Prepared in cooperation with the
NORTH CAROLINA DEPARTMENT OF ENVIRONMENT,
HEALTH, AND NATURAL RESOURCES

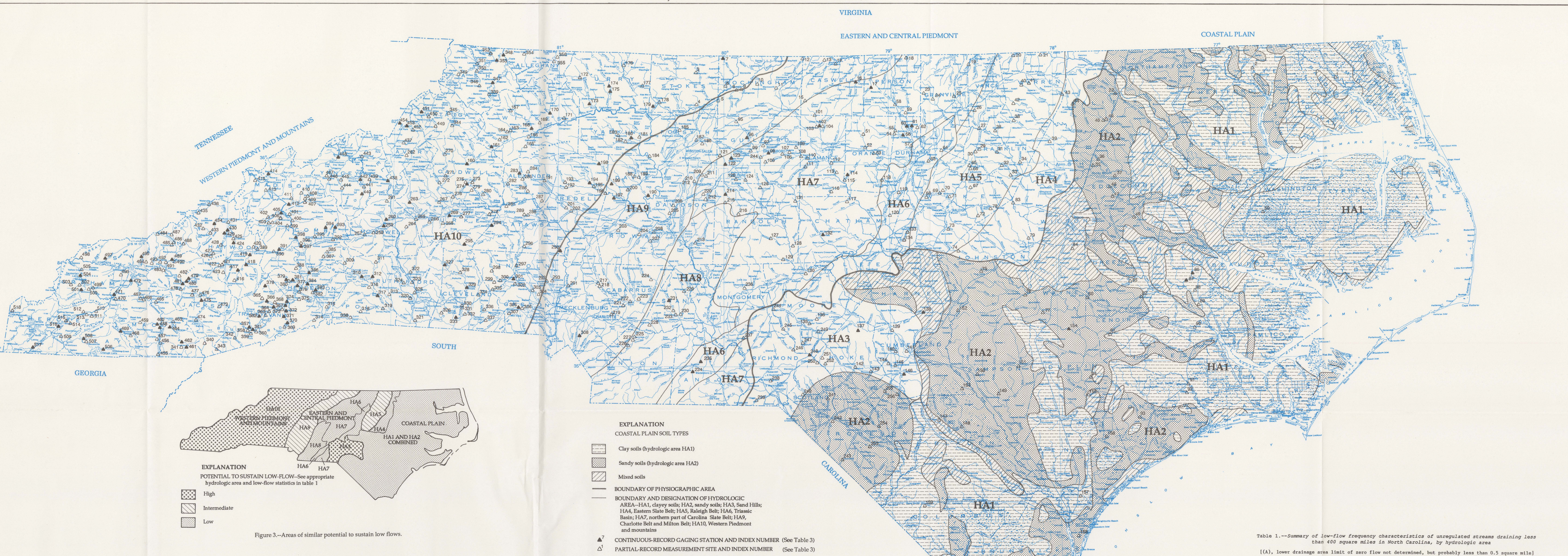

Figure 1.--Low-flow hydrologic areas for North Carolina

Figure 3.--Areas of similar potential to sustain low flows.

INTRODUCTION

Statistics describing the magnitude and frequency of recurrence of low streamflows are useful in evaluating reservoir release requirements, determining allowable waste-discharge loadings, and estimating biological potential of stream reaches. Low flow of streams, as discussed in this report, is equivalent to base flow, or sustained fair weather flow of streams under natural conditions. Base flow is composed of ground-water discharge, the spatial and temporal variations of which are largely dependent on geologic, topographic, and climatic conditions in a drainage basin. In North Carolina, lowest streamflows usually occur during the months of September, October, and November, near the end of the growing season.

Low-flow characteristics may be generated for sites where sufficient continuous or partial records of streamflow are available, using techniques such as those described by Riggs (1972). Goddard (1963) reported low-flow characteristics for hundreds of specific sites in North Carolina for which continuous records of streamflow were available, and Yonts (1971) reported results of low-flow measurements at 2,250 other sites. However, low-flow information commonly is needed on a timely basis at sites where suitable streamflow records are lacking.

This report, prepared in cooperation with the North Carolina Department of Environment, Health, and Natural Resources (EHNR), formerly the Department of Natural Resources and Community Development, presents techniques that may be used to estimate low-flow characteristics for natural conditions at sites on North Carolina streams for which suitable streamflow records are not available. The study approach was to (1) compile a data base of selected low-flow characteristics; (2) subdivide the State into hydrologic areas (fig. 1) where the geologic, topographic, or climatic properties that influence low flows are relatively uniform; and (3) present the low-flow characteristics of those hydrologic areas in terms of cubic feet per second per square mile and, where possible, present regression equations useful for estimating low-flow characteristics.

LOW-FLOW DATA BASE

The initial data base used for this study consisted of streamflow records for 172 continuous-record and flow measurements for 479 partial-record stations. The 1987 climatic year (April 1, 1987, through March 31, 1988) was the last year considered for this analysis. Low-flow frequency characteristics were generated for continuous-record gaging stations by examining a series of annual minimum average flows for the lowest 7 and 30 consecutive days of each climatic year and each winter period (November 1 to March 31) for stations with 8 or more years of record. The values in each of the series were ranked from smallest to largest and subjected to frequency analyses using the log-Pearson type III distribution. The low-flow statistics selected for compilation and analyses from the frequency distribution were: (1) the low-flow 7Q10, which is the annual minimum 7-day consecutive low flow that on average will be exceeded in 9 out of 10 years; or, stated another way, the probability is 10 percent that the 7-day consecutive low flow in any year will be less than the 7Q10; (2) the low-flow W7Q10, which is similar to the low-flow 7Q10, except that it takes into account only the winter months from November through March; (3) the low-flow 7Q2; and (4) the low-flow 30Q2. The low-flow 7Q10, 30Q2, and W7Q10 statistics were selected for inclusion in this study because these statistics are used by the Division of Environmental Management of EHNR to evaluate waste-discharge permit applications, and the low-flow 7Q2 statistic was selected because it is used in draft-storage-frequency analyses in reservoir design in the State (Arteaga and Hubbard, 1975).

The results of the log-Pearson type III analyses were screened for errors or inaccuracies in fitting. Fitted log-Pearson curves were reviewed to detect and adjust for outliers. Stations where values for low-flow characteristics may have been affected by streamflow regulation or diversion were eliminated from the analysis, as were all stations at stream sites with drainage areas greater than 400 mi^2. Most streams draining areas larger than this are affected by some type of regulation or diversion, or drain more than one hydrologic area.

Available low-flow characteristics for partial-record sites at which five or more base-flow measurements were made were also used in the data base. These base-flow measurements were plotted against concurrent base flows at nearby long-term continuous-record stations for which low-flow characteristics had been computed, as illustrated for sites on Big Shoe Heel Creek and Drowning Creek in figure 2. Lines of relation were drawn for each pair of stations. Low-flow characteristics for the partial-record sites were then determined from the graphical relation and corresponding statistics for the continuous-record site.

Once low-flow hydrologic areas were defined, gaging stations measuring substantial flow from more than one hydrologic area were eliminated from the data base. The final data base consisted of 122 continuous-record streamflow sites and 396 partial-record streamflow measurement sites. The locations of these sites are shown in figure 1. Index numbers shown in figure 1 correspond to site numbers in table 3, which is presented on the reverse side of plate 2 and provides estimated low-flow frequency characteristics.

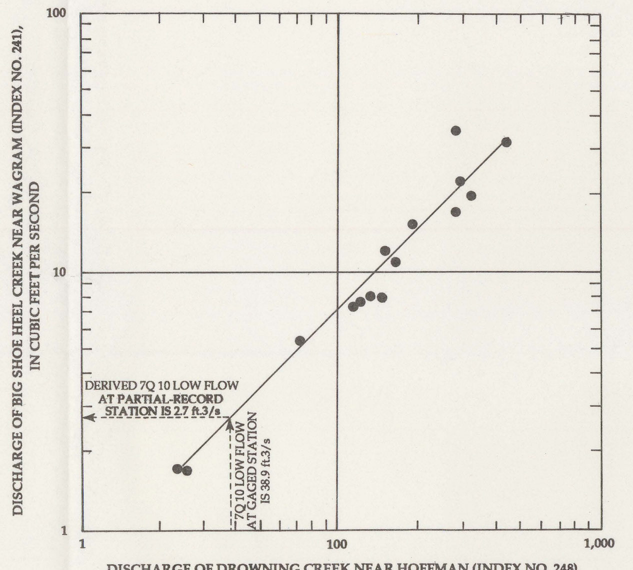

Figure 2.--Relation of base-flow measurements of Big Shoe Heel Creek near Wagram, North Carolina, to concurrent daily mean flows of Drowning Creek near Hoffman, North Carolina.

LOW-FLOW HYDROLOGIC AREAS

The strategy of dividing the State into hydrologic areas precluded the necessity to account for variations across the State in difficult-to-quantify geologic, topographic, and climatic variables; this reduces the probable errors in the regression equations. This approach generally leads to simple equations with few variables that are easy to apply. Yet, the complexities of the true situation with regard to low flows are not ignored, provided that the hydrologic areas are carefully selected with regard to geologic, topographic, and climatic variables which can reasonably be expected to influence low flows, and also provided that these variables are constant (or at least vary within narrow limits) within each hydrologic area.

As the first step in defining hydrologic areas, the four previously-mentioned low-flow characteristics for the initial 651 sites (fig. 1) were plotted on State maps in terms of cubic feet per second per square mile, and areas of similar low-flow values were delineated. Next, maps showing topography, geology, mean annual precipitation, mean annual runoff, soil type, and yield of wells by rock type for all or parts of North Carolina were compared visually with the low-flow maps to identify situations where areas of similar low-flow characteristics coincided with areas of similar geology, topography, or climate. For example, the Sand Hills area of the Coastal Plain (ultimately defined as hydrologic area HA3 as shown in figure 1) coincided with an area on the flow map where low-flow characteristics were much higher than the surrounding area. This suggested that an area delineated by the Sand Hills would be a meaningful hydrologic area. The most useful tools in making initial delineations of hydrologic areas were a State geologic map (Brown and Parker, 1985), well yields for different rock types and topographic settings for over 6,000 wells in the Piedmont and Blue Ridge provinces (Daniel, 1989), a map showing hydrogeologic units (Daniel and Payne, 1990), and a generalized soils map of North Carolina (Winner and Coble, 1989, modified from Tant and others, 1974).

Flow characteristics for preliminary subdivisions were subjected to statistical tests of variance and analyses of residuals from statewide regression equations to (1) test the validity of the hydrologic areas initially delineated and (2) determine which areas could be combined or further subdivided. In this way, 10 final hydrologic areas (HA1-HA10) were identified in North Carolina (fig. 1), forming, in most instances, southwest-northeast bands across the State. These 10 areas lie within 3 broad physiographic areas--the Coastal Plain, the eastern and central Piedmont, and the western Piedmont and mountains (fig. 1). These physiographic areas correspond roughly to Fenneman's (1938) physiographic provinces named Coastal Plain, Piedmont, and Blue Ridge. However, boundaries of physiographic areas described in this report differ slightly in some areas from delineations of physiographic provinces given by Fenneman (1938). Hence, the term physiographic areas is used in this report to avoid implying identity with Fenneman's physiographic provinces.

Ranges of low-flow characteristics computed for the 10 respective hydrologic areas are summarized in table 1. This table lists the number of sites with drainage areas less than 400 mi^2 that were analyzed in each hydrologic area and shows the maximum, 75th-, 50th-, and 25th-percentile, and the minimum low-flow values expressed in cubic feet per second per square mile for each of the four low-flow frequency characteristics. Table 1 also shows the estimated drainage area below which the indicated low-flow characteristic generally has a zero value, as determined from the drainage-area axis intercept of arithmetic bivariate plots of low-flow characteristics and drainage area. The maximum and minimum values are the extremes of the low-flow characteristics computed for a hydrologic area. For example, 0.694 $(ft^3/s)/mi^2$ was the maximum 7Q10 value computed for the 24 stations analyzed in hydrologic area HA3. The 75th-, 50th-, and 25th-percentile values are the low-flow characteristics that were not exceeded by the indicated percent of stations in a hydrologic area. For example, 75 percent of the 38 stations analyzed in the sandy soils hydrologic area, HA2, have 7Q10 values less than or equal to 0.022 $(ft^3/s)/mi^2$.

The following discussions describe in more detail hydrologic, geologic, topographic, and climatic features of the 10 hydrologic areas delineated for North Carolina within the three physiographic areas as they relate to low-flow frequency characteristics. The names given to most hydrologic areas correspond to commonly used geologic names such as those used by Brown and Parker (1985); however, boundaries of some units differ somewhat from those commonly used because subdivisions made in this report were based upon topographic, climatic, and hydrologic factors as well as geologic considerations.

Coastal Plain Physiographic Area

The Coastal Plain physiographic area (fig. 1), as delineated for this report, covers approximately 18,200 mi^2 in eastern North Carolina. Its western limit coincides roughly with the boundary between Fenneman's (1938) Coastal Plain and Piedmont provinces, except where the Eastern Slate Belt hydrologic area (HA4 in fig. 1) forms its western boundary. The geology of the area consists of alternating layers of sand, silt, clay, and limestone that thicken and dip eastward. With few exceptions, notably the Sand Hills hydrologic area (HA3), topographic relief in the Coastal Plain physiographic area is minimal, and the land surface dips coastward at a rate of only a few feet per mile. Mean annual precipitation in the area ranges from 46 to 54 in. (Eder and others, 1983).

For this report, the Coastal Plain physiographic area was divided into three hydrologic areas, mostly on the basis of soil types and topography: clay soils (HA1), sandy soils (HA2), and the Sand Hills (HA3). As indicated in table 1, the clay soils hydrologic area (HA1) tends to have the lowest values of low-flow characteristics of the three hydrologic areas (median 7Q10 value is 0 $(ft^3/s)/mi^2$), sandy soil (HA2) has intermediate values (median 7Q10 value is 0.006 $(ft^3/s)/mi^2$), and the Sand Hills (HA3) has much higher values (median 7Q10 value is 0.318 $(ft^3/s)/mi^2$). Low-flow characteristics of mixed soils (fig. 1) composed of variable percentages of sand and clay are not given explicitly in this report but could be expected to have low-flow characteristics ranging between those of clay soils and those of sandy soils.

The clay soils and sandy soils hydrologic areas (HA1 and HA2) cover combined areas in the Coastal Plain physiographic area of about 8,400 and 8,000 mi^2, respectively. Land-surface gradients in both these areas are commonly only 1 or 2 ft/mi and maximum land-surface elevations are about 150 ft above sea level. Because the water table in most places in humid areas is a more or less subdued version of the land surface, this low topographic relief is reflected in low hydraulic gradients with less potential to move water to streams than in other areas of the State where topographic relief and hydraulic gradients are much greater. The lower values for low-flow characteristics for clay soils as compared to sandy soils (table 1) result partly from the fact that a higher percentage of precipitation that falls on clay soils is rejected as recharge due to the low permeability of the clay and runs off directly to streams. Additionally, clay soils have much lower hydraulic conductivity than do sandy soils and, thus, contribute less water to base flow of streams than do sandy soils.

The Sand Hills hydrologic area (HA3) consists of rolling sand hills and covers an area of about 1,800 mi^2 in the southwestern Coastal Plain. Local topographic relief of 50-200 ft/mi is common in HA3, and maximum altitudes reach more than 700 ft above sea level. The role of topographic relief in determining low-flow characteristics of streams is underscored by a comparison of the Sand Hills hydrologic area (HA3) with the Coastal Plain sandy soils hydrologic area (HA2). The major difference in the two areas with respect to factors which may influence low-flow characteristics is that topographic relief and hydraulic gradients are generally much higher in the Sand Hills hydrologic area (HA3) than in the Coastal Plain sandy soils area (HA2). Otherwise, the two areas are similar with respect to characteristics which could reasonably be expected to affect low-flow characteristics. The primary aquifer material is sand in each case. Climate and average annual precipitation are about the same, with the Sand Hills actually receiving slightly less precipitation than the average for the entire Coastal Plain. Yet, low-flow characteristics given in table 1 are much higher for the Sand Hills hydrologic area (HA3) than for the Coastal Plain sandy soils hydrologic area (HA2). For example, the median (50 percentile) 7Q10 value listed in table 1 for 24 sites in hydrologic area HA3 is 0.318 $(ft^3/s)/mi^2$, the highest in the State. For hydrologic area HA2, the median value for 38 sites is only 0.006 $(ft^3/s)/mi^2$.

In swampy lands in hydrologic areas HA1 and HA2, which otherwise have good potential for agricultural development, stream channelization is a widespread practice. Although this report gives estimates of low-flow characteristics of streams for natural conditions only, it is worthwhile to note that several studies (Heath, 1975; Winner and Simmons, 1977; Daniel, 1981; Mason and others, 1990) have shown that in swampy areas where the water table is at or near land surface, channelization results in both a deeper stream channel and lower stream stage. This causes the ground-water gradient to increase toward the stream which, in turn, results initially in greater ground-water discharge than would have occurred prior to channelization. This channel deepening also allows an additional part of the shallow aquifer that would not have been dewatered prior to channelization to be dewatered between recharge events. Hence, in some cases, base flow in a channelized stream may be sustained for a longer period of time after a recharge event than in an unchannelized stream. When the next recharge event occurs, part or all of the dewatered shallow aquifer may be refilled and a new dewatering cycle begins. Thus, the initial increase in base flow to streams due to channelization may be perpetuated, and values of low-flow characteristics for channelized streams in hydrologic areas HA1 and HA2 may be larger than those given in this report.

Eastern and Central Piedmont Physiographic Area

The eastern and central Piedmont physiographic area consists of about 23,000 mi^2 of rolling hills in central North Carolina. The area is bounded on the east by the Coastal Plain physiographic area and on the west by the western Piedmont and mountains physiographic area. Mean annual precipitation ranges from 44 to 48 in. (Eder and others, 1983). The near-surface geologic materials in much of the area are crystalline or sedimentary rocks that have weathered at the surface to form a thin covering (several feet or more) of unconsolidated material referred to as the regolith. Areas of similar low-flow characteristics within this physiographic area tend to match areas of similar rock type on the State geologic map (Brown and Parker, 1985) to a greater degree than elsewhere in the State. In addition, areas of similar low-flow characteristics tend to coincide with areas of similar well yields reported by Daniel (1989), which in turn relate to rock type. Therefore, delineations of hydrologic areas within this physiographic area are based largely on underlying rock types.

The Eastern Slate Belt hydrologic area (HA4) covers an area of about 1,100 mi^2 and corresponds roughly to the Eastern Slate Belt of Brown and Parker (1985), which is an area underlain by nearly impermeable metavolcanic and metasedimentary rocks that crop out in many places. To the east, topographic relief diminishes, metasedimentary rock outcrops are fewer, and covering soils are more typical of the Coastal Plain. The felsic metavolcanic rocks and argillite found in abundance in this belt are among the lowest-ranked by Daniel (1989) in terms of their yield to wells. Values for low-flow characteristics are also very low in this hydrologic area (median 7Q10 value is 0 $(ft^3/s)/mi^2$) compared with most of the other hydrologic areas of the State (table 1).

The Raleigh Belt hydrologic area (HA5) covers an area of about 1,800 mi^2 and consists predominantly of felsic metaigneous, felsic gneiss, and schist rock types. In terms of low-flow characteristics (table 1), the streams in this hydrologic area have higher low-flow values than those in HA1 and HA2 in the Coastal Plain and most other hydrologic areas of the eastern and central Piedmont. The median 7Q10 value for HA5 is 0.065 $(ft^3/s)/mi^2$.

The Triassic Basin hydrologic area (HA6) (shown as two separate areas in figure 1) covers an area of about 1,100 mi^2 and is composed of sedimentary rocks, including shale, sandstone, and arkose. Daniel (1989) reported the Triassic sedimentary rocks to have the lowest average yield of water to wells of all rock types in the State, inferring that these rocks have small permeabilities. Such low permeabilities are compatible with the low base flows of streams draining the Triassic rock terranes. The 7Q10 values for HA6 (table 1) are zero for all but the largest drainage areas.

The Carolina Slate Belt hydrologic area (HA7) (also shown as two separate areas in figure 1) covers an area of about 4,500 mi^2 and consists predominantly of metavolcanics and metaigneous rocks, which are among the lowest water-yielding rock units studied by Daniel (1989). However, values for low-flow characteristics (table 1) are low (median 7Q10 value is 0.005 $(ft^3/s)/mi^2$) compared to other hydrologic areas in the State.

The Carolina Slate Belt (argillite zone) hydrologic area (HA8) covers an area of about 1,600 mi^2 and consists primarily of argillite. Low-flow characteristics of streams in this hydrologic area are low (the median 7Q10 value is 0.001 $(ft^3/s)/mi^2$). Daniel (1989) showed argillite to be among the lowest-ranked rock units in terms of average yield to wells.

The Charlotte Belt and Milton Belt hydrologic area (HA9) covers an area of about 3,600 mi^2 and consists predominantly of igneous, metaigneous, and metavolcanic rocks, which Daniel (1989) indicates yield more water to wells than rocks in the northern part of the Carolina Slate Belt, hydrologic area HA7. This is reflected in higher values for low-flow characteristics in streams for HA9 in table 1. The median 7Q10 value for HA9 is 0.064 $(ft^3/s)/mi^2$.

Western Piedmont and Mountains Physiographic Area

The western Piedmont and mountains physiographic area covers approximately 13,400 mi^2 in the western part of the State and consists of a single hydrologic area, the western Piedmont and mountains (HA10). Mean annual precipitation varies greatly due largely to orographic effects associated with the relatively great topographic relief of the area. Precipitation over the area ranges from 40 in. to more than 80 in. annually (Eder and others, 1983), with the highest annual rainfall east of the Mississippi River occurring in the Highlands area just north of the North Carolina-Georgia State line.

The predominant rock types in this area are gneiss and quartzite. Subdivisions on the basis of geology were not made in this area because topographic and climatic factors appear to overshadow geologic factors. Daniel (1989) showed significant differences in well yields for different topographic settings in the Piedmont and Blue Ridge provinces. Wells located in draws and valleys had higher yields than wells located on slopes and flats, and wells located on hills and ridges had the lowest average yields. This area has the greatest variability in topographic setting of the three physiographic areas. This may partially account for the high variability in the low-flow characteristics of streams within the area (table 1). The median 7Q10 value for this hydrologic area is 0.317 $(ft^3/s)/mi^2$, but the maximum value is 1.062 $(ft^3/s)/mi^2$, and the minimum is 0 $(ft^3/s)/mi^2$.

Another factor that contributes to the greater variability in low-flow characteristics is the greater areal variation in precipitation here as compared to the rest of the State. Areas of high and low mean annual precipitation and runoff tend to match highs and lows in low-flow characteristics of streams, and this is particularly apparent in the western Piedmont and mountains hydrologic area (HA10). Some of the highest low-flow values in the State occur in streams in this region near the highest precipitation areas.

General

The resultant effect of the various geologic, topographic, and climatological factors on base flow to North Carolina streams may be generalized as follows (fig. 3): the lowest potential for sustaining base flow to streams is in the Coastal Plain physiographic area (excluding the Sand Hills hydrologic area (HA3)) and the eastern and central Piedmont physiographic area (excluding the Raleigh Belt hydrologic area (HA5) and the Charlotte Belt and Milton Belt hydrologic area [HA9]); the highest potential is in the Sand Hills hydrologic area (HA3) and in the western Piedmont and mountains hydrologic area (HA10); lastly, the Raleigh Belt hydrologic area (HA5) and the Charlotte Belt and Milton Belt hydrologic area (HA9) are intermediate in potential for sustaining base flow to streams.

Table 1.--*Summary of low-flow frequency characteristics of unregulated streams draining less than 400 square miles in North Carolina, by hydrologic area*

[(A), lower drainage area limit of zero flow not determined, but probably less than 0.5 square mile]

Hydrologic area name and number	Number of sites	Low-flow characteristics	Flow, in cubic feet per second per square mile: Maximum	75th percentile	50th percentile	25th percentile	Minimum	Drainage area, in square miles, below which indicated low-flow statistic generally has a zero value
Coastal Plain								
Clay soils (HA1)	11	7Q10	0.019	0.002	0.000	0.000	0.000	35
		W7Q10	.060	.010	.008	.000	.000	3
		7Q2	.028	.012	.001	.000	.000	2
		30Q2	.053	.032	.010	.000	.000	2
Sandy soils (HA2)	38	7Q10	.135	.022	.006	.001	.000	2
		W7Q10	.340	.104	.065	.015	.000	2
		7Q2	.250	.083	.043	.009	.000	2
		30Q2	.340	.152	.090	.034	.002	2
Sand Hills (HA3)	24	7Q10	.694	.489	.318	.212	.112	(A)
		W7Q10	1.053	.711	.600	.508	.221	(A)
		7Q2	.876	.618	.495	.391	.217	(A)
		30Q2	1.053	.789	.637	.504	.320	(A)
Eastern and central Piedmont								
Eastern Slate Belt (HA4)	4	7Q10	0.007	0.005	0.000	0.000	0.000	18
		W7Q10	.065	.065	.045	.007	.000	8
		7Q2	.063	.060	.038	.007	.000	8
		30Q2	.140	.130	.083	.016	.000	8
Raleigh Belt (HA5)	25	7Q10	.216	.123	.065	.016	.004	2
		W7Q10	.432	.256	.177	.109	.044	2
		7Q2	.378	.248	.187	.092	.048	(A)
		30Q2	.486	.330	.269	.154	.095	(A)
Triassic Basin (HA6)	10	7Q10	.004	.000	.000	.000	.000	45
		W7Q10	.015	.005	.000	.000	.000	15
		7Q2	.015	.004	.000	.000	.000	22
		30Q2	.025	.014	.005	.001	.000	13
Carolina Slate Belt (HA7)	58	7Q10	.131	.015	.005	.000	.000	3
		W7Q10	.223	.079	.048	.013	.000	1
		7Q2	.211	.069	.038	.016	.000	1
		30Q2	.254	.104	.071	.028	.000	1
Carolina Slate Belt (argillite zone) (HA8)	9	7Q10	.009	.007	.001	.000	.000	12
		W7Q10	.026	.017	.007	.005	.001	(A)
		7Q2	.035	.019	.007	.006	.000	5
		30Q2	.060	.029	.014	.010	.002	(A)
Charlotte Belt and Milton Belt (HA9)	38	7Q10	.160	.104	.064	.031	.000	1
		W7Q10	.330	.232	.164	.090	.027	1
		7Q2	.304	.210	.149	.088	.026	1
		30Q2	.365	.271	.201	.125	.045	1
Western Piedmont and mountains								
Western Piedmont and mountains (HA10)	301	7Q10	1.062	0.451	0.317	0.200	0.000	(A)
		W7Q10	1.357	.583	.448	.338	.098	(A)
		7Q2	1.585	.716	.548	.387	.046	(A)
		30Q2	1.819	.851	.671	.475	.180	(A)

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	by	To obtain
Length		
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.590	square kilometer
Volume		
cubic foot (ft^3)	0.02832	cubic meter
Gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer
Flow		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

LOW-FLOW CHARACTERISTICS OF STREAMS IN NORTH CAROLINA

By
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1991