta (green-algae).	43	42	69
Chrysophyta (diatoms).	5	23	16

(table 7). The similar patterns of dominance apparent in 1975 and 1976, are different from that of 1977. In 1975 and 1976 diatoms and green algae were dominant. The summer months are characterized by an interplay of blue-green and green algal dominance. Diatom genera that prevail include: *Navicula, Nitzschia, Melosira* and *Cyclotella.* Blue-green algal genera that are dominant include: *Oscillatoria, Anacystis* and *Lyngbya. Anacystis* was the dominant algal genus from May 1975 to October 1975 and shared an important role with the diatom genera of *Melosira* and *Cyclotella* in the same period the following year. Green algal genera dominant during 1975–76 include: *Ankistrodesmus, Crucigenia, Dictyosphaerium, Micractinium* and *Scenedemus.* Once again, most of these algal genera contain indicator species that are commonly associated with organically enriched waters (Nemerow, 1974).

In 1977 the pattern of dominance changes both at the division and generic level. Green algae predominate for much of the year. The genera that appeared including *Dictyosphaerium,* and *Sphaerocystis,* are not noted for indicator species of organic pollution. Significantly, this change in the pattern of generic dominance is first apparent in December 1976, when the Neuse River Wastewater Treatment Plant was activated (see Water Use and Waste Disposal). Improved water treatment processes at this large plant may have reduced organic pollution in the Neuse enough to account for the altered pattern of algal dominance.

The recent history of Raleigh waste-water treatment suggests that the improvement of water quality due to the opening of the Neuse River treatment plant was preceded by degradation in water quality (R. S. Taylor, North Carolina Department of Natural Resources and Community Development, written commun., June 20, 1979). In the year prior to the opening of the new plant, as sewer interceptor lines were under construction, the effluent discharge point for one of the old treatment plants was changed from a point several miles upstream in Walnut Creek, to a point near the confluence of Walnut Creek and the Neuse River. This change had the effect of removing any natural treatment or organic material in the effluent that would have occurred along Walnut Creek. Although there is evidence in Geological Survey data of improvement in water quality in the Neuse after the opening of the plant, in the form of reduced TOC concentrations, and changes in algal dominance, no change due to the relocation of the Walnut Creek plant effluent discharge point is apparent.

POLLUTION

A primary goal of this study is to identify how much of the total amount of dissolved and suspended material transported by the Neuse River is man-made pollution; that is, to find how man has changed the natural state of the stream. The accuracy of this evaluation hinges on the data available about the quality of water in the Neuse River prior to the influences of man. Very little, if any, natural water-quality data are available for the Neuse River, therefore, it is necessary to make estimates of the natural state of the river based on data from other comparatively unpolluted streams.

Baseline Water Quality

Simmons and Heath (1979) describe the methods used by the Geological Survey to estimate the approximate natural, or baseline, water quality in North Carolina. A sampling program was designed to measure constituent concentrations during high and low flows in small unpolluted streams distributed across the State. Once the mean value of the constituent concentrations were known for both flow ranges at all of the baseline water-quality sites, the results were related to area geology. Thus, five district geochemical zones were identified, each containing a group of baseline water-quality stations with comparable constituent concentrations. Constituent concentrations from the sites within each group were averaged to give estimates of baseline water-quality concentrations for each geochemical zone.

Nine baseline water-quality stations located within the Neuse basin are shown in figure 1. The geochemical zones which include sections of the Neuse River basin are shown in figure 3. Parts of two geochemical zones lie within the Neuse basin upstream from Clayton. Area I covers 330 mi², and area II covers 810 mi² of this basin. Parts of four geochemical zones lie within the Neuse basin upstream from Kinston. Area I covers 590 mi², II covers 1180 mi², IV covers 730 mi², and V covers 190 mi² of the basin.

Calculations of dissolved constituents derived from baseline sources and transported by large rivers, such as the Neuse, require three steps. First, the annual streamflow volume is broken down into high flow Q_H, and base flow, Q_B (Rorabaugh, 1964). Second, the mean constituent concentrations (C_H for high flow and C_B for base flow) determined from the baseline stations within each geochemical zone are weighted by the ratio of zone area to basin area, and then summed to give basin baseline-water-quality constituent concentrations. Finally, these two basin water-quality concentrations are multiplied by the two components of total streamflow volume giving the annual baseline load (L_N):

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

Separation (step 1) of Neuse River discharge into high flow and base flow components shows that for most years, the volume of high flow is greater than that of base flow. At Clayton, high flow averages 57 percent and base flow averages 43 percent of the total annual streamflow. At Kinston, high flow averages 66 percent and base flow averages 34 percent of the total annual flow. The large difference between the two stations in the relative proportions of high flow to base flow was an unexpected result. The signigicance of this difference warrants further investigation in future studies.

Comparisons of estimated natural water-quality concentrations (step 2) with water quality of samples from the Neuse are shown in table 8 for Clayton and table 9 for Kinston. Constituent concentrations for both the Neuse River and the baseline quality sites include precipitates of air borne pollutants. The impact on water quality of atmospheric precipitation can be considerable (Gambell and Fisher, 1966) but data are not yet available to separate this source of pollution from other sources. An estimate of the portion of the mean sample concentration that is due to man's activity is given by subtracting the estimates of baseline water quality from the corresponding constituent mean sample concentrations. Pollution usually makes up greater than 50 percent of the total constituent concentrations. Higher percentages of pollution at Clayton than at Kinston reinforce the observation that the water upstream is more heavily contaminated than downstream (see Water-Quality Variations).

There are a few cases in tables 8 and 9 where the estimates of baseline water quality are higher than the mean sample concentrations (silica, chromium, and mercury at Clayton; and silica, iron and mercury at Kinston). These cases are probably due to the small number of samples taken at the baseline water-quality sites. Spurious values, whether they represent actual stream concentrations or a combination of sampling and laboratory errors, bias the means calculated from a small number of samples.

Cation-anion diagrams provide a graphic means of comparison of the ionic composition of water at the baseline water-quality sites to the ionic composition of water from the Neuse (Stiff, 1951). The baseline water-quality diagram is superimposed on the observed water-quality diagram for the Neuse at Clayton and Kinston in figure 22. There is little apparent difference in the baseline water-quality between the two stations.

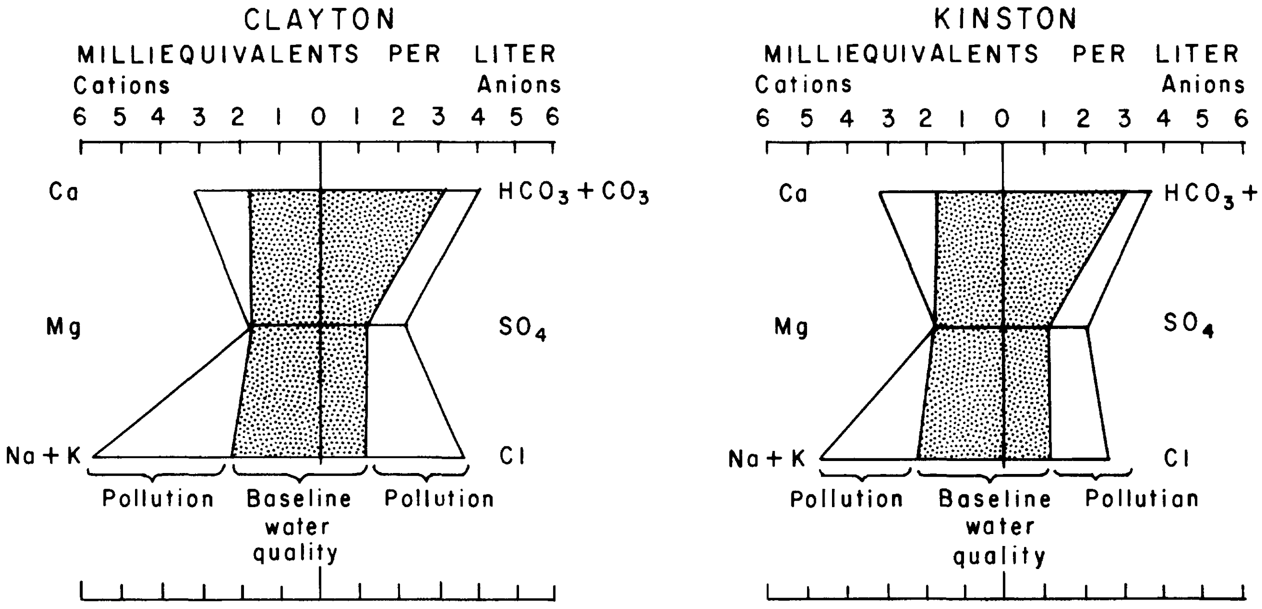

Figure 22. Comparisons of baseline water quality and observed water quality using cation-anion diagrams. The observed-data diagrams represent the mean of all samples taken in the 1974–77 water years. The baseline water-quality diagram represents the mean of all samples taken from baseline stations within the Neuse River basin.

Table 8. Comparison of water quality of samples from the Neuse River near Clayton with samples from baseline water-quality sites in the basin upstream from Clayton

	Neuse River near Clayton			Baseline-quality sites			Percent attributable to pollution	
	Mean Value			Mean Value				
	Base flow (<370 ft^3/s)	High flow (>370 ft^3/s)	Range of all samples	Base flow	High flow	Range of all samples	Base flow	High flow
Major dissolved constituents (mg/L)								
Calcium	9.6	5.3	3.3–12	4.4	2.2	0.5–10	54	58
Magnesium	2.7	1.7	.9–3.3	1.9	.8	.3–4.1	30	53
Sodium	25	8.4	2.6–37	4.6	1.5	.4–7.3	82	82
Potassium	4.3	2.4	1.5–6.4	1	1	.3–1.9	77	58
Bicarbonate	42	22	8.3–70	4.6	5	2–44	89	77
Sulfate	13	9.1	6.3–24	2.5	5.5	.8–8.2	81	40
Chloride	26	8.3	2.7–41	4.1	1.5	0–10	84	82
Fluoride	.5	.2	.1–.8	.1	.1	0–.5	80	50
Silica	16	11	4.9–19	17	6	3.1–29	-	45
Dissolved solids	120	58	34–170	49	21	12–78	60	63
Nutrients (mg/L)								
Total nitrogen	3.7	1.9	.3–6.1	.34	.14	0–1.5	91	93
Organic nitrogen	.87	.83	0–.34	.19	.38	0–.69	86	54
Nitrate nitrogen	2.5	.62	.3–4.4	.14	.1	0–1	94	84
Ammonia nitrogen	.6	.37	0–1.8	.01	.01	0–.07	98	97
Total phosphorus	1.4	.51	.07–2.7	.02	.02	0–.05	99	96
Trace elements (μg/L)								
Total arsenic	9.3	4.2	0–30	3.6	.71	0–.3	96	83
Total chromium	8.3	9.5	0–20	10	10	10–20	50	-
Total copper	16	17	2–70	4	4	0–12	76	76
Total iron	750	4800	520–20,000	570	4100	20–13,000	24	14
Total lead	82	29	2–500	6.4	7.6	0–25	92	74
Total mercury	.25	.25	0–.5	.15	.5	0–.5	40	-
Total selenium	2	6.1	0–12	0	0	0–0	100	100
Total zinc	210	40	0–1400	10	10	0–20	95	75

However, pollution, which is represented in the diagrams by the difference between the measured and baseline water quality, is greater near Clayton than at Kinston.

The third step in calculating baseline material transport (L_N) in the Neuse River is the insertion of the baseline water-quality concentrations (C_H, C_B) summarized in tables 8–9, and the high flow and base flow (Q_H, Q_B) given as an example in tables 10 and 11 (columns C, D, and E) and figures 23 and 24 (items B, C, D) for Clayton and Kinston, respectively.

It is interesting to note that at Clayton the estimated baseline load in high flow is consistently lower than the natural load in base flow while at Kinston the estimated baseline load in high flow is frequently greater than the load in base flow (see figs. 23 and 24). This is because of the relatively large base-flow baseline dissolved-solids concentrations estimated for Clayton and the greater proportion of high flow to base flow at Kinston.

Pollution Loads

Two additional steps are required to estimate the annual pollution load once the annual baseline load has been evaluated. First, the total annual load must be

Table 9. Comparison of water quality of samples from the Neuse River at Kinston with samples from baseline water-quality sites in the basin upstream from Kinston

	Neuse River at Kinston			Baseline-quality sites			Percent attributable to pollution	
	Mean Value			Mean Value				
	Base flow (<370 ft^3/s)	High flow (>370 ft^3/s)	Range of all samples	Base flow	High flow	Range of all samples	Base flow	High flow
Major dissolved constituents (mg/L)								
Calcium	6.9	4.8	3.2–8.8	2.9	1.9	0.2–4.0	58	60
Magnesium	2	1.5	1.1–2.5	1.3	.6	.1–4.1	35	60
Sodium	12	6.3	3.5–17	3.8	1.8	.4–7.3	67	71
Potassium	3.1	2.3	1.7–4	.8	.8	.1–1.9	70	65
Bicarbonate	29	15	7–40	3.4	3.3	0–44	88	78
Sulfate	11	9.5	7.2–15	4.3	6.3	.6–13	61	34
Chloride	11	7.2	3.6–17	3.9	2.3	0–10	66	68
Fluoride	.2	.2	0–.5	.1	.1	0–.5	50	50
Silica	9.4	9.2	3.1–14	13	5.4	1.4–29	-	41
Dissolved solids	70	49	34–91	39	22	11–78	44	55
Nutrients (mg/L)								
Total nitrogen	1.4	1.2	.6–2.1	.4	.5	0–1.5	71	58
Organic nitrogen	.7	.7	.06–1.1	.3	.4	0–.99	57	43
Nitrate nitrogen	-	-	-	.09	.08	0–1	-	-
Ammonia nitrogen	.03	.09	.02–.27	.01	.01	0–.07	67	89
Total phosphorus	.3	.2	.07–.38	.02	.02	0–.05	93	90
Trace elements (μg/L)								
Total arsenic	4.4	5.3	0–50	.3	.6	0–6	93	89
Total chromium	13	12	10–20	10	10	0–20	50	33
Total copper	9.6	9.1	2–40	3.4	3.3	0–12	65	64
Total iron	1100	1400	650–2000	540	2800	60–29,000	50	-
Total lead	30	18	0–100	5.7	6.7	0–29	81	64
Total mercury	.28	.12	0–2.2	.3	.5	0–.5	-	-
Total selenium	.50	.73	0–5	0	0	0–0	100	100
Total zinc	17	42	4–14	10	10	0–30	42	76

determined. Although daily streamflow and specific conductance values are usually available, concentration values for water-quality parameters are determined from samples collected on a monthly or bimonthly basis. The concentration values are regressed on specific conductance, producing linear relations (see Water-Quality Variations) that are in turn used to estimate daily concentrations from daily conductance data. Examples of these relations are shown in figures 14 and 15. Daily concentrations are multiplied by daily streamflows to produce daily loads. The sum of these daily loads for a year's time yields the total annual load. The results of these calculations for Clayton are given in table 10 and figure 23, and for Kinston in table 11 and figure 24.

It is important to note that although daily specific conductances were not measured at either station during 1964–67, specific conductance was evaluated each time a water-quality sample was taken. These periodic values were then regressed on daily specific conductance values measured at an upstream station. The upstream station used for Clayton was Neuse River near Falls (02087182), and the station used for Kinston was Neuse River at

Table 10. Dissolved-solids loads and concentrations for the Neuse River near Clayton

	Measured at Clayton		Estimated from baseline-quality network		Annual loads			Annual concentrations		
	A	B	C	D	E	F	G	H	I	J
Water year	Total discharge (ft³/yr ×10¹³)	Total dissolved solids (tons/yr)	Dissolved-solids load in base flow (tons/yr)	Dissolved-solids load in high flow (tons/yr)	Baseline dissolved-solids load (tons/yr) C+D	Pollution dissolved-solids load (tons/yr) B−E	Percent of total load from pollution (F/B)×100	Total annual concentration (mg/L) (B/A)×1.13 ×10⁻³	Baseline annual concentration (mg/L) (E/A)×1.13 ×10⁻³	Annual pollution concentration (mg/L) H−I
1956	1.0	58,000	18,000	11,000	29,000	29,000	50	67	33	34
1957	1.2	66,000	23,000	11,000	34,000	32,000	49	65	34	31
1958	1.9	100,000	29,000	23,000	52,000	48,000	48	60	31	29
1964[1]	1.2	73,000	28,000	11,000	39,000	34,000	47	68	36	32
1965[1]	1.6	100,000	27,000	19,000	46,000	54,000	54	71	32	39
1966[1]	.95	66,000	16,000	11,000	27,000	39,000	59	79	32	47
1967[1]	.84	60,000	17,000	7,700	25,000	35,000	59	85	34	51
1974	1.2	79,000	21,000	13,000	34,000	45,000	57	76	33	43
1975	1.9	98,000	22,000	26,000	48,000	50,000	51	59	29	30
1976	.69	49,000	16,000	5,700	22,000	27,000	56	83	37	46
1977	.73	53,000	14,000	6,800	21,000	32,000	61	85	35	50

[1] Calculation employed Neuse River near Falls specific conductance data.

Table 11. Dissolved-solids loads and concentrations for the Neuse River at Kinston

	Measured at Kinston		Estimated from baseline-quality network		Annual loads			Annual concentrations		
	A	B	C	D	E	F	G	H	I	J
Water year	Total discharge (ft³/yr ×10¹³)	Total dissolved solids (tons/yr)	Dissolved-solids load in base flow (tons/yr)	Dissolved-solids load in high flow (tons/yr)	Baseline dissolved-solids load (tons/yr) C+D	Pollution dissolved-solids load (tons/yr) B−E	Percent of total load from pollution (F/B)×100	Total annual concentration (mg/L) (B/A)×1.13 ×10⁻³	Baseline annual concentration (mg/L) (E/A)×1.13 ×10⁻³	Annual pollution concentration (mg/L) H−I
1956	2.5	130,000	36,000	27,000	63,000	67,000	52	59	29	30
1961	3.7	180,000	50,000	43,000	93,000	87,000	48	53	29	24
1962	3.6	150,000	42,000	44,000	86,000	64,000	43	47	27	20
1963	3.4	150,000	41,000	39,000	80,000	70,000	47	51	28	23
1964[1]	3.7	160,000	37,000	48,000	85,000	75,000	46	51	26	25
1965[1]	5.1	220,000	50,000	70,000	120,000	100,000	46	48	27	21
1966[1]	2.6	120,000	20,000	37,000	57,000	63,000	53	56	26	30
1967[1]	2.3	120,000	32,000	24,000	56,000	64,000	53	61	29	32
1974	3.2	190,000	39,000	39,000	78,000	112,000	59	68	28	40
1975	4.4	190,000	33,000	61,000	94,000	96,000	51	52	26	26
1976	2.3	130,000	34,000	24,000	58,000	72,000	55	64	30	34
1977	2.3	130,000	25,000	29,000	54,000	76,000	59	67	27	40

[1] Calculation employed Neuse River at Goldsboro specific conductance data.

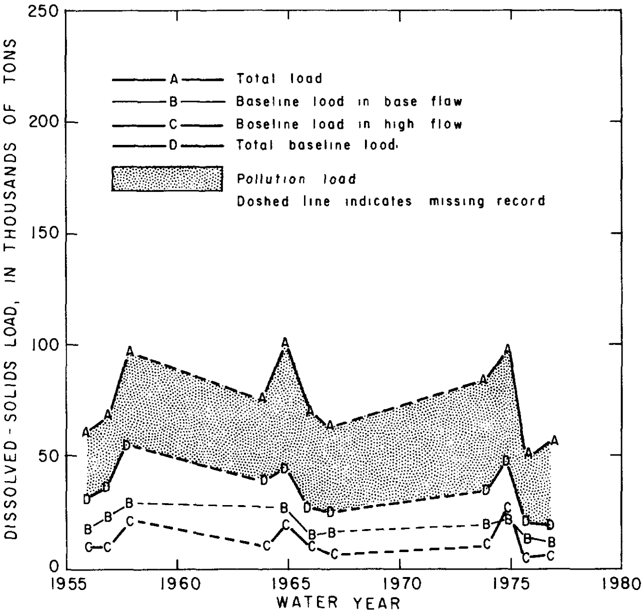

Figure 23. Dissolved-solids load for the Neuse River near Clayton.

Goldsboro (02088821). Equations produced in these regressions were then used to generate estimates of daily values for the Clayton and Kinston stations. The estimated specific conductances have been used in evaluation of total loads for the 1964–67 water-years for both stations.

The pollution load is derived by taking the difference between the total load and the baseline load. The results of the calculation for dissolved-solids pollution loads for Clayton are shown in table 10 and for Kinston in table 11.

The depictions of dissolved-solids loads in figures 23 and 24 vividly demonstrate the importance of pollution in the make up of the overall water quality of the Neuse. The plot of total baseline load gives a representation of what the dissolved solids loads of the Neuse River would be without the presence of man. However, these load estimates are probably high because they include the effects of air-borne pollutants. The areas in figures 23 and 24 between the total baseline load and the total load represent the dissolved solids pollution loads.

The proportion of the total load that is pollution is similar at both stations (figs. 23 and 24). This similarity between Clayton and Kinston is more apparent when that part of the total load attributable to pollution is calculated as a percentage, as shown in figure 25. The dissolved-solids load due to pollution averages 53 percent for the period of record at Clayton and 51 percent at Kinston. On an annual basis the widest difference between stations occurs during the 1960's, when Clayton shows appreciably higher percentages compared to Kinston. This difference is probably due to the process of specific conductance estimation using upstream values to evaluate the total loads.

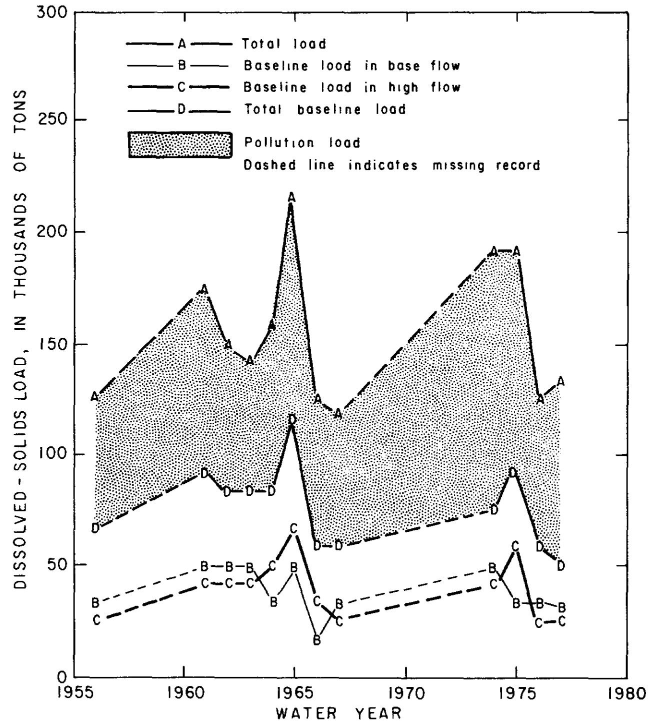

Figure 24. Dissolved-solids load for the Neuse River at Kinston.

When the difference between the dissolved-solids pollution loads at Kinston and Clayton is divided by the difference between the total loads at these two stations, the proportion that results is a measure of the contribution of pollution from the basin area lying between the

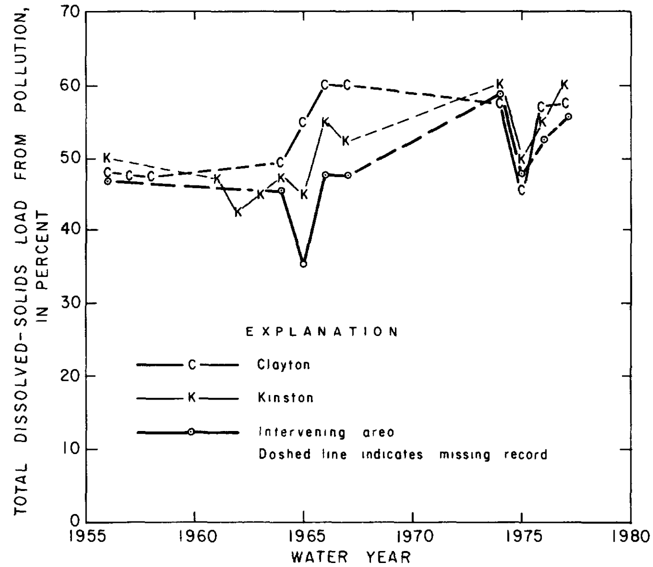

Figure 25. Percentage of total dissolved-solids load from pollution for the Neuse River near Clayton and at Kinston, and the invervening area between stations.

Table 12. A Comparison between total, baseline, and pollution dissolved-solids loads on a tons per square mile per year basis

Water year	Total dissolved-solids load			Baseline dissolved-solids load			Dissolved-solids pollution load		
	Clayton	Kinston	Intervening area	Clayton	Kinston	Intervening area	Clayton	Kinston	Intervening area
1956	51	48	46	25	23	22	25	25	25
1957	58	-	-	30	-	-	28	-	-
1958	88	-	-	46	-	-	42	-	-
1961	-	67	-	-	35	-	-	32	-
1962	-	56	-	-	32	-	-	24	-
1963	-	56	-	-	30	-	-	26	-
1964	64	60	56	34	32	30	30	28	26
1965	88	82	77	40	44	48	47	37	30
1966	58	45	16	23	21	19	34	23	29
1967	53	45	39	22	21	20	31	24	19
1974	69	71	72	30	30	28	40	42	43
1975	86	71	59	42	35	30	44	36	30
1976	43	48	52	19	22	23	24	27	29
1977	47	48	50	18	20	21	28	28	28

two sections. These Kinston-minus-Clayton results (fig. 25) indicate that little pollution is contributed to the Neuse between these two sites.

During the high discharge years of 1965 and 1975 the percentages of total dissolved-solids load from pollution show large decreases (see fig. 25). During these two years the baseline loads are high, so that on a percentage basis of the total load, load due to pollution is less. However, the baseline high-flow loads are calculated assuming the same geochemical zone concentrations for wet and dry years. If in fact these concentrations vary significantly from the average value during extreme discharge years, then the baseline-load estimates are inaccurate. For example: if during years of high discharge the high-flow baseline concentration decreases due to dilution, then the baseline load would be lower than that calculated from an average value.

Comparisons between dissolved-solids loads at the two stations on the basis of load per square mile of drainage area are given in table 12 for total loads, baseline loads and pollution loads. Clayton stands out in the total load comparison as having the greatest loads per square mile in all but the most recent years. Clayton and Kinston show much higher per-square-mile pollution loads in all but the most recent years. The area between the two stations shows loads similar to Kinston.

These results suggest an improvement in water quality at Clayton and Kinston in recent years. The year where improvement was first evident, 1976, matches the time when algal dominance changes were first observed at Kinston (see Biological Characteristics). Both changes correspond to the opening of the Neuse River Wastewater Treatment Plant — possibly the most significant event for water quality of the Neuse River during the period of study.

The results shown in table 12 are particularly interesting in light of the information presented in figures 3 and 4. The density of population in the drainage area above Clayton is the highest in the entire Neuse basin, with roughly 40 percent of the population (fig. 3) and only 20 percent of the drainage area. In contrast, the area between Clayton and Kinston has a much lower population density with about 25 percent of the total basin population and 27 percent of the drainage area. Clearly, there should be a strong correlation between the degree of pollution of a river and the degree of the presence of the polluter-man. This point is echoed by the information presented in figure 4 on industrial point-source discharges. Land-use, industry and pollution are all functions of population, albeit complex and variable functions. Correlations between population and pollution in the Neuse River basin will be explored further in the next section of this report.

Although dissolved-solids loads give rough measures of water-quality, examination of individual dissolved material is necessary to identify the nature of water-quality changes with time. Summary breakdowns of the total of sodium, sulfate, and chloride, into baseline and pollution loads for both stations are given in table 13. Although the percent of the average load at-

Table 13. Average loads of sodium, chloride, and sulfate transported by the Neuse River near Clayton and at Kinston, 1974–77 water years

Constituent	Total load (tons/yr)	Baseline load (tons/yr)	Pollution load (tons/yr)	Percent attributable to pollution
		CLAYTON		
Sodium	8,300	2,200	6,100	73
Chloride	8,200	2,500	5,700	70
Sulfate	8,600	4,200	4,400	51
		KINSTON		
Sodium	16,000	6,000	10,000	63
Chloride	18,000	7,000	11,000	61
Sulfate	22,000	15,000	7,000	32

tibutable to dissolved solids pollution was earlier shown to be similar for Clayton and Kinston (fig. 25), there is a wide variation between average values for other constituents. In all three constituents listed in table 13, Kinston shows a much lower percentage of load attributable to pollution than Clayton. The variation in degree of pollution among constituents cannot be explained adequately without a detailed pollution sources study. However, the following section will attempt to quantify the trends that can be observed in this pollution data.

TRENDS

Trend Analysis Techniques

The final goal of this study is to quantify how water quality in the Neuse River has changed historically. Determination of trends is not a simple problem. Ideally, the data used in trend analysis should be derived from standardized measurements of samples collected randomly or according to well-defined experimental design, over a continuous and long-term period. However, the Neuse River data available for trend analysis does not fit this ideal format. Sample collection in the past, as well as the present, is conducted on a temporal basis influenced by sampling costs, available personnel, weather conditions, field trip schedules and a host of other variables. The resultant sampling intervals are not random, set to any experimental design, or long term. The data are also discontinuous, with several periods of missing water-quality records lasting four or more years.

In spite of these inconsistencies, the water-quality data is valuable because it is neither replaceable nor reproducable. The data collected by the U.S. Geological Survey represents the longest water-quality record available for the Neuse River, dating back at least twenty years. In order to use these data to evaluate water-quality trends, several different methods of data modeling and data transformation have been applied. All of the methods for trend analysis that have been used were developed for this study. Since all data-smoothing trend analysis techniques are subject to error, the methods used and their results are described in detail. To facilitate discussion, the data manipulations will be catagorized into three methods of evaluating trends:

1. Pollution-load estimation
2. Discharge normalization, and
3. Discharge-frequency weighting

These three methods of trend analysis share a few basic assumptions. First, the laboratory data are assumed to be comparable from year to year. Several consitutuents that show suspicious changes in concentration levels from one year to the next have been dropped from consideration in trend analysis. We have also assumed that grouping the data by water year, and data transformation procedures employed in the trend analysis methods will counter sampling bias.

Pollution-load estimation technique

The pollution-load estimation technique has been briefly outlined in the Pollution section of this report and is described fully by Wilder and Simmons (1978), and Simmons and Heath (1979). The annual pollution loads estimated by this technique (tables 10 and 11) are plotted against time, and the regression line through the points provides a gross measure of trend over the period of record. An example of this type of plot is presented in figure 26 which shows increasing trends in potassium pollution loads at both stations. The regression lines indicated in figure 26 both have slopes that are significantly different from zero slope (two-tailed *t*-test, 0.05 probability level).

Although figure 26 indicates that there has been an increase in potassium load over the past 20 years, there is still a great deal of year-to-year variation in the data. The pollution load is the product of pollution concentration and discharge, therefore, annual pollution loads vary directly with annual discharges. The pollution load estimation process (see POLLUTION) employs several procedures that are important to consider in trend analysis. Hydrograph separation adds error to pollution-load estimates already highly influenced by year-to-year variances in discharge. The combination of hydrograph-separation error with the annual variation due to discharge explains much of the scatter seen in the plot of figure 26. Clearly, extraction of the effect that discharge has on constituent loads is highly desirable, particularly to detect trends in constituents that may not be of sufficient magnitude to overshadow the effects of discharge. The discharge-normalization and discharge-frequency-weighting methods, to be described presently, are both techniques designed to reduce or eliminate the variation in constituent concentration due to discharge.

The dependency of the pollution-load estimation technique on the accuracy of regression relations adds a complicating factor to trend analysis. Some yearly variation due to inaccuracy of the constituent- specific conductance relations is expected, and can be demonstrated by a comparison of observed and computed constituent concentrations. This inaccuracy is generally ± 5 to 10 percent. However, this variance is year-by-year, and does not necessarily cause a bias in the overall 20-year trends. Therefore, the pollution-load estimation technique has been applied only in the evaluation of long-term trends.

Discharge-normalization technique

The second approach of transformation of the water-quality data, discharge normalization, was developed by Charles Daniel (U.S. Geological Survey, written commun., December 1978). This method can be broken down into three steps:

1. Shift daily discharges on an annual basis toward a central period-of-record discharge value,
2. Adjust daily specific conductance to compensate for the shift in discharges, and
3. Estimate daily constituent concentrations using the adjusted specific conductance values and con-

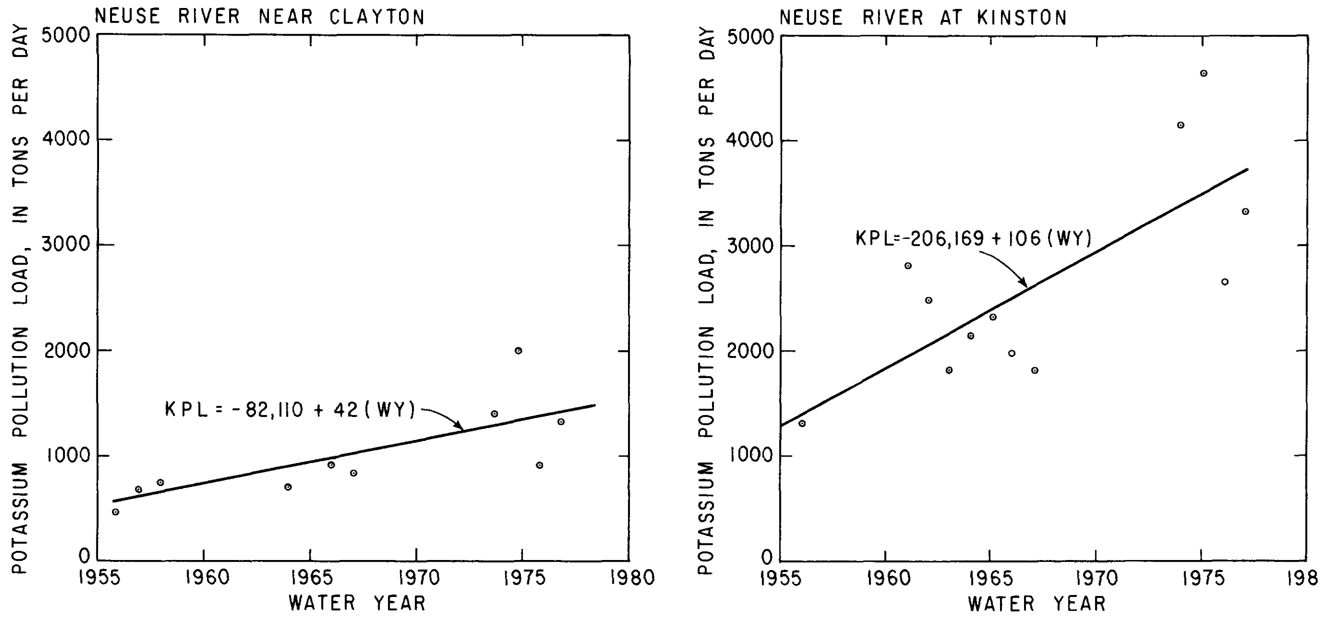

Figure 26. Potassium pollution loads (KPL), with regression lines for the Neuse River near Clayton and at Kinston (WY=water year).

stituent concentration versus specific conductance relations.

The estimated concentrations are averaged to produce normalized annual concentrations, or normalized annual loads are derived from the concentrations and the normalized discharges. The term "normalization" as used here refers to the process of adjusting discharge so that the central value of each annual discharge-frequency distribution coincides with the central value of the period-of-record discharge-frequency distribution. A flow chart of the discharge-normalization technique is presented in figure 27.

The first step initially requires the calculation of a central discharge value for the period of discharge record. The central value used in this analysis was the average of the mean (x) and median (m) discharges for the period of record (R, steps 1–3 in fig. 27):

$$\frac{\bar{x}_R + m_R}{2} = V_R \qquad (4)$$

where V_R is the central discharge value for the period of record. The same procedure is followed to calculate values for each year (Y) that has daily specific conductance record (steps 4 and 5 in fig. 27):

$$\frac{x_Y + m_Y}{2} = V_Y \qquad (5)$$

where V_Y is the central discharge value for a single year.

The difference between the central discharge values for each year (V_Y), and the period of record value (V_R) is the value (V_{RY}) used to normalize the daily discharges (Q_D, steps 6 and 7 in fig. 27):

$$V_R - V_Y = V_{RY} \qquad (6)$$

and

$$Q_D + V_{RY} = Q_S \qquad (7)$$

where Q_S is the shifted daily discharge for one day. This is done for each day of each year with specific conductance data.

The second step of the normalization procedure is recalculation of daily specific conductances to compensate for the shifted discharges. Using discharge–specific conductance relations, values of specific conductance are estimated from the actual daily discharges (SC_E) and from the shifted daily discharges (SC_S). The differences between these two different calculated specific conductances (SC_{ES}) are in turn subtracted from the observed daily specific conductances (SC_D), to produce normalized specific conductance values (SC_N, steps 8–13 in fig. 27):

$$\mathrm{SC}_E - \mathrm{SC}_S = \mathrm{SC}_{ES} \qquad (8)$$

and

$$\mathrm{SC}_D - \mathrm{SC}_{ES} = \mathrm{SC}_N \qquad (9)$$

where SC_N is calculated for each day of each year that has daily specific conductance data. The shifted specific conductance (SC_S) is used in equation 6 to compensate for discharge variation. To preserve any variation that is due to causes other than dilution, the actual specific conductance (SC_D) is used in equation 9.

Finally, to calculate normalized constituent concentrations, the normalized specific conductances (SC_N) are entered into constituent concentration–specific conductance relations (steps 14–16 in fig. 27). The resultant daily constituent concentrations are averaged to produce annual concentrations, or are used with normalized daily discharges to evaluate annual loads. Normalized annual loads or concentrations are regressed with time to produce trend lines. Example results of the discharge-normalization approach for annual potassium concentrations are given in figure 28. Increasing trends in potassium concentrations are apparent at both stations. The regression lines shown in figure 28 both have slopes that are significantly different from a slope of zero (two-tailed t-test, at a probability level of 0.05). Normalized dissolved-solids loads at Kinston, are compared to total annual loads in figure 29. The actual total loads show a higher degree of irregularity than the normalized loads. This comparison illustrates that the discharge-normalization technique can reduce the apparent data variation that is thought to be caused by fluctuation in discharge. Water-quality trends evaluated by this technique are presented in the Results section of this report.

The discharge-normalization technique employs two sets of regression relations to produce normalized values. Just as in the pollution-load estimation technique, these regression relations may add error to trend analysis. Furthermore, in the normalization analysis for the Neuse River, it was necessary to use estimates of daily specific conductance for the 1964–67 water years. These estimates were derived from regressions between daily specific-conductance values measured at upstream stations (Neuse River near Falls, and at Goldsboro) and the instantaneous specific conductance values measured from periodic samples taken near Clayton and at Kinston (see Pollution section). In other words, as many as three sets of regression equations were used to produce normalized values for several of the years.

Discharge-frequency-weighting technique

The third method of evaluating water-quality trends, discharge-frequency weighting, involves a simple process of weighting of the constituent concentrations relative to the discharge-frequency distribution for the entire period of record. The discharge-frequency-weighting technique was developed by the author

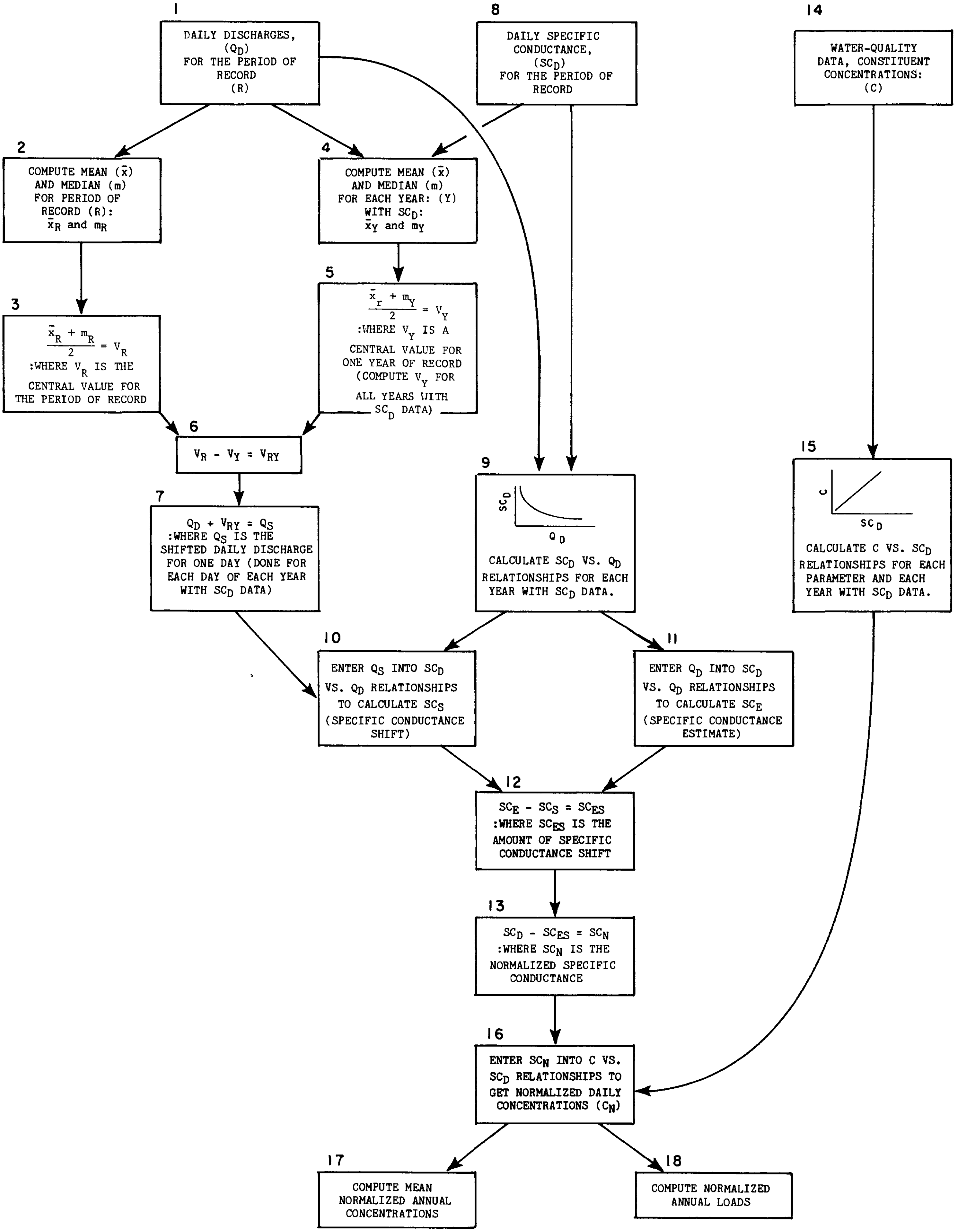

Figure 27. Flow diagram of the discharge-normalization technique.

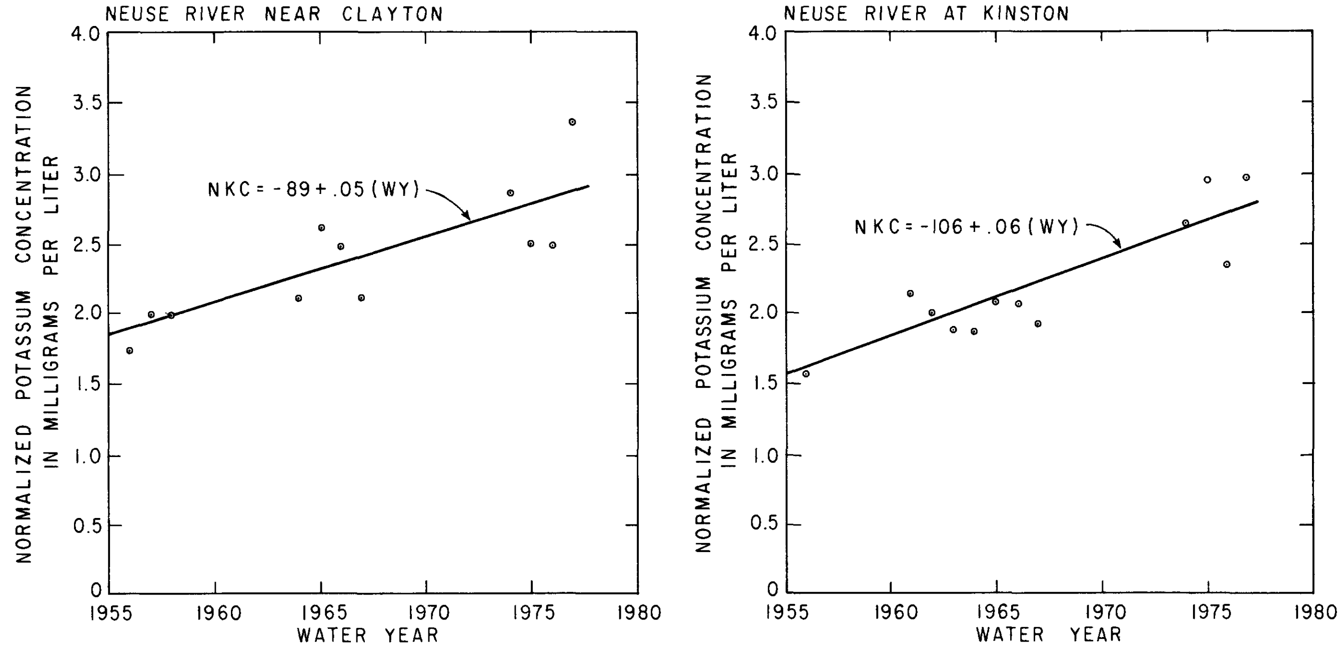

Figure 28. Normalized potassium concentrations, with regression lines for the Neuse River near Clayton and at Kinston.

(March, 1978) specifically for this study. A summary flow chart of this approach is presented in figure 30.

The first step in this procedure is to calculate the discharge-frequency distribution for the entire period of discharge record for each station (steps 1 and 2 in fig. 30). The instantaneous discharges associated with each sample (step 3 in fig. 30) are then matched to the corresponding discharge-frequency intervals (step 4 in fig. 30). If two or more samples have associated discharges that fall within the same frequency interval, then the constituent concentrations for these samples are averaged (step 5 in fig. 30). Next, the area beneath the discharge-frequency curve is apportioned to the sample concentrations. To do this, each sample concentration is assigned the area of its matched frequency interval (step 4 in fig. 30) plus the area of adjacent intervals, up to the midpoint between two sample values (step 6 in fig. 30). The resultant apportioning associates each sample concentration with a certain range of flows. The total area of the frequency intervals assigned to each sample value (a_i), or average sample value in the case where several instantaneous discharges are similar, is divided by the total area of all frequency intervals (a_T). The result is an interval weight (W_i; step 7 in fig. 30):

$$W_i = a_i / a_T \qquad (10)$$

The interval weights (step 7 in fig. 30), are multiplied by the interval concentrations ($\bar{C}_i$) and summed to produce an annual weighted concentration(C_W;step 8 in fig. 30).

$$C_W = \sum_{i=1}^{n} W_i \bar{C}_i \qquad (11)$$

The annual weighted concentrations are then regressed on time to produce trend lines.

Example results of the discharge-frequency-weighting approch for potassium are given in figure 31. Once again, increasing trends in potassium concentrations are apparent at both stations.

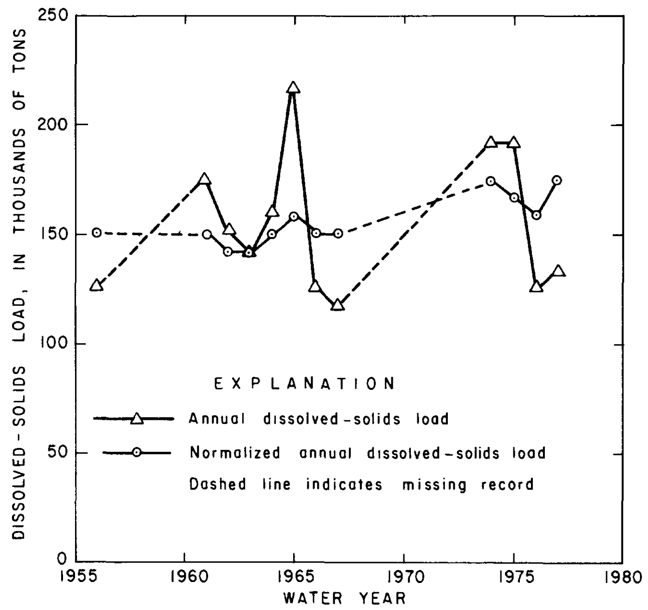

Figure 29. A comparison of normalized and nonnormalized annual dissolved-solids loads for the Neuse River at Kinston.

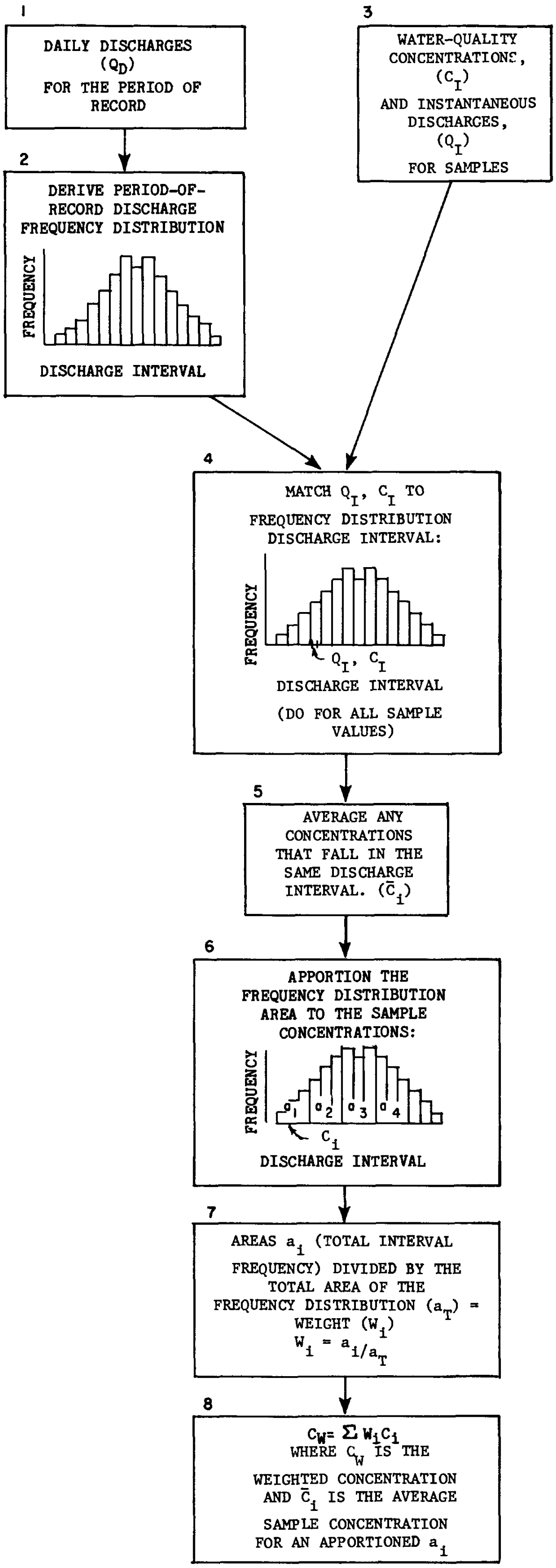

Figure 30. Flow-diagram of the discharge-frequency-weighting tecnhique used for trend analysis.

One advantage of the discharge-frequency-weighting technique is that it is not restricted in application only to years with complete daily specific conductance records. Therefore, the concentrations shown in the plots of figure 31 are annual averages of weighted constituent analyses.

Discharge normalization and discharge-frequency weighting are two approaches to remove the effects of variation in discharge on constituent concentrations. The two methods attempt to reduce yearly discharges to a constant value, in order to allow year-to-year comparison of water-quality variation from sources other than streamflow changes. One test of whether the two techniques produce values that are independent from discharge is to regress the normalized or weighted values against streamflow. In all cases studied for trend analysis, no significant correlations were found between annual discharges and the results of the normalizing or weighting methods. This indicates that the techniques remove or reduce the effects of discharge to a level below that of other causes of water-quality variation.

The weighted potassium concentrations plotted in figure 31 show scatter similar to the results for potassium of the discharge-normalization technique shown in figure 28. In fact, the results of both methods for many of the water-quality constituents are similar. A regression comparison of the results of the two methods produces several highly correlated ($r=.85$) relationships. Although there is more overall scatter in the weighted results than in the normalized results, the conclusions that can be drawn from both methods are comparable.

Results

Long-term trends

The pollution-load estimation, discharge-normalization, and discharge-weighting methods all produce annual values for water-quality parameters. These values are plotted against time, and regression lines evaluated for these plots represent trends over the period of record. Possible explanations for peaks or dips in values for individual years are of interest, however, such evaluation is beyond the scope of this report.

Equations for regression curves fit through the annual values produced by each of the three methods are shown in table 14. Equations with slope terms that are statistically different from a zero slope (two-tailed *t*-test, probability level=0.05) are also indicated in table 14.

Trend lines for dissolved solids produced by the three methods indicate that although a slight long-term increase in concentration is evident at Kinston, overall, the change has been slight. Plots of the results of the normalization and weighting techniques (fig. 32) illustrate that the exact nature of the slight change in dissolved solids is unclear.

Table 14. Regression equations for results of the pollution-load method, discharge-normalization technique, and the discharge-frequency-weighting approach.

[The test of significance of the regression slope was a two-tail t-test at a probability level of 0.05. (T = water year - 1900)]

	Neuse River near Clayton			Neuse River at Kinston		
	Regression equation	r	Slope different from zero?	Regression equation	r	Slope different from zero?
Normalized calcium conc.	$=301-13.7(T)+0.212(T^2)$ $-0.001(T^3)$	0.60	No	$=2.4+0.041(T)$	0.61	Yes
Calcium pollution load	$=49+35(T)$	.42	No	$=-958+92(T)$	.49	No
Weighted magnesium conc.	$=4.7-0.081(T)+0.0062(T^2)$	.36	No	$=0.35+0.019(T)$	.59	Yes
Normalized sodium conc.	$=-95+3.1(T)-0.023(T^2)$	.85	Yes	$=-173+8.3(T)-0.125(T^2)$ $+0.00063(T^3)$	.36	No
Weighted sodium conc.	$=-140+4.6(T)-0.034(T^2)$	.60	No	$=631.8-29.14(T)+0.451(T^2)$ $-0.0023(T^3)$	.35	Yes
Sodium pollution load	$=-78{,}228+2514(T)-18.5(T^2)$	.67	Yes	$=-62285+2189(T)-16.4(T^2)$	.52	No
Normalized potassium conc.	$=-0.72+0.046(T)$	.80	Yes	$=-1.5+0.055(T)$	.87	Yes
Weighted potassium conc.	$=-0.68+0.049(T)$	.82	Yes	$=-0.29+0.038(T)$	.86	Yes
Potassium pollution load	$=-1828+42(T)$	.76	Yes	$=-4484+106(T)$	.74	Yes
Normalized sulfate conc.	$=-3.8+0.19(T)$	.73	Yes	$=-13+0.33(T)$	.78	Yes
Weighted sulfate conc.	$=-8.7+0.25(T)$	.80	Yes	$=-6+0.22(T)$	.70	Yes
Sulfate pollution load	$=-10{,}657+204(T)$	.78	Yes	$=-29{,}480+514(T)$	.81	Yes
Normalized chloride conc.	$=112+3.6(T)-0.027(T^2)$	.69	Yes	$=-29+1.1(T)-0.008(T^2)$	.52	No
Weighted chloride conc.	$=-157+5.4(T)-0.041(T^2)$	.68	No	$=1015-48(T)+0.74(T^2)$ $-0.0038(T^3)$	.77	Yes
Chloride pollution load	$=98{,}699+3132(T)-23.2(T^2)$	.67	Yes	$=-266{,}708+8203(T)-59.9(T^2)$	.70	Yes
Normalized dissolved-solids conc.	$=-325+12.3(T)-0.090(T^2)$	.71	Yes	$=26+0.62(T)$	.78	Yes
Weighted dissolved-solids conc.	$=6476-294.3(T)+4.49(T^2)$ $-0.022(T^3)$	.48	No	$=5928-268(T)+4.05(T^2)$ $-0.020(T^3)$	.81	Yes
Dissolved solids pollution load	$=-34{,}2441+11{,}517(T)-86(T^2)$	.42	No	$=8735.8+1020(T)$	.43	No

Trend lines for potassium have already been shown in figures 26, 28 and 31. The regression equations for the potassium results are all linear, and have positive slopes significantly different from a slope of zero. These results indicate a definite long-term increase in potassium concentration. The normalization and weighting techniques give potassium regression lines that have 1977 concentrations approximately 50 percent greater than 1956 values.

Trend lines for sulfate given by the normalization and weighting techniques are shown in figure 33. As found for the potassium results, the sulfate regression equations are linear and have positive slopes significantly different from a slope of zero. These results show a definite long-term increase in sulfate concentration. The discharge-normalization technique indicates a 62 percent sulfate concentration increase at Clayton and a 124 percent increase at Kinston. The weighting approach shows a 108 percent increase at Clayton and a 93 percent increase at Kinston.

The results for calcium, chloride, and sodium show no conclusively increasing or decreasing long-term trends. Although subtle long-term changes are shown by each of the methods, no distinct pattern is evident, suggesting that concentrations of these constituents have remained relatively constant since 1956. The lack of change since 1956 is in itself an important result. Current levels of calcium, chloride and sodium in the Neuse are higher, due to pollution, than levels measured at baseline water-quality station sites (see fig. 22). Yet trend analysis shows no conclusive increases or decreases in the loads or concentrations of these constituents in over 20 years. This may indicate that levels of calcium, chlorides and sodium in the Neuse River stabilized before 1956.

A few other of the regression equations shown on table 14 have statistically significant non-zero slopes. At Kinston, normalized calcium concentrations, weighted magnesium concentrations, and weighted specific conductance values have positive slopes, indicating increas-

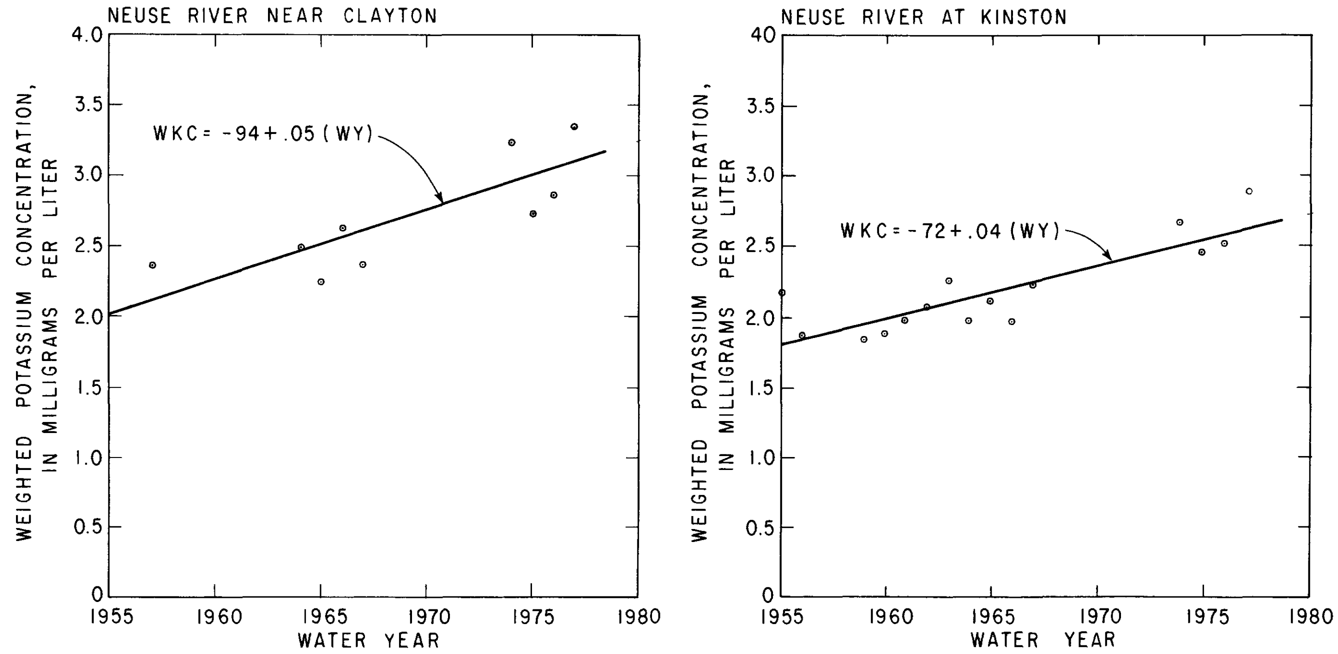

Figure 31. Weighted potassium concentrations, (WKC) with regression lines, for the Neuse River near Clayton and at Kinston, (WY=water year).

ing long-term trends. However, these trends were not detected at Clayton. Significantly, the increasing trend in weighted specific conductance reinforces the conclusion that dissolved solids has shown a slight increase over time at the Kinston station.

Overall, increasing trends in potassium and sulfate levels are indicated by all three trend analysis methods for both Clayton and Kinston. An increasing trend for dissolved solids at Kinston is shown by the normalization technique. None of the parameters studied show con-

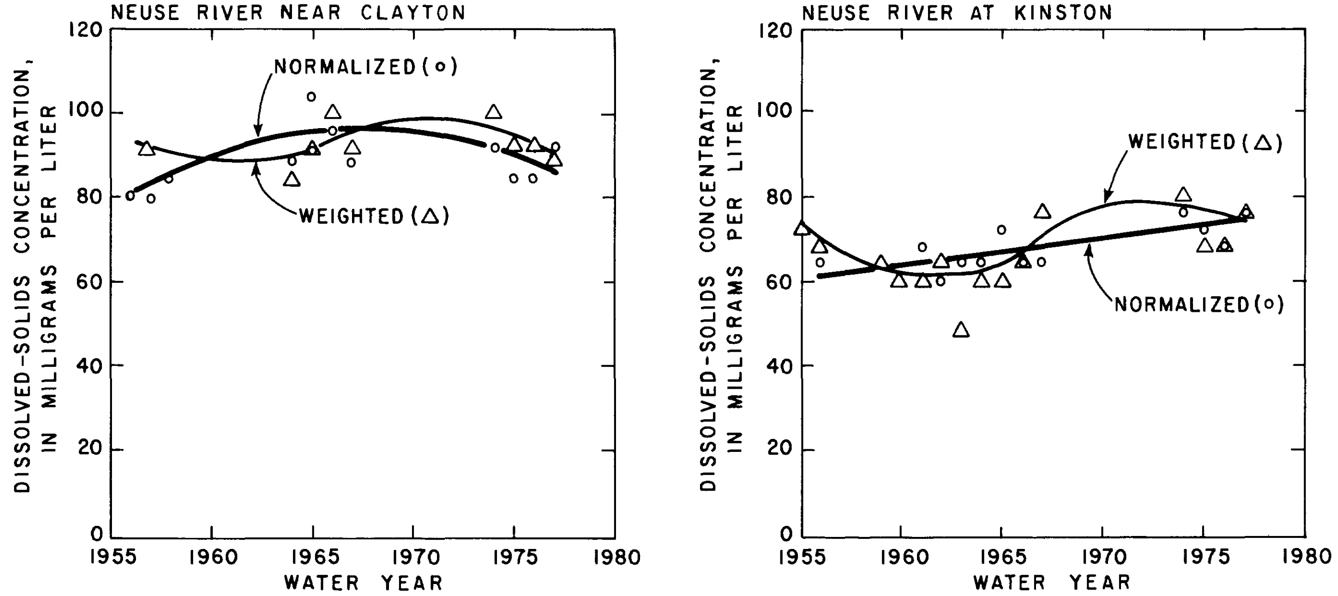

Figure 32. Weighted and normalized dissolved-solids concentrations, with regression lines, for the Neuse River near Clayton and at Kinston.

clusively decreasing trends. However, the relatively stable dissolved-solids trend observed for Clayton implies that some other dissolved components have decreased to offset the increases in potassium and sulfate. It is possible that concentration levels of some of the constituents actually have decreased, but in amounts undetectable by the trend-analysis methods.

The cause of the increase in potassium and sulfate concentration in the Neuse regardless of improved water treatment is unclear, however, the increase serves to illustrate an important point. Modern wastewater treatment plants are rarely designed to treat all of the materials dissolved in wastewater. Many dissolved constituents simply pass through the treatment plant, while other constituents may increase in concentration due to the addition of chemical materials used in the treatment process. Although potassium and sulfate are not as relevant to water-quality impact evaluation as constituents such as nutrients or toxic materials, the long-term increases observed for potassium and sulfate are indications of the increasing impact of man on the Neuse River. Other dissolved materials that are not routinely measured in the Neuse and that are unaffected by wastewater treatment processes may have had similar long-term increases in concentrations.

One probable cause for the observed increase in sulfate concentration is air pollution. Sulfate is but one of the many forms that sulfur may take when released into the air from the combustion of coal and oil. Oxidation in the atmosphere of inorganic gases including hydrogen sulfide (H_2S), sulfur dioxide (SO_3) and sulfur trioxide (SO_3) can produce acids, such as sulfuric acid (H_2SO_4), which are prime components of acid precipitation (Likens and others, 1979). Although the current evidence of a long-term change in pH in the Neuse River is inconclusive, it is probable that much of the observed increase in sulfate concentration is a result of acid rain.

Water quality—population relations

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

The best relations relating demography to water-quality for the Neuse basin were obtained using population statistics combined with measures of industrial activity. Population has shown a fairly uniform linear increase in the Neuse River basin over the past 20 years. But, industiral activity, as measured by manufacturing employment, has not been as uniform as the increase in population. A combined index of the two demographic measures gives a better means of explanation of the wide year-to-year variation seen in the annual values produced by the trend analysis for the Neuse.

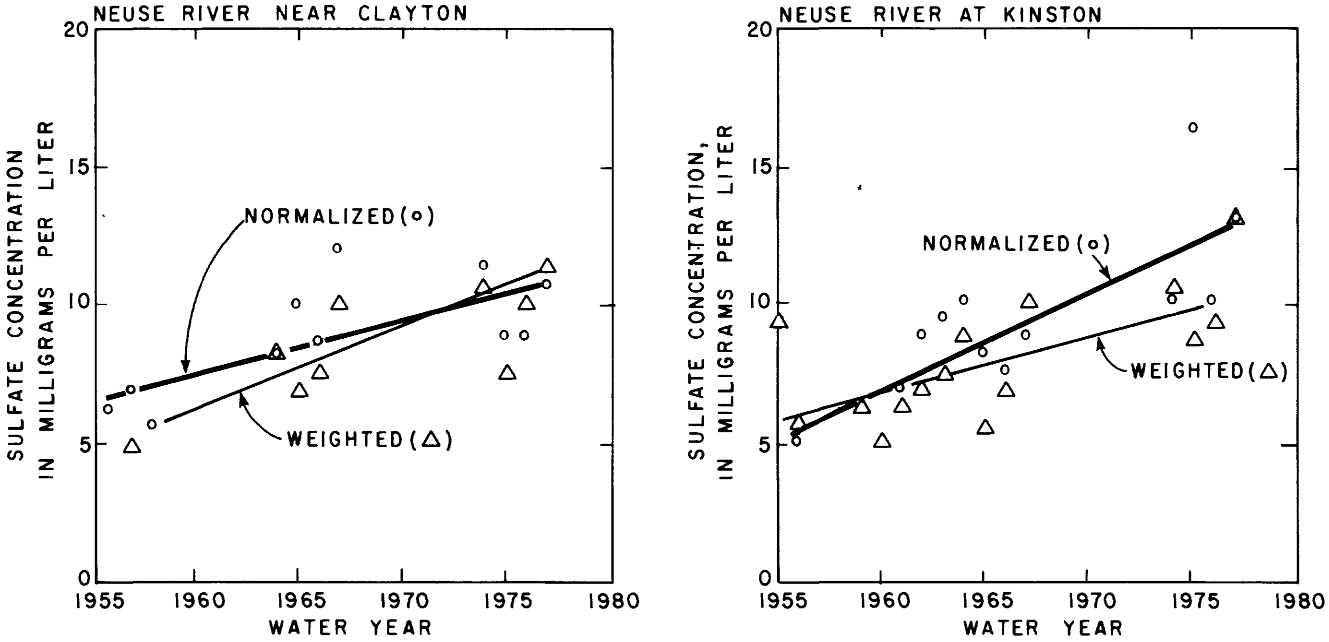

Figure 33. Weighted and normalized sulfate concentrations, with regression lines, for the Neuse River near Clayton and at Kinston.

Table 15. Regression equations for relations between chemical or physical constituents and the manufacturing employment-population index for the Neuse River near Clayton and at Kinston.

Constituent	CLAYTON Regression equation ME=Manufacturing employment-population index	Correlation coefficient r	KINSTON Regression equation ME=Manufacturing employment-population index	Correlation coefficient r
Normalized dissolved-solids concentration (NDS)	-	-	$NDS=48+.00050(ME)$	0.85
Potassium pollution load (PK)	$PK=-82110+42(ME)$	0.76	$PK=-206{,}169+106(ME)$	.73
Normalized potassium concentration (NK)	$NK=-88+.046(ME)$	.80	$NK=-106+.055(ME)$	.87
Weighted potassium concentration (WK)	$WK=-94+.049(ME)$	.82	$WK=-72+.038(ME)$	.85
Sulfate pollution load (PS)	$PS=-398{,}482+204(ME)$	.77	$PS=-1{,}006{,}707+514(ME)$	.81
Normalized sulfate concentration (NS)	$NS=-362+.19(ME)$	.73	$NS=-642+.33(ME)$	.78
Weighted sulfate concentration (WS)	$WS=-485+.25(ME)$	.80	$WS=-421+.22(ME)$	.70
Normalized calcium concentration (NC)	-	-	$NC=-76+.041(ME)$	.61
Weighted specific conductance (WSC)	-	-	$WSC=-1492+.81(ME)$	.52

Monthly manufacturing employment estimates for each county are prepared by the North Carolina Employment Security Commission (1978). Manufacturing employment includes food, textile, apparel, lumber, transportation equipment and other industries. Excluded from the manufacturing employment count are: agricultural, construction, trade, utility, service and government employment. The county manufacturing employment values supplied by the Employment Security Commission were weighted by subbasin population estimates provided by the North Carolina Department of Water and Air Resources (1972). The result of this calculation is a combined index of manufacturing employment and population for the drainage area upstream of each station.

The best regressions between the manufacturing employment-population index and water-quality constituents were for the normalized and weighted potassium and dissolved solids concentrations at Kinston. The relation for normalized dissolved solids at Kinston is shown in figure 34. These relations and all other regressions that passed tests of significance at the 95 percent probability level are listed in table 15.

Overall, the relations show increasing constituent concentrations with increasing manufacturing employment weighted by population. In fact, even a considerable amount of year-to-year variation is explained by the changes in economic conditions reflected by the index. Given a projected manufacturing-population scenario, these relations could be used to approximate future water-quality conditions in the Neuse River.

SUMMARY

Assessment of Neuse River water quality centered on the identification of water-quality variations in

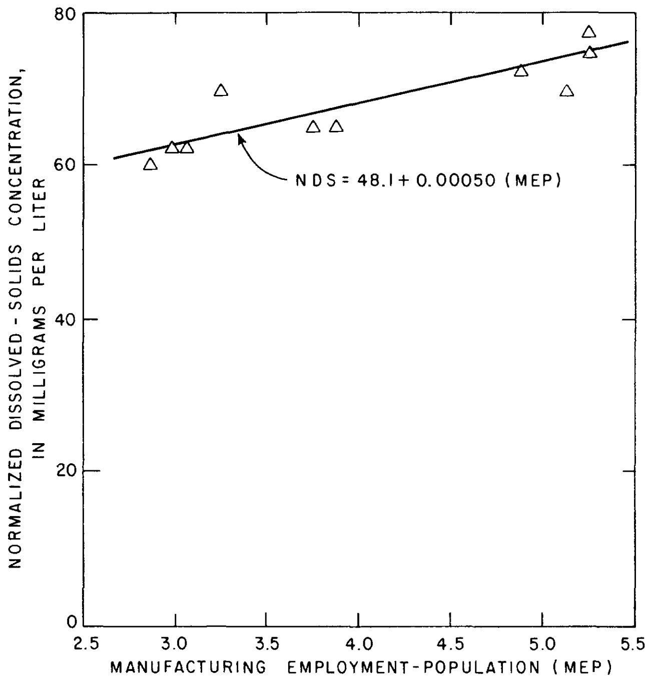

Figure 34. Normalized dissolved-solids concentration for the Neuse River at Kinston plotted against the manufacturing employment-population index for the river basin upstream of Kinston.

reference to water-quality standards, an estimation of the amount of pollution caused by man and an evaluation of long-term trends in concentrations of major dissolved constituents.

Two sampling stations, Neuse River near Clayton (02087500) and Neuse River at Kinston (02089500) have more than 12 years of water-quality data collected during the period from 1955 to 1978. The Clayton station provides information on the urbanized upper fourth of the basin (1,129 mi^2), and the Kinston station gives data from the predominantly rural mid-section of the basin (2,690 mi^2). The records are discontinuous, containing periods where no samples were collected for several years at a time.

A network of temporary stations located on small rural streams was used to define essentially unpolluted water quality. The constituent concentrations measured in these streams were extrapolated to the Neuse River in order to estimate baseline loads of the major chemical constituents.

The Neuse River is an important water-supply, and a valuable recreational and ecological resource. Fourteen percent of the total population of North Carolina currently live within the boundaries of the basin, and continued growth will make the river increasingly important as a water supply. A major reservoir on the Neuse River, Falls Lake, is currently (1979) under construction. The water quality of the streams feeding this lake will influence the use of the reservoir and its lifetime. This reservoir project and other ongoing stream modification will impact the Neuse River environment in future years. Presence of nuisance algal blooms downstream from the dam site is evidence of the current impact of stream modification.

The Neuse also serves an important role in waste disposal. Over 80 percent of the total waste-water discharge upstream from Clayton comes from waste-water treatment plants. Over 90 percent of the effluent discharged into the Neuse River segment between Clayton and Kinston comes from municipal waste-water treatment plants.

Overall, the water quality of the Neuse River is satisfactory for most uses. However, dissolved-oxygen levels at Clayton are low during the summer, when concentrations are less than 5 mg/L in 60 percent of the samples. Iron and manganese concentrations, and pH frequently reach undesirable levels. Approximately 20 percent of the analyses for lead and cadmium are at or above criteria levels for domestic water supply sources (EPA, 1976). Nutrient levels are generally high enough to allow rich algal growth, presently evident in summer at Kinston and just downstream from the Falls dam site. Currently, the problem of eutrophication is a growing concern in areas downstream from Kinston. Future problems with algal growth may occur in the completed Falls reservoir.

Levels of suspended sediment in the Neuse River are high in comparison to levels observed in pristine streams; however, the impacts of sediment concentrations are difficult to define. The response of suspended sediment concentration to flood discharges at Clayton is characterized by a rapid peaking of concentration at the beginning of a flood, followed by a recession. At Kinston, however, changes in discharge are nearly paralleled by changes in sediment concentration. The response observed at Clayton is typcial of discharge-sediment and discharge-pollutant first flush relations often seen in urbanized areas. This flush effect is due to the rapid storm runoff that occurs in urban areas; nutrient concentrations at Clayton are a good example of this effect.

Biological data indicate some organic pollution of the river. Algal genera often associated with organically enriched water appeared profusely in the Neuse River until 1976. At that time, the Neuse River Waste-water Treatment Plant, an advanced facility designed to treat sewage from the Raleigh metropolitian area, was put into operation. Algal assays taken in more recent years show algae not generally associated with organic enrichment. In addition, TOC concentrations in the Neuse River have decreased significantly since 1976. These results provide evidence of improvement of the water-quality of the Neuse due to activation of this treatment plant.

High total ammonia (median=0.25 mg/L as N) and moderate BOD_5 concentrations (median=3 mg/L) measured at Clayton also characterize the upper Neuse as organically enriched. However, no conclusive reduction in ammonia or BOD_5 is apparent after 1976, the year of the activation of the Raleigh treatment plant. In fact, significant increases in nitrogen and phosphorus concentrations are evident. These increases are probably due to the location of the new treatment plant, which is downstream from the discontinued plants, and closer to the Clayton site where water samples were collected.

Bacterial levels are high at both Clayton and Kinston. The recommended fecal coliform levels for bathing (EPA, 1976) are exceeded in 20 percent of the samples at Clayton and 40 percent of the samples at Kinston.

An estimate of pollution in the Neuse was determined by subtracting estimated baseline constituent loads from measured total loads. Only parameters that showed good correlations with specific conductance, and that had a complete historical record were used in this analysis. This method shows approximately 50 percent of the sulfate load at Clayton, 30 percent of the sulfate load at Kinston, 50 percent of the dissolved-solids load for both stations, 70 percent of the sodium and chloride loads at Clayton and 60 percent of the chloride and sodium loads at Kinston, to be pollution caused by man.

A comparison between dissolved-solids loads measured at Clayton and Kinston shows Clayton to have the greatest loads per square mile in all but the most recent years. This correlates well with the observation that the density of population in the area upstream from Clayton is the highest in the entire Neuse basin. A reduction of loads at Clayton and Kinston in recent years may be due to improved waste-water treatment provided by the Neuse River Waste-water Treatment plant.

Annual pollution-load estimates give rough measures of trends in water quality. However, these load estimates are the end result of several steps of data manipulation that may introduce some uncertainty. Furthermore, the annual loads are highly dependent on annual discharge. Clearly, extraction of the effect of discharge on constituent loads is necessary in order to define trends.

Two different data transformation methods made it possible to identify trends in water-quality constituent concentrations. These transformation recomputed concentrations as if the samples were collected at equal discharges over the period of record.

Both methods indicate that there has been a slight change in the chemistry of the Neuse River since 1956. Although long-term data are not available for constituents that are more relevant to water-quality impact analysis such as nutrients or toxic chemicals, increases of over 50 percent since 1956 in concentrations of sulfate and potassium are indicated. This is probably because modern waste-water treatment plants are not often designed to treat all of the materials dissolved in waste water; and sulfate and potassium, for example, simply pass through the treatment works and are released into the stream. Therefore, the increasing quantity of sulfate and potassium over the years is a good indication of the increasing impact that man has had on the water quality of the Neuse. The increase in sulfate especially is probably largely a result of acid percipitation, which is a growing problem in large areas of the United States.

The relation between pollutant levels and an index of demographic change provides a rough means of predicting future water quality. Regressions of dissolved-solids and potassium levels of the Neuse River at Kinston with basin manufacturing employment and basin population are examples of these realtions.

Demographic changes in the Neuse River basin have probably resulted in modifications of the chemistry of the Neuse that have not been detected in this limited study. Increases in population, or industrial and urban development may have resulted in pollution of the Neuse River by materials other than those emphasized in this report. A growing environmental awareness and improved laboratory techniques have promoted accurate identification of a wide variety of important trace materials in water, some of which that are collected now on a routine basis. These data will be invaluable in future assessments of the water quality of the Neuse River.

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