

GEOLOGICAL SURVEY CIRCULAR 764



Program for Evaluating Stream Quality in North Carolina

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

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

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V. E. McKelvey, *Director*

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ENGLISH-METRIC CONVERSION

[The following table gives the factors used to convert English units to metric or International System (SI).]

Multiply English units	by	to obtain SI units
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square feet (ft ²)	.0929	square meters (m ²)
square miles (mi ²)	2.590	square kilometers (km ²)
feet per mile (ft/mi)	.1894	meters per kilometer (m/km)
feet per day (ft/d)	.3048	meters per day (m/d)
cubic feet per second (ft ³ /s)	.02832	cubic meters per second (m ³ /s)
cubic feet per second per square mile (ft ³ /s ⁻¹ mi ⁻²)	.01093	cubic meters per second per square kilometer (m ³ s ⁻¹ km ⁻²)
cubic feet per day (ft ³ /d)	.02832	cubic meters per day (m ³ /d)
short ton	.9072	metric ton (t)
tons per day (ton/d)	.9072	metric ton per day (t/d)
tons per cubic feet (tons/ft ³)	32.03	metric tons per cubic meter (t/m ³)

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 loca-

tions 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 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

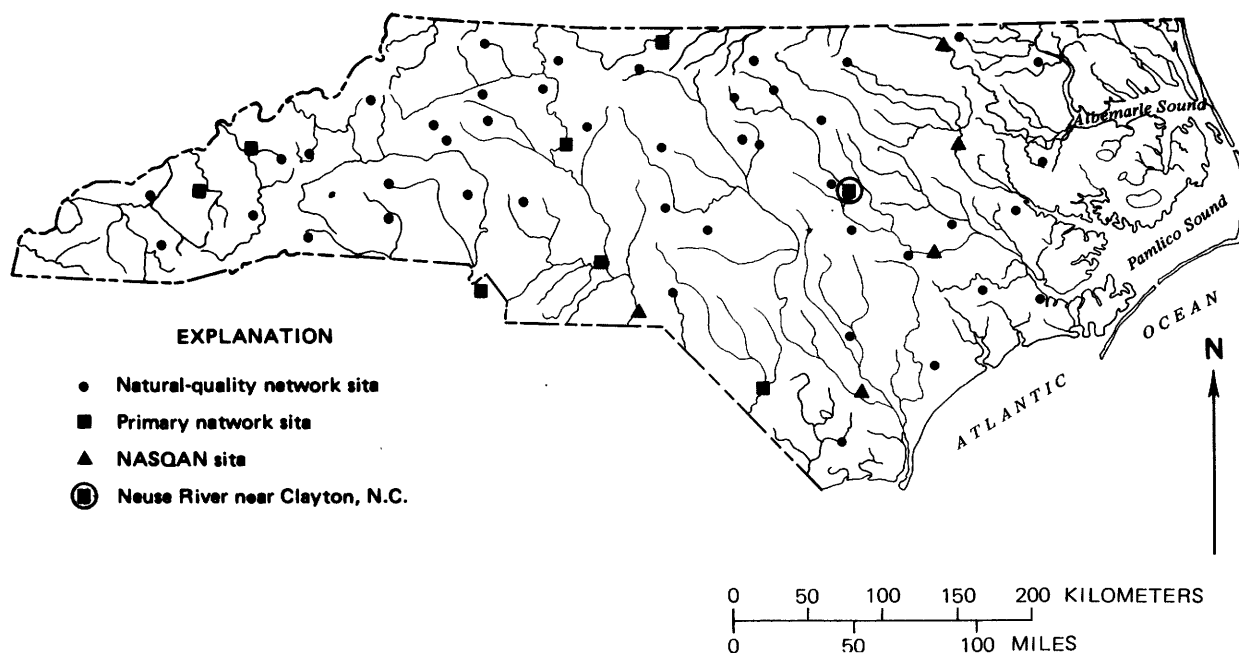


FIGURE 1. — Sampling stations in North Carolina's water-quality program.

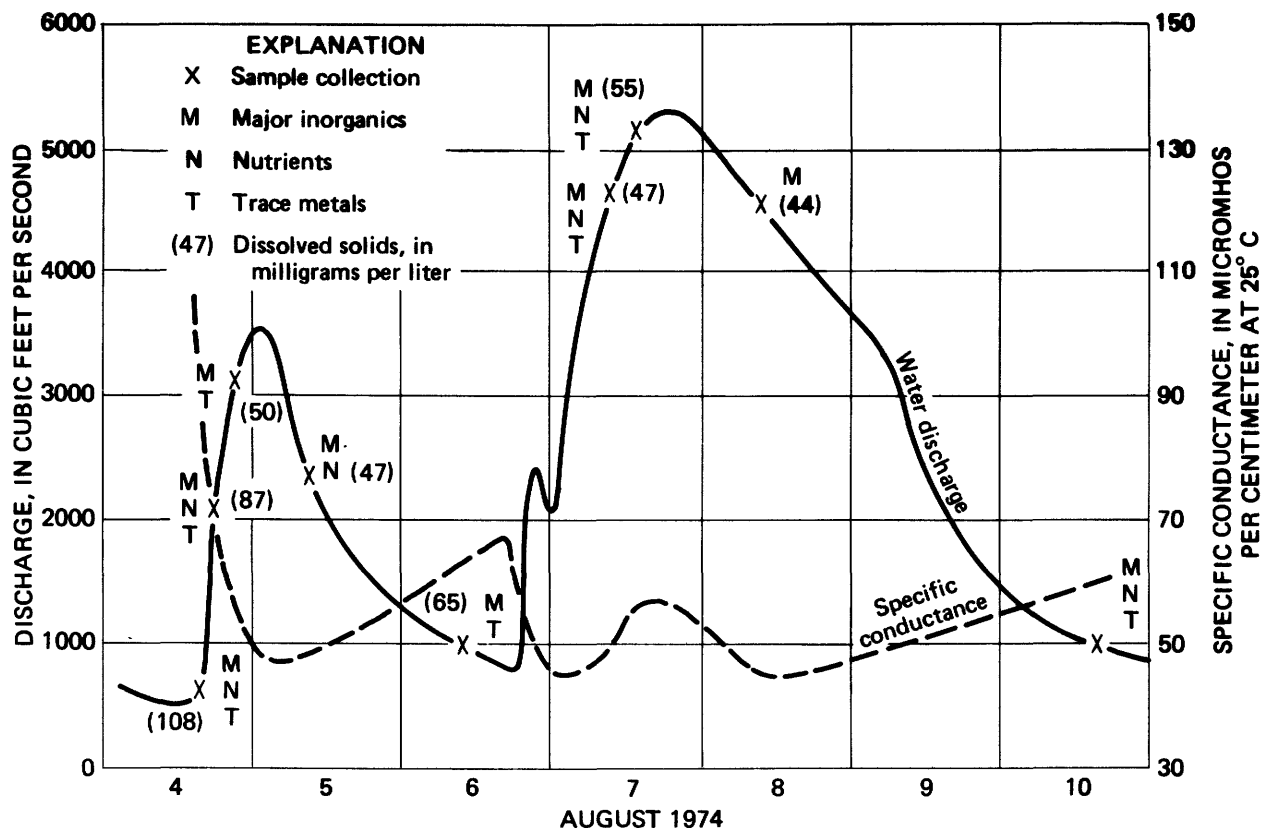


FIGURE 2. — Flood peaks on Neuse River near Clayton showing water-quality samples collected, types of analyses, and values of specific conductance and dissolved solids.

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 has 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 antecedent 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

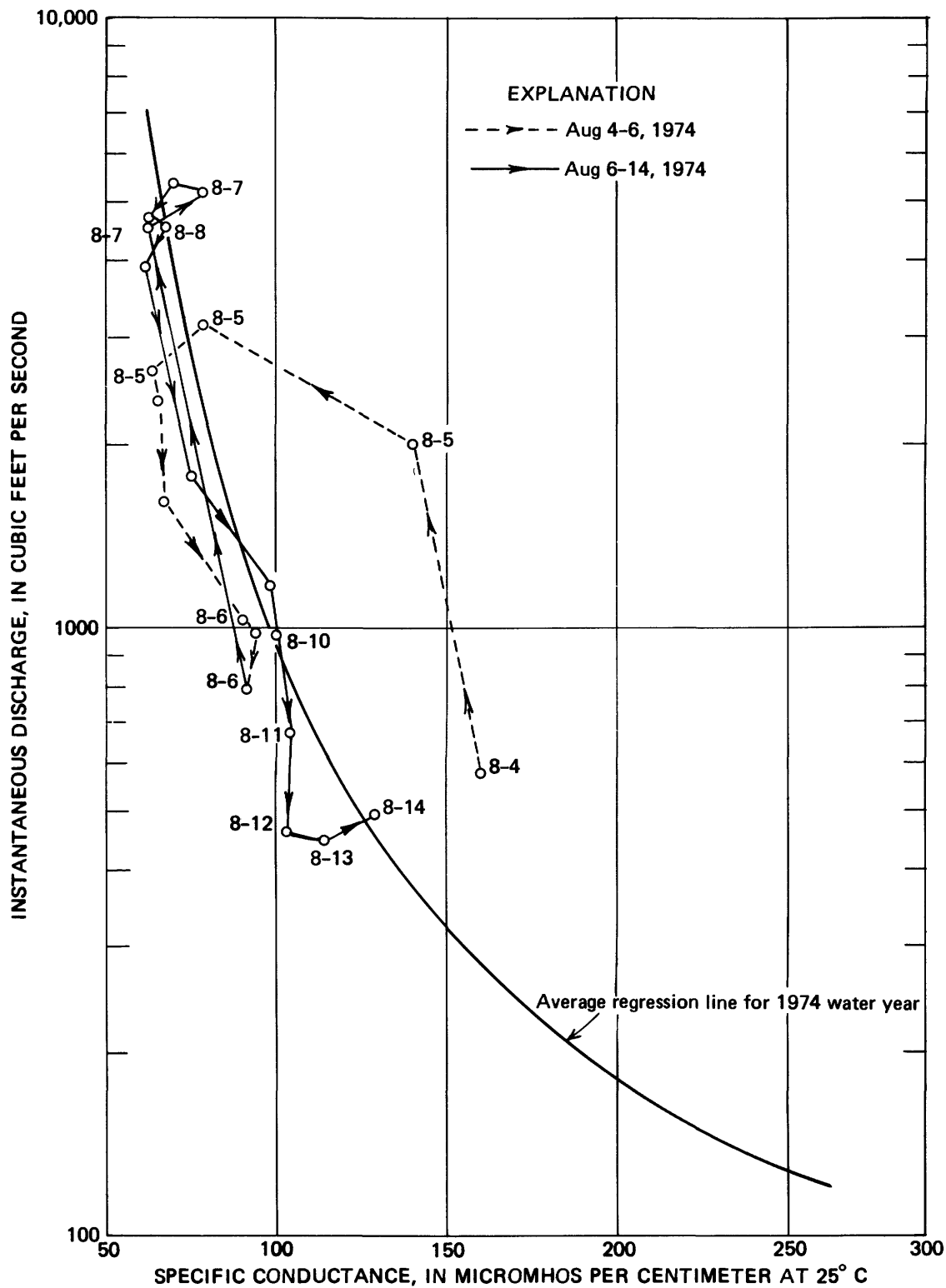


FIGURE 3. — Variations in specific conductance over two closely-spaced floods, Neuse River near Clayton.

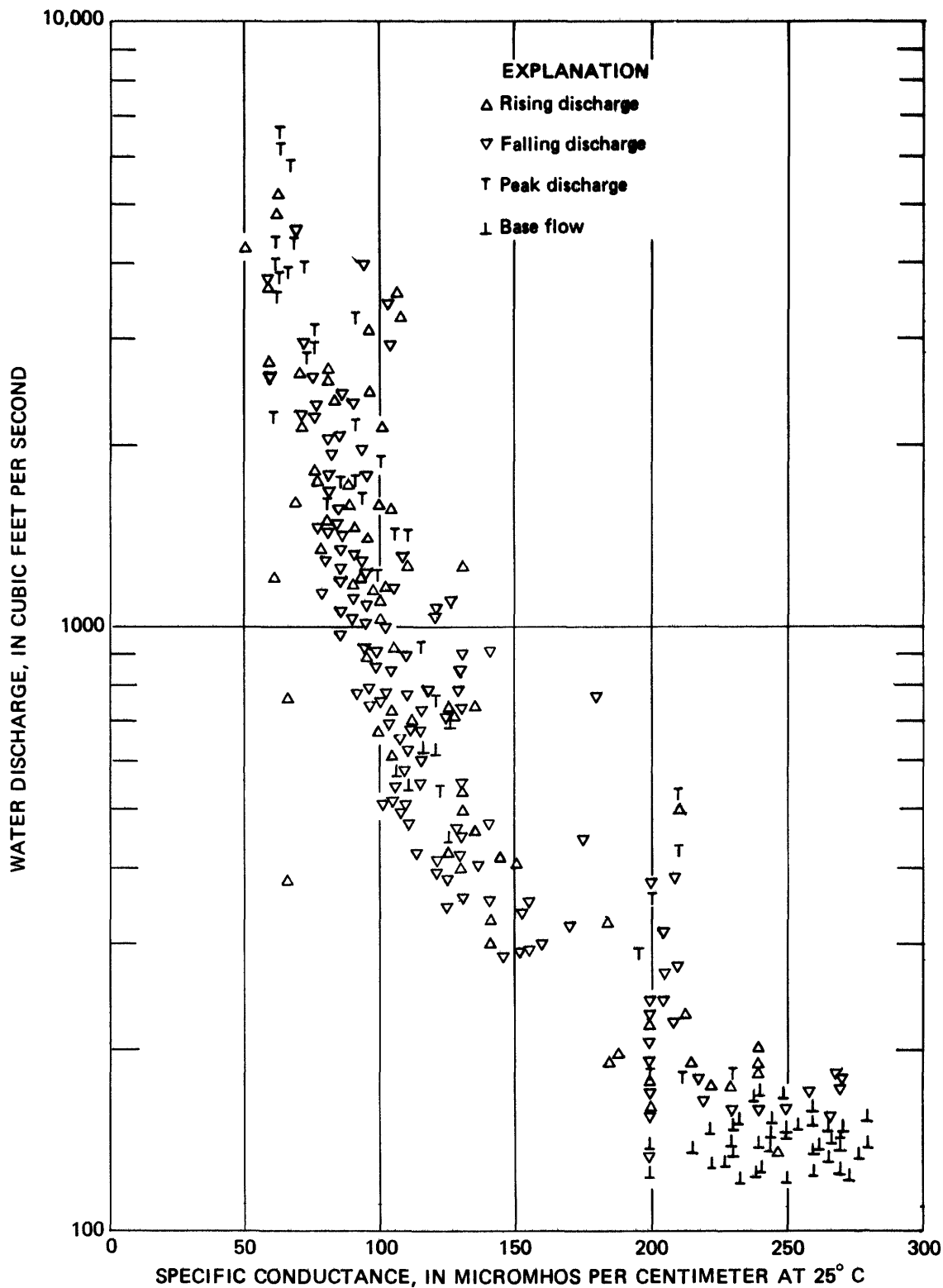


FIGURE 4. — Relations of specific conductance to discharge for rising, falling, and stable stages of Neuse River near Clayton, 1974.

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.

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

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

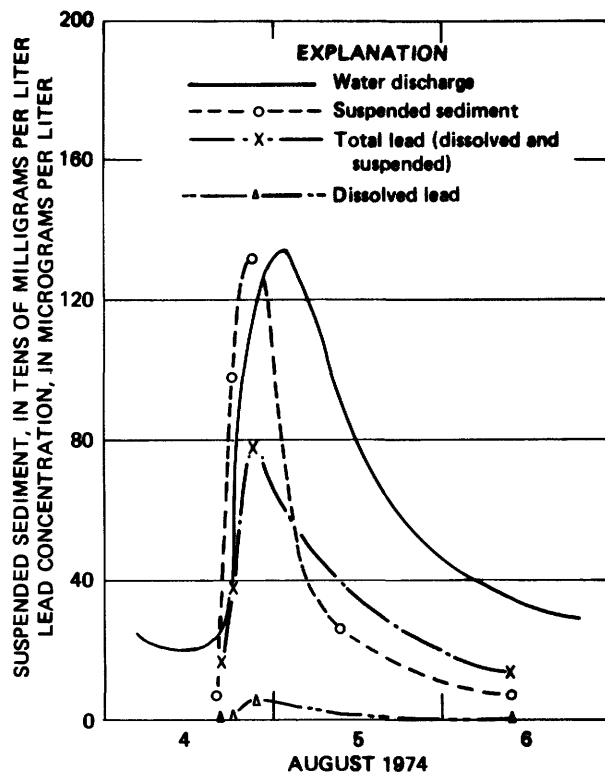


FIGURE 5. — Suspended sediment, and total and dissolved lead, Neuse River near Clayton.

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

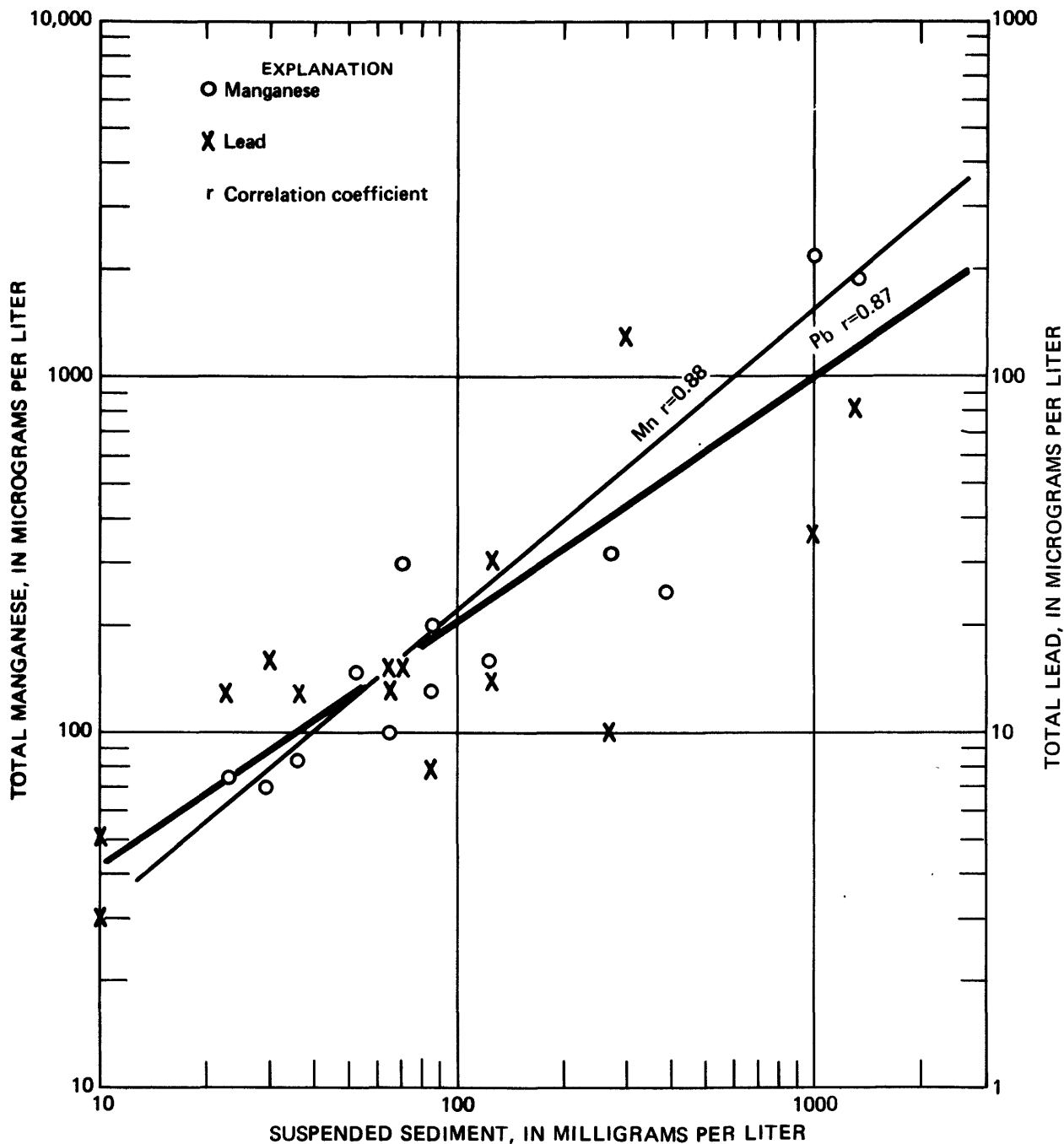


FIGURE 6. — Regressions of lead and manganese with suspended sediment, Neuse River near Clayton.

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.

For periods when water quality is constant the total dissolved load of any constituent being

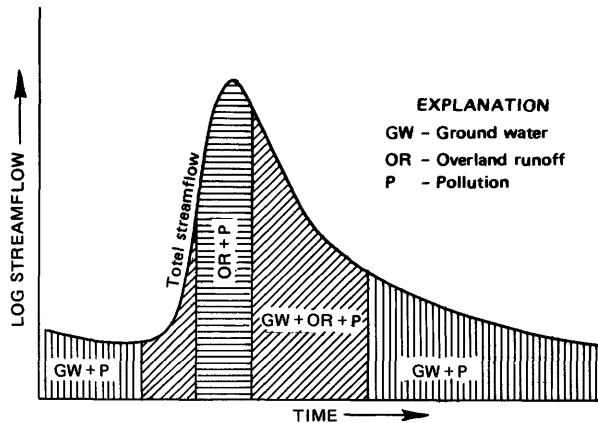


FIGURE 7. — Current sources of water and transported materials for a flood in an idealized stream.

transported by a stream can be calculated as follows:

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

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.

From figure 7 it follows that:

$$\text{total load} = \text{overland runoff load } (L_{or}) + \text{ground-water load } (L_{gw}) + \text{pollution load } (L_p)$$

$$L_t = k(Q_{or}C_{or} + Q_{gw}C_{gw} + Q_pC_p), \quad (2)$$

and, combining equations 1 and 2,

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

Only Q_t and C_t are subject to direct measurement. If methods can be found to make usefully accurate estimates 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 flood-flow 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 mi² (0.8 to 44 km²). 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 entrenchment 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

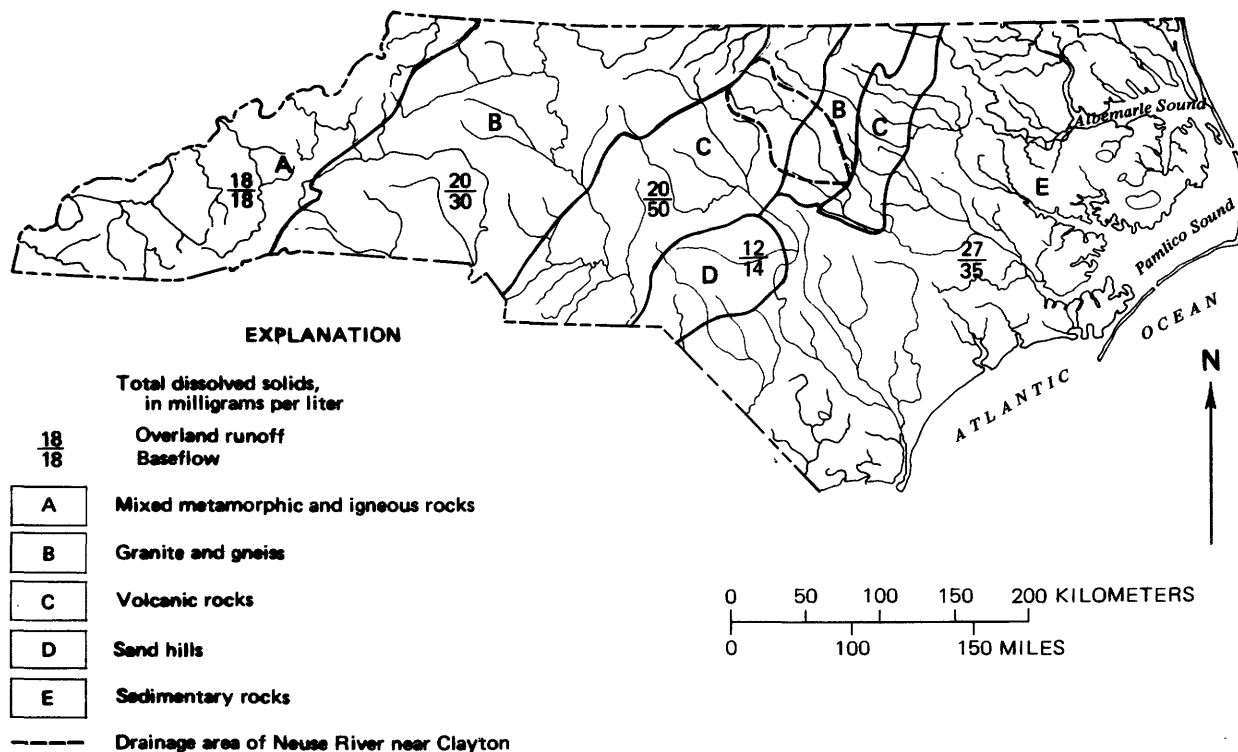


FIGURE 8.—Regionalized dissolved-solids concentrations of natural surface waters during periods of overland runoff and baseflow.

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 ground-water 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 experimentally defensible, but hydrologists can obtain useful answers with any of the methods. The answers are

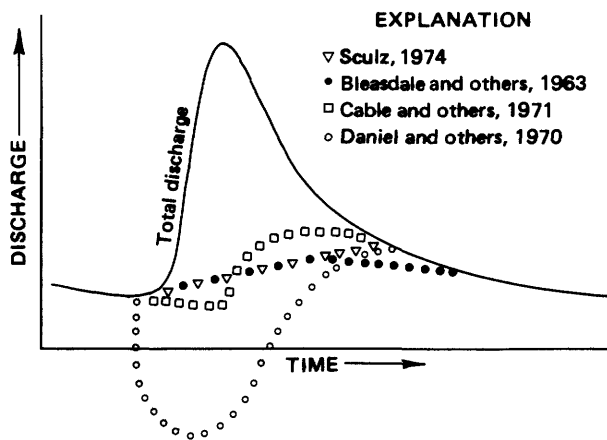


FIGURE 9.—Diagram of various proposals for sketching ground-water contribution during a flood.

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.

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:

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

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 $\frac{Tt}{a^2 S}$ 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:

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

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 $t \geq \frac{0.2a^2 S}{T}$ to $T = \infty$:

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

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

$$V = \frac{2q_c \left(0.933 \frac{a^2 S}{T} \right)}{2.3}. \quad (6)$$

The quantity $0.933 \frac{a^2 S}{T}$ 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 $\frac{a^2 S}{T}$ and the critical time (t_c) at which the recession becomes a straight line ($t_c = \frac{0.2a^2 S}{T}$), if the time of the recharge impulse is known. Once both the slope of the recession and $\frac{a^2 S}{T}$ are known they can be substituted into equation 6 along with the instantaneous discharge at t_c to calculate the undrained volume of 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 mixture of water from the most recent precipitation with that from an

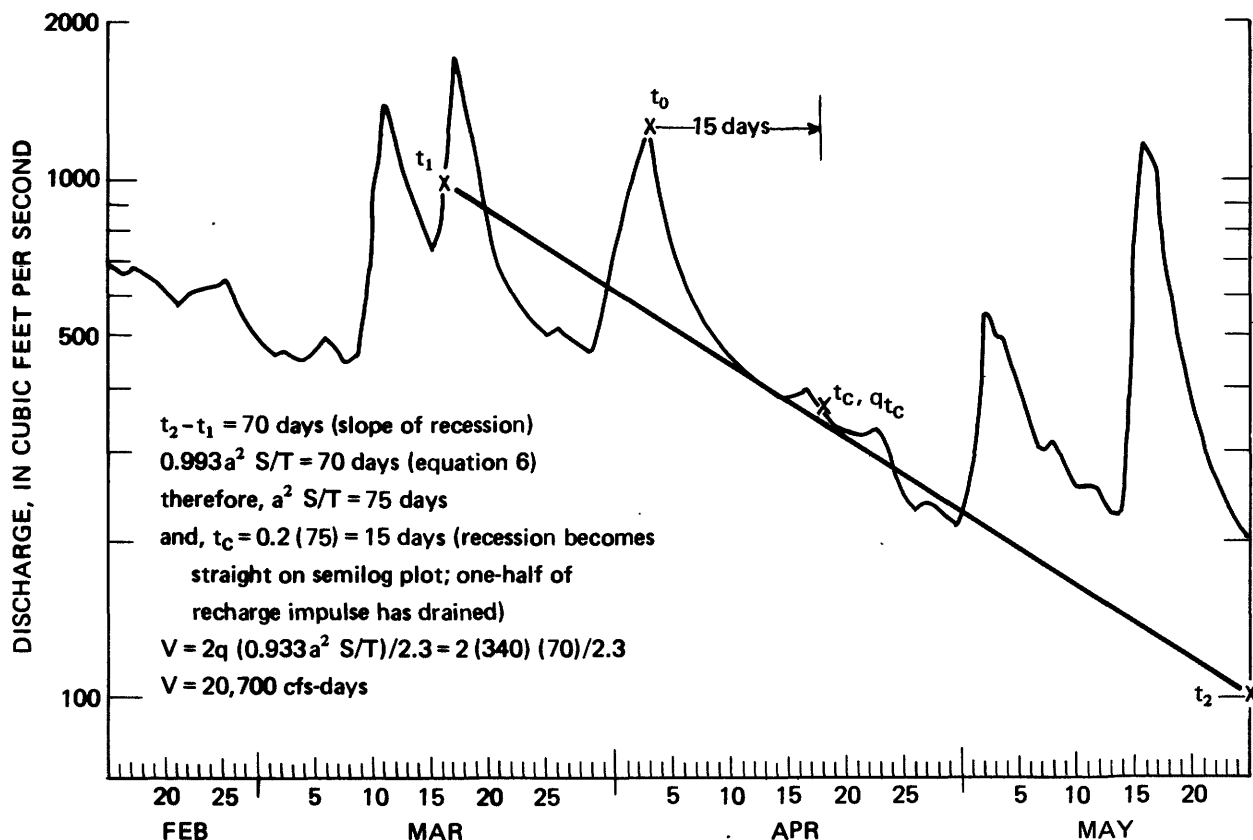


FIGURE 10. — Procedure for calculating ground-water contribution from a single flood event, Neuse River near Clayton.

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 analyses 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 assumptions 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:

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

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

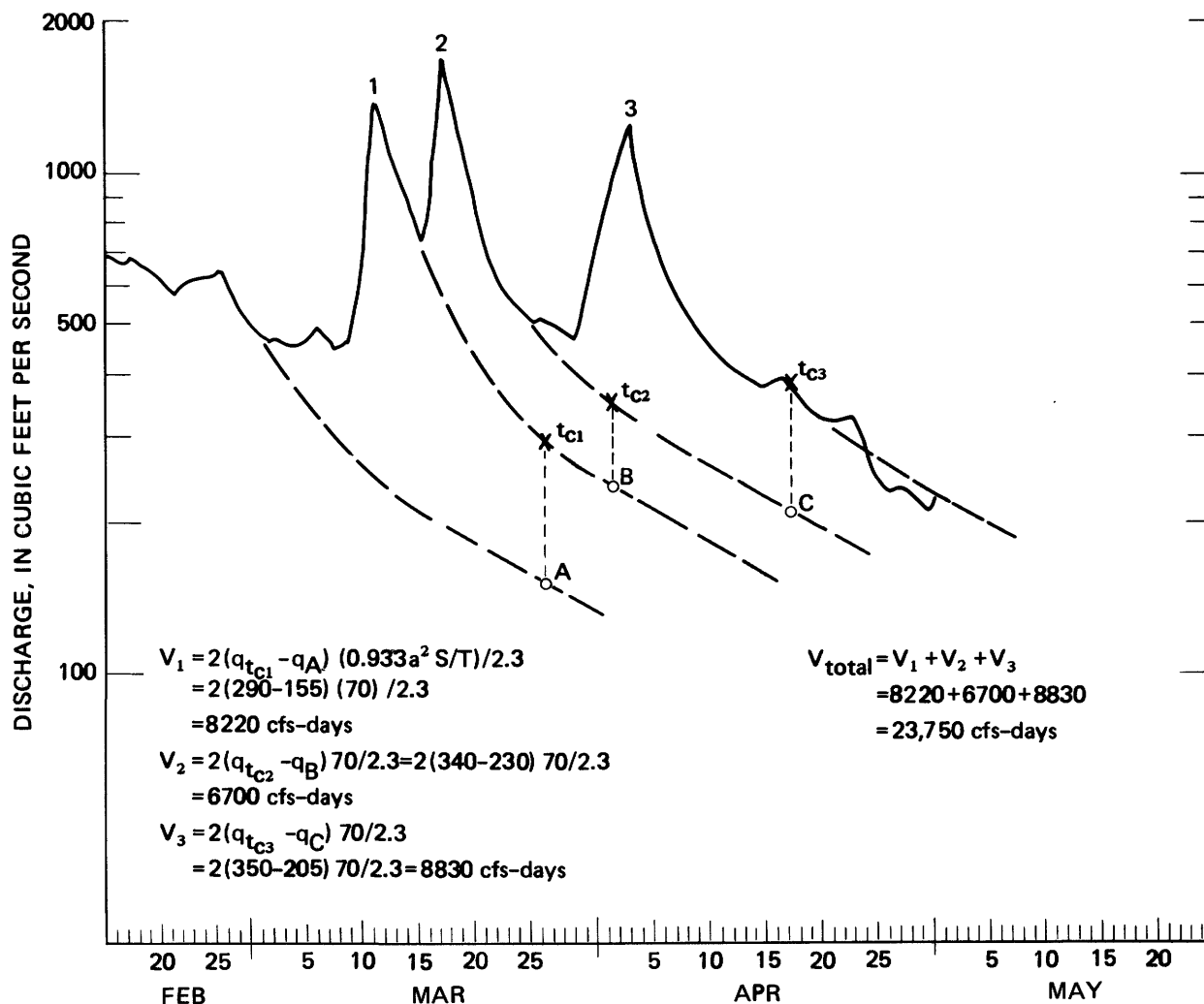


FIGURE 11. — Method of computing ground-water contribution from more than one flood, Neuse River near Clayton.

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 three 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

TABLE 2. — Comparison of selected constituents for stations in the Natural-Quality Network with stations in the Primary Network, October 1974–September 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 Calyton, 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).	1260–320	1700–1900	64–490	1700–28000
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/m ²).	1.5–3.9	3.1–18	4.6–18	4.6–5.4
Periphyton — biomass dry wt. (g/m ²).	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.

(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 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 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.

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

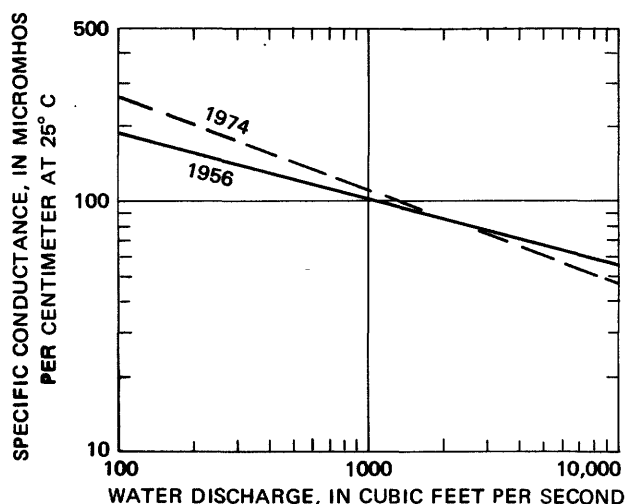


FIGURE 12. — Relation between water discharge and specific conductance, Neuse River near Clayton.

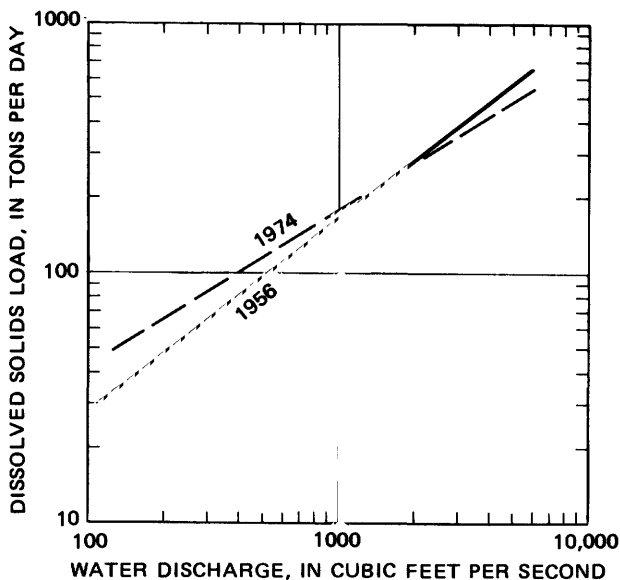


FIGURE 13.—Relation between water discharge and dissolved-solids load, Neuse River near Clayton.

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 ft³), 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.

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.

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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