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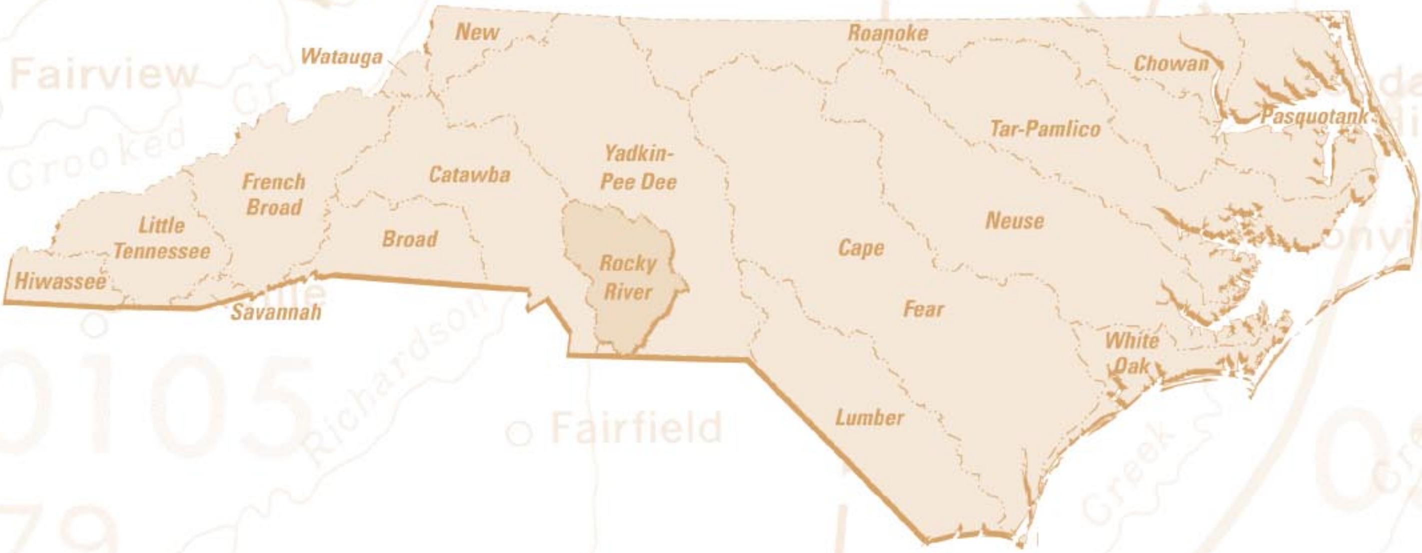
Low-flow Characteristics and Profiles for the Rocky River in the Yadkin-Pee Dee River Basin, North Carolina, through 2002

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 03–4147

Prepared in cooperation with the
Water and Sewer Authority of Cabarrus County,
Charlotte-Mecklenburg Utilities, and Union County



U.S. Department of the Interior
U.S. Geological Survey

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By J. Curtis Weaver and Jason M. Fine

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Raleigh, North Carolina
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CONVERSION FACTORS, TEMPERATURE, DATUMS, AND ACRONYMS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Flow	
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
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
	Volume per time	
inch per year (in/yr)	2.54	centimeters per year

Temperature: In this report, temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (° C) by using the following equation:

$$°C = 5 / 9 (°F - 32)$$

Vertical coordinates: Vertical coordinates in this report are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinates: Unless otherwise specified, horizontal (latitude and longitude) coordinates in this report are referenced to the North American Datum of 1927 (NAD 27).

Acronyms:

7Q2	7-day, 2-year low-flow discharge
7Q10	7-day, 10-year low-flow discharge
W7Q10	winter 7-day, 10-year low-flow discharge
30Q2	30-day, 2-year low-flow discharge
DWQ	North Carolina Division of Water Quality
GIS	geographic information system
HA	hydrologic area
MOVE.1	Maintenance of Variance Extension
NAD 27	North American Datum of 1927
NAVD 88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WTP	water-treatment plant
WWTP	wastewater-treatment plant

Low-Flow Characteristics and Profiles for the Rocky River in the Yadkin-Pee Dee River Basin, North Carolina, through 2002

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ABSTRACT

An understanding of the magnitude and frequency of low-flow discharges is an important part of protecting surface-water resources and planning for municipal and industrial economic expansion. Low-flow characteristics are summarized for 12 continuous-record gaging stations and 44 partial-record measuring sites in the Rocky River basin in North Carolina. Records of discharge collected through the 2002 water year at continuous-record gaging stations and through the 2001 water year at partial-record measuring sites were used. Flow characteristics included in the summary are (1) average annual unit flow; (2) 7Q10 low-flow discharge, the minimum average discharge for a 7-consecutive-day period occurring, on average, once in 10 years; (3) 30Q2 low-flow discharge; (4) W7Q10 low-flow discharge, which is similar to 7Q10 discharge but is based only on flow during the winter months of November through March; and (5) 7Q2 low-flow discharge.

The Rocky River basin drains 1,413 square miles (mi^2) of the southern Piedmont Province in North Carolina. The Rocky River is about 91 miles long and merges with the Yadkin River in eastern Stanly County to form the Pee Dee River, which discharges into the Atlantic Ocean in South Carolina. Low-flow characteristics compiled for selected sites in the Rocky River basin indicated that the potential for sustained base flows in the upper half of the basin is relatively higher than for streams in the lower half of the basin. The upper half of the basin is underlain by the Charlotte Belt, where streams have been identified as having moderate potentials for sustained base flows. In the lower half of the basin, many streams were noted as having little to no potential for sustained base flows. Much of the decrease in base-flow potential is attributed to the underlying rock types of the Carolina Slate Belt. Of the 19 sites in the basin having minimal (defined as less than 0.05 cubic foot per second) or zero 7Q10 discharges, 18 sites are located in the lower half of the basin underlain by the Carolina Slate Belt. Assessment of these 18 sites indicates that streams that have drainage areas less than about 25 square miles are likely to have minimal or zero 7Q10 discharges. No drainage-area threshold for minimal or zero 7Q10 discharges was identified for the upper half of the basin, which is underlain by the Charlotte Belt.

Tributaries to the Rocky River include the West Branch Rocky River (22.8 mi^2), Clarke Creek (28.2 mi^2), Mallard Creek (41.2 mi^2), Coddle Creek (78.8 mi^2), Reedy Creek (43.0 mi^2), Irish Buffalo/ Coldwater Creeks (110 mi^2), Dutch Buffalo Creek (99 mi^2), Long Creek (200 mi^2), Richardson Creek (234 mi^2), and Lanes Creek (135 mi^2). In the 20-mile reach upstream from the mouth (about 22 percent of the river length), the drainage area increases by 648 mi^2, or about 46 percent of the total drainage area as a result of the confluences with Long Creek, Richardson Creek, and Lanes Creek.

Low-flow discharge profiles for the Rocky River include 7Q10, 30Q2, W7Q10, and 7Q2 discharges in a continuous profile with contributions from major tributaries included. At the gaging stations above Irish Buffalo Creek and near Stanfield, the 7Q10 discharges are 25.2 and 42.3 cubic feet per second, corresponding to 0.09 and 0.07 cubic feet per second per square mile, respectively. At the gaging station near Norwood, the 7Q10 discharge is 45.8 cubic feet per second, equivalent to 0.03 cubic foot per second per square

mile. Low-flow discharge profiles reflect the presence of several major flow diversions in the reaches upstream from Stanfield and an apparent losing reach between the continuous-record gaging stations near Stanfield and Norwood, North Carolina.

INTRODUCTION

The need for a better understanding of low-flow hydrology and for improved techniques in determining low-flow characteristics of streams has become more critical as demands for sustained, high-quality water supplies and effective waste assimilation have increased. The simultaneous occurrence of increasing water demands and recent droughts in North Carolina have heightened the importance of determining low-flow characteristics.

Low flow, also referred to as base flow or sustained fair-weather flow, is composed largely of ground-water discharge from aquifers to streams. Ground-water discharges have large spatial and temporal variations that are highly dependent on topographic, geologic, and climatic conditions. The high variability of such conditions across North Carolina, and sometimes even within a drainage basin or along the same stream, results in complex low-flow hydrology. Moreover, the characterization of low-flow hydrology is further complicated by withdrawals, point-source discharges, impoundments, and land use within the drainage basin. Low flows in North Carolina typically occur at the conclusion of the growing season in late summer and early autumn as a result of evaporation from surface-water bodies and use of ground water (by way of soil moisture) by crops and other vegetation. In addition, the higher temperatures of summer and early autumn encourage increased water use, which causes a higher demand for withdrawals from streams, reservoirs, and ground-water wells. An understanding of low-flow characteristics is crucial in evaluating water-supply potential and reservoir-release requirements, determining and regulating wastewater discharges to streams, and maintaining aquatic habitats in streams.

In 1991, the Division of Water Quality (DWQ, formerly the Division of Environmental Management) of the North Carolina Department of Environment and Natural Resources, began using a basinwide approach in assessing and managing water quality and, in particular, in permitting point-source discharges. This approach has been applied to each of the 17 major river basins in the State (fig. 1) so that all point-source discharges in a basin are permitted simultaneously. The process is repeated in each basin at 5-year intervals. In conjunction with the basinwide approach, the U.S. Geological Survey (USGS), in cooperation with the DWQ, has conducted studies to define low-flow characteristics and develop discharge profiles for selected streams in several river basins (Weaver, 1996, 1997, 1998; Weaver and Pope, 2001). This basinwide investigation of the low-flow characteristics in the Rocky River basin was conducted in cooperation with

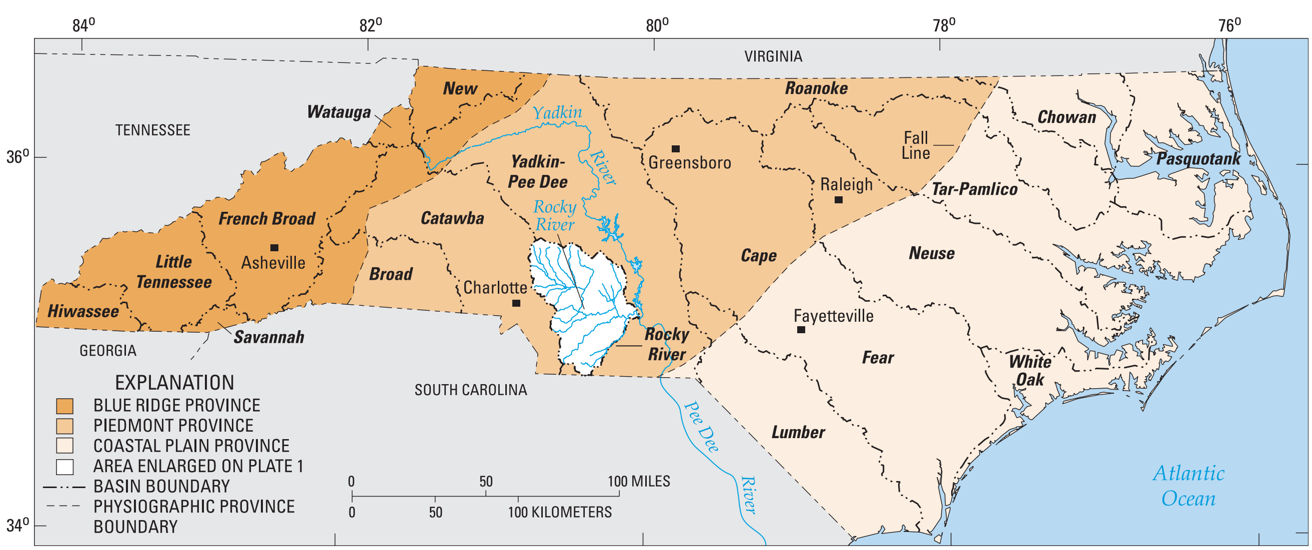


Figure 1. Locations of major river basins, the Rocky River basin (shown in white), and physiographic provinces in North Carolina.

the Water and Sewer Authority of Cabarrus County, Charlotte-Mecklenburg Utilities, and Union County.

Where sufficient discharge records are available at continuous- and partial-record sites, application of statistical techniques, such as those described by Riggs (1972), form the basis for determining low-flow characteristics. The number of sites with sufficient record to determine low-flow characteristics, however, is far outnumbered by locations with little or no record for developing low-flow estimates.

Low-flow characteristics are defined by a set of discharges that are statistically derived values having associated duration (expressed as days) and recurrence intervals (also referred to as return period and expressed in years). The recurrence interval represents the average period of time between occurrences of a specified low-flow or high-flow hydrologic event (see definition in *Glossary* for more information). An example of a widely used low-flow statistic is the 7-day, 10-year low-flow discharge (hereafter referred to as 7Q10 discharge). The annual minimum average streamflow for a 7-consecutive-day period will be at or below the 7Q10 discharge, on average, one time in 10 years. If the 7Q10 discharge is 5 cubic feet per second (ft^3/s), then the annual minimum average streamflow for a 7-consecutive-day period would be 5 ft^3/s or lower, on average, 1 time in 10 years, 5 times in 50 years, or 10 times in 100 years. A recurrence interval of 10 years implies that the annual minimum average streamflow for a 7-consecutive-day period will exceed the 7Q10 discharge, on average, in 9 of 10 years. Stated another way, the probability is 10 percent (the inverse of the recurrence interval) that the lowest average 7-consecutive-day flow in any given year will be less than the 7Q10 discharge (Giese and Mason, 1993).

In North Carolina, other low-flow statistics used by State regulatory agencies in determining permitting limits for withdrawals from and discharges to streams include the 30-day, 2-year (30Q2) low-flow discharge; winter 7-day, 10-year (W7Q10) low-flow discharge; and 7-day, 2-year (7Q2) low-flow discharge. The W7Q10 discharge, or winter 7Q10, is defined in a similar manner as the 7Q10 discharge except that only flows during the months of November through March are considered in the analysis.

In addition to providing information to the DWQ and other agencies and interested organizations on low-flow characteristics for streams in the Rocky River basin and other river basins, the determination of low-flow characteristics provides an expanded knowledge of low-flow hydrology and the factors that affect low flows in one region as compared to another. As many factors become better understood through improved and detailed mapping applications, a potential future product of this expanded knowledge is the development of statistical relations using explanatory variables obtained from map products to estimate low-flow discharges at ungaged sites.

Purpose and Scope

This report presents low-flow characteristics for selected streams in the Rocky River basin of North Carolina. Low-flow statistics at streamgaging stations are summarized, and drainage-area and low-flow discharge profiles for the Rocky River are presented. The discharge profiles show the relation of 7Q10, 30Q2, W7Q10, and 7Q2 discharges to river miles for the Rocky River. Descriptions of selected basin characteristics include impoundments, flow diversions (water-supply withdrawals and return point-source discharges), climate, geology, soils, and land use. The report also contains an inventory of sites in the study area where records of discharge and(or) stage have been collected through the 2002 water year for continuous-record gaging stations and as of the 2001 water year for partial-record measuring sites; selected site attributes also are listed for each site.

Low-flow statistics are summarized for 12 continuous-record gaging stations and for 44 partial-record measuring sites including the average annual unit flow and the 7Q10, 30Q2, W7Q10, and 7Q2 discharges. The number of zero-flow days for continuous-record sites and zero-flow discharge measurements for partial-record sites also are included. Although the period of record varies from site to site, records of discharge collected through the 2002 water year for continuous-record gaging stations and through the 2001 water year for partial-record measuring sites were used in the analyses for this report. The records of discharge available through the 2002 water year for continuous-record sites were included in the analyses to account for low flows recorded during the 1998–2002 drought that affected streams in the Rocky River basin and other river basins in North Carolina.

Although low-flow characteristics are presented for many sites in the Rocky River basin, no techniques similar to those presented by Giese and Mason (1993) are presented here for estimating low-flow discharges at ungaged locations in the study area. Information presented in this report is not intended to supersede the use of regional relations (Giese and Mason, 1993), particularly in the upper parts of the basin where such relations are available, but is intended to add to the overall means of estimating low-flow discharges in the Rocky River basin. Low-flow discharges at ungaged locations can also be estimated by examining the unit low flows at nearby gaged sites for which low-flow characteristics are presented in this report. To the extent possible, nearby sites were selected for use as index sites based on similarities in basin characteristics of the ungaged and index sites. For the upper parts of the basin, comparing low-flow discharges estimated by using nearby unit low flows to those estimated by using regional relations (Giese and Mason, 1993) can provide a basis for better understanding the range in values that may be applicable to an ungaged site.

Previous Low-Flow Studies

Prior to World War II, low-flow characteristics of North Carolina streams were determined only for continuous-record gaging stations. Following World War II and the subsequent economic expansion, there was an increasing need for hydrologic information at sites where no data previously had been collected (Yonts, 1971). Thus, the USGS expanded its data-collection program in the late 1940's to include partial-record measuring sites where discharge measurements were made on a periodic basis. Discharge measurements made under base-flow conditions along with observations of zero flow became the foundation of data used in the initial assessments of low-flow characteristics of streams in North Carolina. With data available from the network of partial-record measuring sites, the USGS began to respond to requests for low-flow characteristics on a site-specific basis, including those for ungaged sites.

Several studies have been conducted to investigate low flows for streams in North Carolina. Goddard (1963) presented low-flow characteristics for many continuous-record gaging stations in North Carolina, along with drainage area and 7Q10 discharge profiles developed for selected main-stem rivers. Yonts (1971) reported base-flow measurements made at over 2,200 continuous-record gaging stations and partial-record measuring sites throughout the State.

Giese and Mason (1993) evaluated low-flow characteristics at 122 continuous-record gaging stations and 396 partial-record measuring sites with drainage areas ranging from 1 to 400 mi^2 and streamflows unaffected by regulation or diversions. Sites were characterized on the basis of similarity in their ranges of low-flow discharges and potential to sustain base flow. Ten hydrologic areas (HA's) were delineated, and regression equations, which related low-flow characteristics to basin characteristics, were derived for ungaged sites. Equations for only 4 of the 10 hydrologic areas—HA10, representing the mountains and western Piedmont; HA3, the Sand Hills; and HA's 5 and 9, the eastern and central Piedmont, respectively—had standard errors that were considered small enough to permit use of the equations in estimating low-flow characteristics at the ungaged sites.

Evett (1994) investigated the effects of urbanization and land-use changes on low flows. Trends of decreasing low flows with increasing urbanization were detected in data from selected continuous-record gaging stations in the Asheville, Charlotte, Greensboro, and Raleigh metropolitan areas (fig. 1) and at gaging stations in nearby rural areas. Because of the decreasing trends noted at both urban and rural gaging stations used in the analyses, Evett described the results as being statistically inconclusive.

Weaver (1996) conducted a study of low-flow characteristics in the Roanoke River basin as part of the DWQ's program of basinwide assessment and management of water quality in major river basins of North Carolina. Low-flow characteristics were summarized for 82 streamflow sites—79 sites in North Carolina and 3 sites in Virginia—and profiles of drainage area and low-flow discharge were developed for 10 selected streams. Total drainage areas for the profiled streams range from 22 mi^2 to about 9,700 mi^2. Low-flow discharges for each stream include 7Q10, 30Q2, W7Q10, and 7Q2 discharges in a continuous profile, and contributions from major tributaries also were included.

Weaver (1997) also investigated low-flow characteristics in the Deep River basin in the central Piedmont Province of North Carolina. The Deep River is tributary to the Cape Fear River and drains slightly over 1,440 mi^2 in parts of Guilford, Randolph, Moore, and Chatham Counties. Low-flow characteristics were summarized for 7 continuous-record gaging stations and 23 partial-record measuring sites. Drainage-area and low-flow discharge profiles were developed for the Deep River and were presented in a similar manner as those for the Roanoke River basin (Weaver, 1996).

Continuing the series of basinwide low-flow investigations, Weaver (1998) summarized low-flow characteristics for 50 continuous-record gaging stations and 113 partial-record measuring sites in the Neuse River basin. Drainage-area and low-flow discharge profiles were developed for 10 selected streams in the basin. Total drainage areas for the profiled streams range from 9 to about 5,600 mi^2. The low-flow discharges for each stream include 7Q10, 30Q2, W7Q10, and 7Q2 discharges in a continuous profile with contributions from major tributaries.

Weaver and Pope (2001) also compiled low-flow characteristics for 67 continuous-record gaging stations and 121 partial-record measuring sites in the Cape Fear River basin. Drainage-area and low-flow discharge profiles were developed for 13 selected streams in the basin. Total drainage areas for the profiled streams range from about 44 to almost 9,100 mi^2. As with the previous basins, low-flow discharges for each stream include 7Q10, 30Q2, W7Q10, and 7Q2 discharges in a continuous profile with contributions from major tributaries. Because the Deep River is part of the Cape Fear River basin, the summary of low-flow characteristics at continuous-record gaging stations and partial-record measuring sites in the Deep River basin (Weaver, 1997) was re-published in the Cape Fear River report (Weaver and Pope, 2001). However, the drainage-area and low-flow discharge profiles developed for the Deep River and associated discussions of low-flow characteristics were not re-published in the Cape Fear River report.

The methods used by Weaver (1996, 1997, 1998) and Weaver and Pope (2001) in previous low-flow investigations are the same methods used in this study. The presentation of results is similar to the presentation of results for the Roanoke, Deep, Neuse, and Cape Fear River basins.

Acknowledgments

The authors acknowledge the staffs of the Water and Sewer Authority of Cabarrus County, Charlotte-Mecklenburg Utilities, the Town of Mooresville, and the North Carolina Divisions of Water Quality and Water Resources for their assistance in compiling information about point-source discharge permits, water withdrawals, and impoundments. Additional information provided by many superintendents and operators at local water-treatment plants, including local and industrial wastewater-treatment facilities in the Rocky River basin, was helpful in the assessment of flow modifications on low-flow characteristics.

Finally, the authors gratefully acknowledge the contributions of Ms. Cara Hamilton, formerly with the U.S. Geological Survey, to this investigation of low-flow characteristics in the Rocky River basin. Ms. Hamilton's research and descriptions of the geology and soils in the basin are the basis for much of the discussion on these topics.

DESCRIPTION OF THE ROCKY RIVER BASIN

The Rocky River basin drains 1,413 mi^2 of the southern Piedmont Province in North Carolina (fig. 1), and the Rocky River merges with the Yadkin River in eastern Stanly County to form the Pee Dee River, which discharges into the Atlantic Ocean in South Carolina. The Rocky River basin occupies about 21 percent of the Yadkin-Pee Dee River basin and lies within parts of seven counties—Iredell, Rowan, Mecklenburg, Cabarrus, Stanly, Union, and Anson (pl. 1). The Rocky River basin is characterized by rolling and hilly topography. Average ground elevations in the basin range from about 180 feet (ft) at the mouth of the Rocky River to about 920 ft in the northernmost areas of the basin in southeastern Iredell and southwestern Rowan Counties.

The Rocky River basin lies in parts of 3 of the 10 hydrologic areas identified by Giese and Mason (1993)—the Charlotte Belt and Milton Belt hydrologic area (HA9), the Carolina Slate Belt (argillite zone) hydrologic area (HA8), and the Triassic Basin hydrologic area (HA6; fig. 2). The Charlotte and Milton Belts consist predominantly of igneous, metaigneous, and metavolcanic rocks, which yield more water to wells than rocks in the Carolina Slate Belt and Triassic Basin (Daniel, 1989; Giese and Mason, 1993). The potential for sustained base flows in streams in the Charlotte and Milton Belts is considered intermediate (or moderate) relative to the other hydrologic areas in the State. Many streams in the Carolina Slate Belt and Triassic Basin hydrologic areas have 7Q10 discharges close to zero as a result of low permeabilities associated with rock types in these areas. Thus, streams in the Carolina Slate Belt and Triassic Basin have little to no potential for sustained

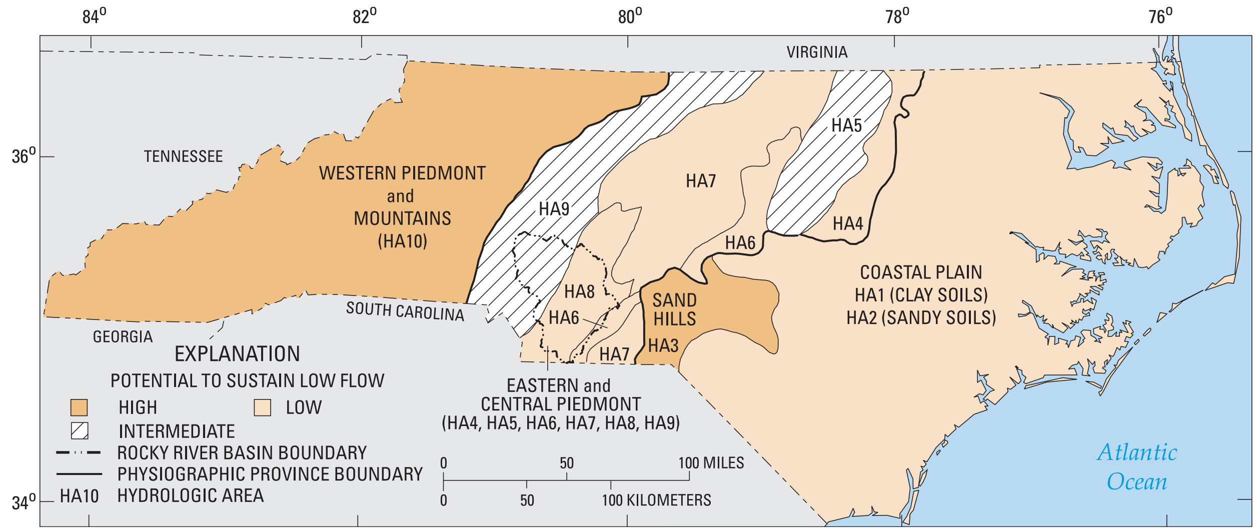


Figure 2. Hydrologic areas of similar potential to sustain low flows in North Carolina.

base flow relative to the other hydrologic areas in the State. As will be discussed in subsequent sections, unit low-flow discharges (expressed as cubic feet per square mile of drainage area) at streams in the Rocky River basin were noted to decrease in the downstream direction, generally concurrent with changes in the underlying geologic characteristics.

Drainage System

Rivers and streams in the Rocky River basin constitute one of the units defined in the system of hydrologic units in the USGS National Water Data Network (Seaber and others, 1987). The unit is identified as "03040103 Rocky [River], North Carolina" and defines the study area for this report. Selected gaging stations and measurements at sites in this basin are the basis for the low-flow characteristics and profiles presented in this report.

Major Rivers and Tributaries

The Rocky River begins near Mooresville in Iredell County and extends nearly 91 miles (mi) from the headwaters to the mouth of the river. From the headwaters, the Rocky River flows southeast through Iredell and Cabarrus Counties, turns south in southeastern Cabarrus County, and then constitutes the county boundary between Stanly and Anson Counties and Stanly and Union Counties before merging with the Yadkin River to form the Pee Dee River (pl. 1).

The drainage area of the Rocky River at its mouth is 1,413 mi^2. The basin gradually broadens in width as the river flows downstream from the northwest to the southeast. Major tributaries draining to the Rocky River include Clarke Creek (28.2 mi^2) and Mallard Creek (41.2 mi^2) in Mecklenburg and Cabarrus Counties; Coddle Creek (78.8 mi^2) in Iredell and Cabarrus Counties; Irish Buffalo/Coldwater Creek (110 mi^2) and Dutch Buffalo Creek (99 mi^2) in Rowan and Cabarrus Counties; Long Creek (200 mi^2) in Stanly County; and Richardson Creek (234 mi^2) and Lanes Creek (135 mi^2) in Union and Anson Counties (pl. 1).

Major Flow Modifications

Major flow modifications are an important factor affecting low-flow characteristics. Flow modifications can be classified in two general categories—impoundments and flow diversions. The ongoing addition and, in some instances, removal of these modifications results in continual changes in the low-flow characteristics and renders an additional level of complexity to the efforts in determining low-flow characteristics.

Impoundments

Impoundments are formed when dams are constructed on streams to store water for a variety of purposes, including water supply, recreation, irrigation, and cooling water. The effects of impoundments on downstream low-flow characteristics vary. Changes in streamflow patterns can occur when water is stored, when water is diverted (for supply purposes—a common occurrence in impoundments), and to a smaller extent, when water evaporates from impoundments. Post-impoundment flow durations for downstream flows, particularly below major impoundments, generally are different from pre-impoundment conditions. The most common, and usually most obvious, difference is the reduction in peak discharges observed in post-impoundment flows. Some impoundments also serve to augment downstream flows during droughts and, thus, increase low flows observed below a dam relative to pre-impoundment conditions.

Approximately 175 impoundments with dams having structural heights exceeding 15 ft were identified in the Rocky River basin (North Carolina Department of Environment, Health, and Natural Resources, unpub. data, 1993). Many are privately owned impoundments having relatively small surface areas at the spillway level. These impoundments primarily are used as (1) farm ponds, which provide water for irrigation and help reduce sediment discharges to streams; (2) recreational lakes at campgrounds and park facilities; and(or) (3) landscape features (ponds) in developed areas.

A number of impoundments in the Rocky River basin cause widespread inundation of the river valley upstream from the dam. The impoundment having the largest surface area is Lake Howell, formerly known as Coddle Creek Reservoir (1,300 acres), in Cabarrus County (pl. 1; North Carolina Department of Environment, Health, and Natural Resources, 1992). Completed in 1993, Lake Howell drains approximately 47 mi^2 of Coddle Creek. Other impoundments having surface areas greater than 200 acres or serving as water-supply sources for the larger municipalities in the Rocky River basin are listed in table 1.

Minimum-flow releases are assigned to some dams to ensure that a sustained level of flow occurs in the stream reaches below the dams. In North Carolina, State agencies that may be involved in the determination and assignment of minimum-flow releases are the North Carolina Division of Land Resources (Dam Safety Program), Division of Water Resources, Division of Water Quality, Wildlife Resources Commission, and on rare occasions, the North Carolina Utilities Commission (James Mead, North Carolina Division of Water Resources, oral commun., June 13, 2003). Federal agencies that may be involved in the determination of minimum-flow releases are the Federal Energy Regulatory Commission, U.S. Fish and Wildlife Service, U.S. Forest Service, U.S. Army Corps of Engineers, and the National Marine Fisheries Service. Determinations of minimum-flow releases are made to address issues concerning available downstream flows and maintenance of water quality and aquatic habitats.

Minimum-flow releases can occur in one of two forms—a release based on operations that involve the opening and closing of gates at the dam to adjust magnitudes of discharges, or a release based on the structural characteristics of the dam's flow-release system, such as a riser-barrel orifice commonly found in smaller impoundments. Only one lake in the Rocky River basin has an assigned minimum-flow release. Lake Howell presently has a minimum-flow release of 6.0 ft^3/s (James Mead, North Carolina Division of Water Resources, oral commun., June 24, 2002). However, minimum releases as low as 2.0 ft^3/s from the dam to Coddle Creek were allowed during the recent (1998–2002) drought conditions observed across North Carolina, consisting of 1.0 ft^3/s from the dam and 1.0 ft^3/s from filter backwash associated with water-treatment operations downstream from the dam. Presently (2003), a tiered set of minimum releases is being considered to allow for flexibility in adjusting minimum releases during low-flow conditions (James Mead, North Carolina Division of Water Resources, oral commun., April 9, 2003).

No other lakes were identified as having minimum-flow releases in the Rocky River basin (James Mead, North Carolina Division of Water Resources, oral commun., June 24, 2002). Variations in the presence of minimum-flow releases at impoundments in the basin apparently reflect the ages of dams more than any other factor. Increased awareness of environmental concerns in recent decades has resulted in revised procedures for maintaining downstream flows. The effect of having no minimum-flow release at an impoundment would mean that flows could potentially decrease to zero flow in the reaches immediately downstream from the dam depending on the seepage characteristics through the dam. Thus, for low-flow characteristics at downstream locations on an impounded stream, the effect could be flows that are equivalent to those at nearby locations having drainage areas equal to the intervening drainage area between the dam and a downstream location.

Table 1. Summary of selected impoundments and minimum-flow releases in the Rocky River basin in North Carolina

[mi^2, square miles; ft^3/s, cubic feet per second; —, no minimum-flow release specified. Impoundments are listed in general downstream order and have surface areas greater than 200 acres or serve as water-supply sources for the larger municipalities in the Rocky River basin]

County	Impoundment name	Stream	Drainage area, (mi^2)	Year of completion[a]	Surface area[a], (acres)	Minimum-flow release[b] (ft^3/s)	Remarks
Cabarrus	Lake Don T. Howell (formerly Coddle Creek Reservoir)	Coddle Creek	47[c]	1993	1,300	6.0	Minimum-flow release is 6.0 ft^3/s. However, minimum releases to Coddle Creek during recent drought conditions (1998–2002) were as low as 2.0 ft^3/s, consisting of 1.0 ft^3/s from dam and 1.0 ft^3/s from filter backwash associated with water-treatmemt operations just downstream from the dam. Presently (2003), a tiered set of minimum releases is being investigated for this dam.[d]
Rowan	Kannapolis Lake	Irish Buffalo Creek	10.4	1938	289	—	Lake is kept full by pumping from Second Creek in adjacent South Yadkin River basin and Lake Howell in Cabarrus County. Lake is privately owned but serves as a water-supply source for the city of Kannapolis.
Cabarrus	Lake Fisher	Coldwater Creek	18.9	1948	277	—	
Cabarrus	Lake Concord	Reedy Branch[e]	4.7[c]	1926[f]	85[f]	—	
Union	Lake Monroe	Little Richardson Creek	9.3[c]	1955	140	—	
Union	Lake Lee	Richardson Creek	51.2	1927	125	—	
Union	Lake Twitty (formerly Lake Stewart)	Stewarts Creek	35.4	1972	82	—	Stewarts Creek is tributary to Richardson Creek.

[a] North Carolina Department of Environment, Health, and Natural Resources, 1992.

[b] James Mead, North Carolina Division of Water Resources, oral commun., June 24, 2002.

[c] Approximate drainage area.

[d] James Mead, North Carolina Division of Water Resources, oral commun., April 9, 2003.

[e] Other stream names for this impoundment have been identified as Patterson Branch (Powell, 1968) and Chambers Branch (North Carolina Department of Environment, Health, and Natural Resources, 1992).

[f] Powell, 1968.

Diversions

Diversions, collectively defined in this report as water-supply withdrawals and return point-source discharges, have the effect of immediately altering downstream low flows by an amount equal to the diversion rate. Withdrawals commonly are made by municipalities and by some major industries. Additionally, some withdrawals are made for agricultural and livestock operations. Until 1999, the State of North Carolina required registration of all withdrawals equal to or exceeding 1 million gallons per day (Mgal/d), or approximately 1.5 ft^3/s. Changes in State legislation, however, now require registration of non-agricultural withdrawals equal to or exceeding 100,000 gallons per day (approximately 0.15 ft^3/s); agricultural withdrawals exceeding 1 Mgal/d must be registered (Woodrow L. Yonts, North Carolina Division of Water Resources, oral commun., September 2000). In the Rocky River basin, a total of 40 registered withdrawals were identified (http://www.dwr.ehnr.state.nc.us/, maintained by the North Carolina Division of Water Resources, accessed April 11, 2003). Because the State requires that decreased flows downstream from withdrawals must be sufficient to sustain downstream uses during drought conditions, including the assimilation of treated effluent, knowledge of low-flow characteristics is important.

Point-source discharges to streams are permitted through the issuance of National Pollutant Discharge Elimination System (NPDES) permits. In North Carolina as well as in other States, permits that set limits for discharges of treated effluent are based, in part, on the 7Q10 discharge. In a similar manner to withdrawals, flows upstream from the discharge point must be sufficient to assimilate the treated effluent while maintaining other uses of the stream. As of 2002, the DWQ issued about 60 NPDES permits for point-source discharges to more than 55 facilities and municipalities in the Rocky River basin (Betsy Albright, North Carolina Division of Water Quality, unpub. data, February 20, 2002). The number of NPDES permits continuously changes as a result of the addition and rescission of permitted discharges in the basin. Among the NPDES permits in the basin, 5 permit holders (all municipal) are designated by the DWQ as major dischargers. The major dischargers are generally defined as facilities discharging more than 1 Mgal/d or facilities having discharges that include high levels of toxicants or metals (Charles Weaver, North Carolina Division of Water Quality, oral commun., July 2000).

Data describing major withdrawals and point-source discharges in the study area were obtained from the different State agencies that monitor flow diversions (North Carolina Department of Environment, Health, and Natural Resources, written commun., 2001) and from local water-treatment and wastewater-treatment operators. For selected facilities, average surface-water withdrawals and return point-source discharges reported for 2001 were compiled into a summary that lists the magnitudes of streamflow changes in the affected streams (table 2). In some instances, point-source discharges were paired with a corresponding surface-water withdrawal made by a given facility. For each facility, the NPDES permit number and permitted flow rate assigned to the permit also are listed. Due to changes in growth and subsequent demands, the amounts of withdrawals and the point-source discharges vary over time. Also, given that hydrologic conditions during 2001 (the most recent calendar year when the information was compiled) were low due to effects of a drought that occurred during 1998–2002, the amounts should not be considered reflective of normal conditions. Nevertheless, the information compiled for 2001 provides a snapshot of the varying magnitudes of diversions that occur in the basin.

The withdrawals and point-source discharges occurring in the Rocky River basin are characterized by a series of interconnections among many of the municipalities. The largest withdrawals in the basin are made by the cities of Concord and Kannapolis, which obtain water from several nearby reservoirs (table 2). In 2001, the withdrawals by Concord and Kannapolis averaged 9.8 and 6.1 Mgal/d (15.2 and 9.4 ft^3/s), respectively. The largest point-source discharge in the basin is made by Cabarrus County, which treats wastewater for a number of municipalities in the county including Concord and Kannapolis. This point-source discharge to the Rocky River, which occurs just upstream from the confluence with Irish Buffalo Creek, averaged 16.3 Mgal/d (25.2 ft^3/s) in 2001 (table 2).

Other significant diversions are point-source discharges made by the town of Mooresville and by Charlotte-Mecklenburg Utilities into tributaries of the Rocky River. Mooresville discharges treated wastewater, which averaged 2.4 Mgal/d (3.7 ft^3/s) in 2001 (table 2), into Dye Branch just upstream from its mouth. Similarly, Charlotte-Mecklenburg Utilities

Table 2. Summary of selected surface-water withdrawals and return point-source discharges to streams in the Rocky River basin, North Carolina, 2001

[Mgal/d, million gallons per day (1 Mgal/d is equivalent to approximately 1.5 cubic feet per second); NPDES, National Pollutant Discharge Elimination System; N/A, not applicable; N/L, not limited; WTP, water-treatment plant; WWTP, wastewater-treatment plant. Facilities are listed in general downstream order in the Rocky River basin. For streams profiled in this report, river miles to the nearest tenth are listed in parentheses beside stream names. For municipalities having multiple withdrawals and(or) point-source discharges, the sum of withdrawals should be compared against the sum of point-source discharges for more meaningful comparisons. Where point-source discharge(s) is greater than withdrawal amount(s) for some municipalities, these facilities treat wastewater for nearby smaller municipalities]

County	Municipality or facility name	Purpose of water supply	Source of water supply	Average withdrawal (Mgal/d)	Destination of point-source discharge	Average point-source discharge (Mgal/d)	NPDES permit number	Permitted NPDES discharge (Mgal/d)
Iredell	Town of Mooresville	Public water supply	Lake Norman in Catawba River basin	3.5	Dye Branch	2.4	NC0046728	5.2
Mecklenburg	River Run Country Club, Inc.	Public water supply	Supplied by Charlotte-Mecklenburg Utilities	N/A	West Branch Rocky River	0.13	NC0067920	0.30
Mecklenburg	Charlotte-Mecklenburg Utilities	Public water supply	Mountain Island Lake[a] in Catawba River basin	98.3	Mallard Creek[a]	6.0	NC0030210	6.0
Cabarrus	City of Concord	Public water supply[b]	Lake Don T. Howell (formerly Coddle Creek Reservoir)	4.6	Coddle Creek[c]	0.55	NC0083119	0.60
			Lake Concord	2.0				
			Lake Fisher	3.2				
Cabarrus	Cabarrus Woods Community	Public water supply	Ground-water wells	0.40	Reedy Creek	0.30	NC0035033	0.45
Cabarrus	Bradfield Farms Community	Public water supply	Ground-water wells	0.24	McKee Creek	0.15	NC0064734	0.46
Cabarrus	City of Kannapolis	Public water supply	Kannapolis Lake[d]	6.1	Irish Buffalo Creek[c]	0.58	NC0006220	N/L
Cabarrus	Water and Sewer Authority of Cabarrus County	Public water supply	No withdrawal[e]	N/A	Rocky River (river mile 56.8)	16.3	NC0036269	24.0
Cabarrus	City of Mount Pleasant	Public water supply	Dutch Buffalo Creek[f]	0.28	N/A[c]	N/A	N/A	N/A
			Ground-water wells	0.04				
Union	Hemby Acres Community	Public water supply	Supplied by Union County	N/A	North Fork Crooked Creek	0.10	NC0035041	0.30
Union	Country Wood Community	Public water supply	Supplied by Union County	N/A	Goose Creek	0.09	NC0065684	0.09

Table 2. Summary of selected surface-water withdrawals and return point-source discharges to streams in the Rocky River basin, North Carolina, 2001—Continued

[Mgal/d, million gallons per day (1 Mgal/d is equivalent to approximately 1.5 cubic feet per second); NPDES, National Pollutant Discharge Elimination System; N/A, not applicable; N/L, not limited; WTP, water-treatment plant; WWTP, wastewater-treatment plant. Facilities are listed in general downstream order in the Rocky River basin. For streams profiled in this report, river miles to the nearest tenth are listed in parentheses beside stream names. For municipalities having multiple withdrawals and(or) point-source discharges, the sum of withdrawals should be compared against the sum of point-source discharges for more meaningful comparisons. Where point-source discharge(s) is greater than withdrawal amount(s) for some municipalities, these facilities treat wastewater for nearby smaller municipalities]

County	Municipality or facility name	Purpose of water supply	Source of water supply	Average withdrawal (Mgal/d)	Destination of point-source discharge	Average point-source discharge (Mgal/d)	NPDES permit number	Permitted NPDES discharge (Mgal/d)
Union	Union County Public Works Department	Public water supply	Supplied by Catawba River WTP in Yadkin River basin	N/A	South Fork Crooked Creek	1.1	NC0069841	1.9
						0.02	NC0069523	0.05
			Supplied by Anson County Water System in Yadkin River basin	N/A	Clear Creek			
						0.14	NC0072508	
					Goose Creek			0.231
Stanly	City of Albemarle	Public water supply	Narrows (Badin) Resevior in Yadkin River basin	4.0	Long Creek	9.6	NC0024244	16.0
			Tuckerton Resevoir in Yadkin River basin	3.3				
Stanly	Town of Oakboro	Public water supply	Supplied by the Stanly County Utility Department	N/A	Long Creek	0.28	NC0043532	0.50
			Ground-water wells	0.06				
Union	City of Monroe	Public water supply	Lake Twitty[g]	7.5	Richardson Creek	7.2	NC0024333	9.0
					Stewarts Creek	0.30	NC0080381	N/L
Stanly	Town of Norwood	Public water supply	Lake Tillery in Yadkin River basin	0.41	Rocky River (river mile 4.3)	0.50	NC0021628	0.75

[a] Charlotte-Mecklenburg Utilities also obtains water from Lake Norman in the Catawba River basin. Water from the two lakes is distributed throughout Mecklenburg County, which lies within the two basins (Catawba, 75 percent; Rocky, 25 percent). No information is known concerning the percentage of the water supply used in Mecklenburg County that drains to the Rocky River. In addition to the Mallard Creek WWTP, the utility has other facilities for the discharge of treated wastewater into streams throughout Mecklenburg County in the Catawba River basin. Based on information submitted to the North Carolina Division of Water Resources under the 1997 Local Water Supply Plan program, the permitted discharge from the Mallard Creek WWTP represented about 7 percent of the total permitted discharges made by the utility (online database http://www.dwr.ehnr.state.nc.us/, maintained by the North Carolina Division of Water Resources, accessed April 9, 2003).

[b]The city of Concord obtains water supply from three sources. Water from Lake Howell is treated at the Coddle Creek Treatment Plant, and water from Lake Concord and Lake Fisher is treated at the Hillgrove Water Treatment Plant (Jeff Isley, City of Concord, oral commun., April 24, 2003).

[c]The cities of Concord, Kannapolis, and Mount Pleasant rely on the Water and Sewer Authority of Cabarrus County to treat and discharge most or all of their wastewater.

[d]Water supply in Kannapolis Lake is supplemented by two other sources: Lake Howell in Cabarrus County and Second Creek in the adjacent South Yadkin River basin. In 2001, all water withdrawn from Kannapolis Lake came from Lake Howell (1.8 Mgal/d) and Second Creek (4.3 Mgal/d).

[e]The Water and Sewer Authority of Cabarrus County withdraws no water. The facility treats and discharges wastewater for the cities of Concord, Kannapolis, and Mount Pleasant.

[f]Based on information submitted to the North Carolina Division of Water Resources under the 1997 Local Water Supply Plan program, Mount Pleasant is also able to withdraw water from Black Run Creek Reservoir during emergencies (online database http://www.dwr.ehnr.state.nc.us/, maintained by the North Carolina Division of Water Resources, accessed April 9, 2003).

[g]The city of Monroe pumps an unmetered amount of water from Lakes Monroe and Lee into Lake Twitty for water-supply use.

discharged an average of 6.0 Mgal/d (9.3 ft^3/s) of treated wastewater during 2001 into Mallard Creek. These municipalities obtain their water supply from Mountain Island Lake and Lake Norman, respectively, in the adjacent Catawba River basin, indicating the presence of interbasin transfers to the Rocky River basin. The city of Monroe withdrew an average of 7.5 Mgal/d (11.6 ft^3/s) from Lake Twitty, an impoundment of Stewarts Creek, and returned a combined 7.5 Mgal/d (11.6 ft^3/s) to Richardson Creek in 2001 (table 2). Other smaller municipalities in the eastern part of the Rocky River basin obtain their water supply from impoundments of the Yadkin River located east of the study area. The city of Albemarle withdrew a combined average of 7.3 Mgal/d (11.3 ft^3/s) from Narrows and Tuckertown Reservoirs and returned 9.6 Mgal/d (14.9 ft^3/s) to Long Creek, a tributary to the Rocky River (table 2). Water-supply withdrawals by the town of Norwood averaged about 0.4 Mgal/d (about 0.6 ft^3/s) from Lake Tillery, and return discharges averaged about 0.5 Mgal/d (about 0.8 ft^3/s) to the Rocky River in 2001 (table 2).

Climate

The climate in the Rocky River basin, as throughout most of North Carolina, consists of long, hot, humid summers and short, mild winters with periods of more moderate conditions during the spring and autumn seasons. The average annual temperature (1961–90) in the study area is about 60 degrees Fahrenheit (°F) and ranges, on a monthly basis, from about 40 °F in January to about 79 °F in July (National Oceanic and Atmospheric Administration, 2001). In all areas of the Rocky River basin, temperature extremes in the summer reach levels exceeding 90 °F for long periods of consecutive days.

Average annual precipitation (1961–90) in the study area ranges from nearly 46 inches (in.) at the Concord reporting station to about 48 in. at the Monroe and Albemarle reporting stations (National Oceanic and Atmospheric Administration, 2001). On a monthly basis, the highest amounts of rainfall occur during July and August, and the lowest monthly rainfall generally occurs during April. Most rainfall during the warmer months comes from isolated, convective-type storms that occur in the late afternoons and evenings as a result of daytime heating. Rainfall during cooler months is commonly from more organized frontal storms that cover broad areas of the region.

Since 1900, major droughts have occurred in North Carolina resulting in low flows throughout the Rocky River basin. The drought of longest duration affecting streams in the Rocky River basin occurred during 1950–57 (Zembrzuski and others, 1991). At Rocky River near Norwood (site 169, pl. 1) in Stanly County, the lowest annual 7-day minimum discharge (26 ft^3/s on October 7) and instantaneous discharge (17 ft^3/s on October 8) for the period of record (1929–2002) occurred during the fall of 1954 (Ragland and others, 2003).

While the 1950–57 drought was the longest in duration, the drought having the most intense effects on streamflow occurred during 1998–2002. At Rocky River near Norwood (site 169), no record low 7-day minimum or instantaneous discharge was set, but the lowest annual mean discharge of 406 ft^3/s occurred during the 2002 water year, compared to nearly 1,340 ft^3/s for the period of record (Ragland and others, 2003). The lowest annual mean discharge for the period of record also occurred during the 2002 water year for nearby sites in the Rocky and Catawba River basins—Big Bear Creek near Richfield (site 113), Long Creek near Paw Creek (USGS station 0214290 in western Mecklenburg County in the Catawba River basin), McAlpine Creek at Sardis Road near Charlotte (USGS station 02146600 in southeastern Mecklenburg County in the Catawba River basin), and Twelve Mile Creek near Waxhaw (USGS station 02146900 in southwestern Union County in the Catawba River basin).

Analysis of monthly rainfall data from the National Oceanic and Atmospheric Administration (NOAA) rain gages in Concord, Albemarle, and Monroe indicates that cumulative departures from spring 1998 through early fall 2002 ranged from 30 to 45 in. (Ryan Boyles, State Climate Office of North Carolina, written commun., April 14, 2003). Considering that average annual rainfall for these locations ranges from 46 to 48 in., the cumulative departures are equivalent to a range of between 9 and 12 months of rainfall that did not occur during the 1998–2002 period.

Geology and Soils

An understanding of the geology and soils in the study area may provide some insight into the low-flow characteristics for streams in the Rocky River basin. Although these factors should be considered in any analysis of low flows, identification of an underlying geologic unit or soil cannot be used solely to determine the potential for sustaining base flow during drought conditions.

The Rocky River basin spans two of the major geologic belts in North Carolina—the Charlotte Belt and the Carolina Slate Belt. The Charlotte Belt region underlies the upper half of the basin in the counties of Iredell, Rowan, Mecklenburg, and Cabarrus. The Charlotte Belt consists largely of intrusive igneous rocks, both felsic and mafic, that range in age from 300 to 500 million years and include granite, diorite, and gabbro (North Carolina Geological Survey, 1991). The Rocky River flows through the middle of the Concord ring dike, which consists of a ring of syenite surrounding a gabbro pluton, before exiting the Charlotte Belt region and flowing into the Carolina Slate Belt.

The portion of the Rocky River basin that is underlain by the Carolina Slate Belt includes Stanly, Union, and Anson Counties. The Carolina Slate Belt is composed of the remnants of a former chain of volcanic islands (North Carolina Geological Survey, 1991). Thus, the rocks in this part of the basin are primarily metamorphic and have sedimentary and volcanic origins. The rocks of the Carolina Slate Belt range in age from 550 to 650 million years (North Carolina Geological Survey, 1991). Specific rock types found in this portion of the basin include metamorphosed mudstone, argillite, and graywacke, and metavolcanic flows and tuffs (North Carolina Geological Survey, 1985).

Twelve major soil series are present directly adjacent to the Rocky River and its tributaries. As with the geology, the soils of the Rocky River basin can be divided into three general categories: (1) piedmont upland, (2) lowland and intermediate, and (3) flood plain. The soils generally reflect the underlying geologic parent material with a mixture of soils derived from crystalline rock and soils derived from fine-grained Carolina Slate rock present throughout the basin. The dominant soil texture among the 12 soil series is loam with a high occurrence of loam combination textures, including sandy loam, silt loam, and clay loam. The silt loam is the most common series, and 2 of the 12 series are clay soils. In general, all of the soils are considered moderately permeable (0.6 to 2 in. per hour).

Piedmont upland soils (Badin, Goldston, Enon, and Poindexter series) include soils present on slopes and knolls that generally are well drained with slopes ranging from 2 to 45 percent (U.S. Department of Agriculture, 1996). Soil textures range from clay to sandy loam. The Badin and Goldston series are by far the most prevalent upland soils, present along almost the entire reach of the Rocky River. Both Enon and Poindexter soils are found on gentle to steep slopes. The Badin series consists of clayey soils weathered from fine-grained Carolina Slate graywacke and argillite and is found on gentle to steep upland slopes (U.S. Department of Agriculture, 1996). The Goldston series, which has a silt loam texture, also is weathered from the Carolina Slate rocks and found on slopes and knolls; however, the Goldston series tends to be shallower than the Badin series. The Enon series consists of a sandy loam soil, and the Poindexter series consists of loam (U.S. Department of Agriculture, 1988).

The lowland and intermediate soils (Coronaca, Cullen, Kirksey, and Misenheimer series) are found on flood plains, broad ridges, depressions, and heads of drainageways (U.S. Department of Agriculture, 1988). These soils range from well drained to poorly drained, and their slopes range from 0 to 15 percent (U.S. Department of Agriculture, 1988). The Coronaca and Cullen series are clay loams with slopes ranging from 2 to 15 percent; both series are weathered from crystalline rocks that include gneiss, gabbro, and diorite (U.S. Department of Agriculture, 1988). The Misenheimer and Kirksey series are moderately well drained, have slopes ranging from 0 to 4 percent, and are silt loams weathered from argillites and graywacke sandstones (U.S. Department of Agriculture, 1988).

Flood-plain soils of the Rocky River basin have slopes that range from 0 to 2 percent and include the Chewacla, Congaree, Oakboro, and Wehadkee series (U.S. Department of Agriculture, 1988, 1989). The Chewacla and Wehadkee series are the most prevalent flood-plain series and are poorly drained alluvium weathered from crystalline rocks such as schist, gneiss, and granite (U.S. Department of Agriculture, 1988). The Oakboro series is a silt loam alluvium that is well drained and weathered from various Carolina Slate rocks such as slate, siltstone, and tuff (U.S. Department of Agriculture, 1989). The fourth flood-plain series, the Congaree, is a fine sandy loam alluvium that is well drained, like the Oakboro series, but is formed from crystalline rock (U.S. Department of Agriculture, 1989).

While low-flow characteristics cannot be described solely on the basis of knowing the geology and soils of a given area, average well yields determined for different hydrogeologic units in the Piedmont and Blue Ridge Provinces of North Carolina provide yet another indicator of the potential for sustained base flow. Daniel (1989) identified 18 hydrogeologic units in the Blue Ridge and Piedmont Provinces of North Carolina and determined an average well yield for each unit. The average well yield for all 18 of the hydrogeologic units was 18.2 gallons per minute (gal/min), equivalent to 0.040 ft^3/s. In the Rocky River basin, 12 of the 18 hydrogeologic units were identified. Seven of the 12 units, composing nearly 64 percent of the Rocky River basin (Daniel and Payne, 1990; fig. 3), have well yields less than this average. Six of the seven units having less-than-average well yields are derived from igneous and metavolcanic rocks, and among this group is the unit characterized by argillite rocks (ARG unit, fig. 3), which covers nearly 48 percent of the basin. The average well yield of argillite rocks is 14.6 gal/min (or 0.032 ft^3/s), which is significantly below the average of 18.2 gal/min as determined by Daniel (1989). The seventh unit, which covers less than 1 percent of the Rocky River basin, is characterized by Triassic rocks (TRI unit, fig. 3) and has the lowest average well yield (14.6 gal/min, or 0.025 ft^3/s) of all the hydrogeologic units studied by Daniel (1989).

Land Use

Land-use information for the study area was obtained from the Multi-Resolution Land Characteristics data set, a product of the Ecological Monitoring and Assessment Program of the U.S. Environmental Protection Agency (USEPA) and other agencies, including the U.S. Forest Service, NOAA, and the USGS (Eimers and others, 1999). The USEPA land-cover information was collected by the Landsat Thematic Mapper sensor using remote-sensing techniques (Vogelmann and others, 1998) and compiled from aerial photographs taken primarily during the spring seasons of 1991–93. Information was processed into 15 land-use classes established for the development of a consistent and generalized land-cover data base for all of the United States (Vogelmann and others, 1998). In the Rocky River basin, 6 general categories were identified from the 15 land-use classes in the study area (table 3).

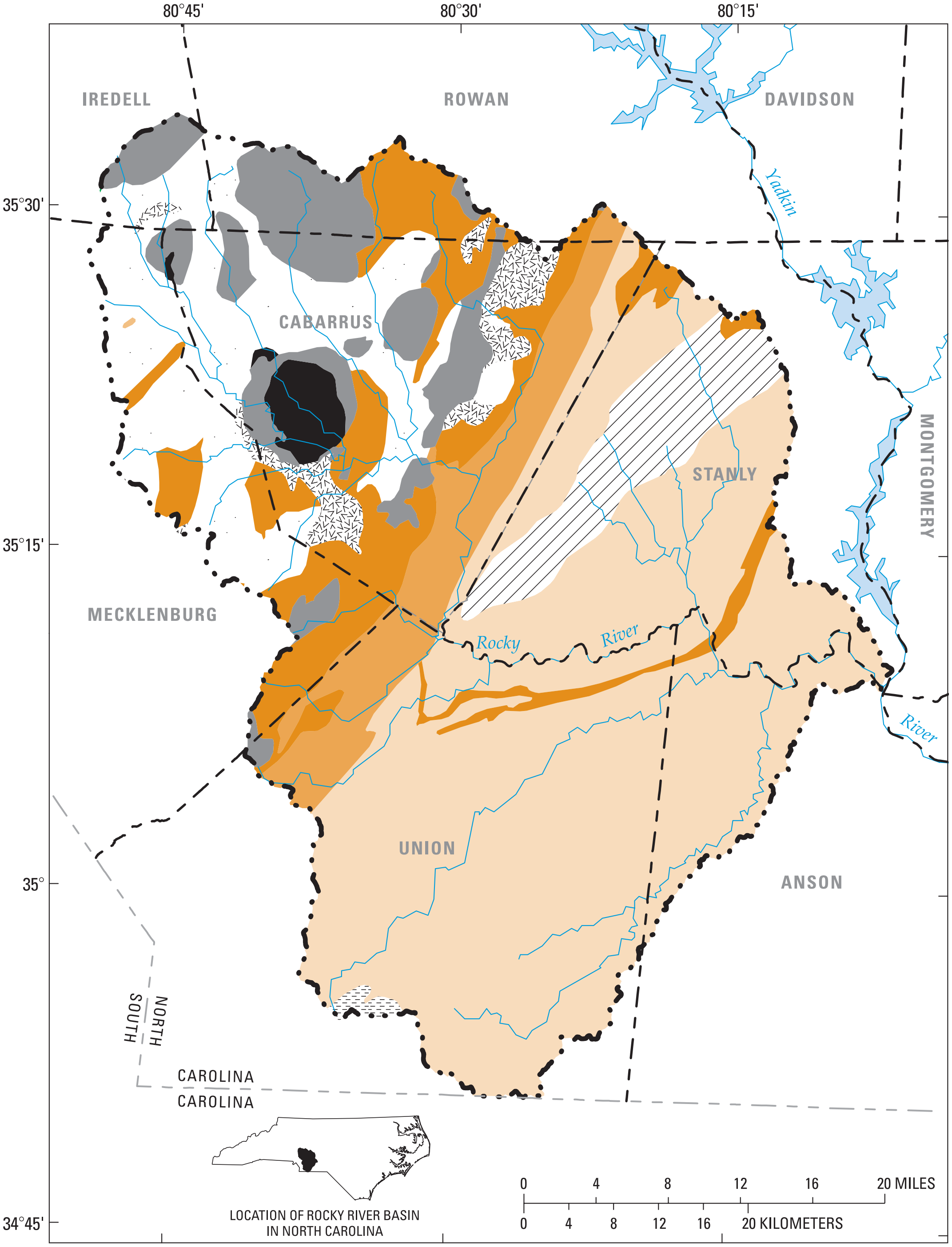
Table 3. Land use in the Rocky River basin in North Carolina

Land-use category	Percent of study area covered by land-use category[a]
Developed (includes urban areas)	7.3
Agricultural	40.4
Forested	50.3
Water	0.5
Wetlands	1.0
Barren (includes quarries, gravel pits, and transitional areas such as clear-cut areas)	0.5
Totals	100.0

[a] From U.S. Environmental Protection Agency Land-Cover Data Set (Vogelmann and others, 1998).

Overall, most of the land use in the Rocky River basin is rural with forested and agricultural land uses occupying about 91 percent of the basin. Urban land uses (low- and high-density residential, high-density commercial, industrial, and transportation uses) compose 7.3 percent of the basin. Concord and Kannapolis in Cabarrus and Rowan Counties, respectively, compose the greatest extent of urban land use in the basin. A large extent of urban land use also occurs on the western border of the basin near Charlotte and its suburbs. Other municipalities in the basin include Mooresville in Iredell County, Albemarle in Stanly County, and Monroe in Union County (pl. 1).

Changes in land use and effects on low flows in North Carolina generally have not been investigated extensively. Only two continuous-record gaging stations with long-term records of discharge (sites 113 and 169) are located in the Rocky River basin; however, land use in the basins upstream from these sites is generally rural, thereby precluding any insight into the effects of land-use changes on low-flow characteristics. As previously discussed, Evett (1994) investigated the effects of urbanization and land-use changes on low flows. While the conclusions from that investigation tended to support the hypothesis of decreasing low flows with increasing urbanization, Evett (1994) described the results as being statistically inconclusive.



Modified from Daniel and Payne (1990), digitized by North Carolina Center for Geographic Information and Analysis, 1998, 1:500,000; State plane projection, North American Datum of 1983

EXPLANATION

- TRI (11.6 gal/min, 0.04 percent)
- MVF (13 gal/min, 0.3 percent)
- ARG (14.6 gal/min, 47.59 percent)
- MVE (16.9 gal/min, 5.54 percent)
- GNF (17.4 gal/min, 0.01 percent)
- IFI (17.7 gal/min, 8.63 percent)
- IMI (17.8 gal/min, 1.41 percent)
- MII (18.4 gal/min, 14.71 percent)
- QTZ (18.6 gal/min, 0.01 percent)
- MIM (19.7 gal/min, 2.51 percent)
- MVU (20.2 gal/min, 12.07 percent)
- PHL (20.3 gal/min, 7.18 percent)

ROCKY RIVER BASIN BOUNDARY

Letters represent hydrogeologic units from Daniel (1989). First number is average well yield in gallons per minute (gal/min) (Daniel, 1989); second number is percentage of basin area within indicated hydrogeologic unit

Figure 3. Hydrogeologic units in the Rocky River basin, North Carolina.

Nevertheless, speculation among hydrologists has been that increasing urbanization results in decreased low flows due to less infiltration of water to shallow aquifers. In other words, the runoff from impervious areas is directed toward stream channels for immediate removal; thus, little or no storage of water occurs in the soils for later release during periods of low flow. As developed areas in North Carolina's larger municipalities continue to expand, additional investigations may aid in the understanding of land-use effects on low-flow hydrology.

LOW-FLOW CHARACTERISTICS IN THE ROCKY RIVER BASIN

Low-flow characteristics were determined for selected streamflow sites in the Rocky River basin study area in North Carolina. Available records of streamflow collected through the 2002 water year for continuous-record gaging stations and through the 2001 water year for partial-record measuring sites were compiled for 173 sites (table 4, p. 41–50; pl. 1) and evaluated to identify sites where low-flow characteristics could be determined. The period of record varies from site to site. Of the 173 sites, 8 are continuous-record gaging stations, 161 are partial-record sites, and 4 are sites having a combination of continuous- and partial-record discharges. The low-flow characteristics for selected sites in the Rocky River basin are presented in this section.

Continuous-Record Stations

Low-flow characteristics based on continuous records of discharge were developed for 12 sites—8 continuous-record gaging stations and 4 sites that have both continuous- and partial-record discharges. Available records of discharge collected through the 2002 water year were used in the analyses. The magnitude and frequency of low flows for the continuous-record gaging stations are given in table 5.

Estimates of low-flow discharges for two continuous-record sites (113, 169) having more than 10 years of record were developed by using frequency curves (Riggs, 1972; fig. 4). The curves depict the relation between recurrence interval and the lowest average annual discharge for a specified number of days at a gaging station. Using available periods of record, frequency curves of measured annual (climatic year) 7-day and 30-day lowest average discharges and winter (November through March) 7-day lowest average discharge were developed; then a log-Pearson Type III frequency distribution was fitted to the measured values. The computed log-Pearson distribution generally corresponds closely to the distribution of annual low flows for sites having long-term periods of record (fig. 4). The method of analysis for these sites is denoted as "LP" in table 5.

The remaining 10 gaging stations have periods of record less than 10 years (and usually less than 5 years) and were treated as partial-record measuring sites by using the methods of correlation described in the subsequent section Partial-Record Sites. The method of analysis for these sites is denoted as "C" in table 5. The period of analysis for these sites is denoted as "PR" representing application of methods used at partial-record sites, and the available period of record listed in table 4 was included in the analyses.

In the determination of low-flow characteristics for continuous-record gaging stations, the available periods of record were used in the analyses. Due to the short and varying periods of records at most continuous-record sites, no common period of record could be identified for use in the analyses. Doing so would have removed some sites from the compilation of low-flow characteristics or limited the amount of data available for inclusion in the analyses.

The last year of data collection for a discontinued site on Richardson Creek was 1944 (site 146, table 5), and low-flow characteristics (table 5) for this site cannot necessarily be interpreted as reflecting low-flow characteristics that would be calculated if the gage were still in operation. Changes in basin characteristics, such as development, artificial drainage, and(or) flow modifications, could result in changes in low-flow characteristics. Thus, when examining the low-flow characteristics for any discontinued site, the period of record should be considered, particularly in basins that have experienced major changes. More recent data are needed to provide a better understanding of the current low-flow characteristics.

Streamflows on the Rocky River, particularly in the reaches upstream from Stanfield (pl. 1), are affected by major flow diversions in the form of NPDES point-source discharges. The low-flow characteristics determined for the continuous-record gaging stations near Rocky River, Stanfield, and Norwood (sites 40, 85, and 169, respectively; table 5) reflect, to varying degrees, the effects of these major diversions, all of

Table 5. Magnitude and frequency of annual low-flow characteristics at selected continuous-record gaging stations in the Rocky River basin in North Carolina

[USGS, U.S. Geological Survey; mi^2, square miles; (ft^3/s)/mi^2, cubic feet per second per square mile; ft^3/s, cubic feet per second; 7Q10, 7-day, 10-year low flow; 30Q2, 30-day, 2-year low flow; W7Q10, winter 7-day, 10-year low flow; 7Q2, 7-day, 2-year low flow. Flow regulation: U, unregulated flow; R, regulated flow. Method of analysis: C, estimates based on correlation techniques; LP, estimates based on log-Pearson frequency distribution. PR, gaging station having less than 10 years record of daily mean discharge, treated as a partial-record site where low-flow characteristics were developed by using correlation techniques; <, less than; NPDES, National Pollutant Discharge Elimination System. For each continuous-record site using the period of analysis (usually the available period of record), the number of daily discharges equal to zero or less than or equal to the indicated 7Q10 discharge are provided for informational purposes]

Site index no. (pl. 1)	USGS downstream order number	Station name	Drainage area (mi^2)	Period of analysis	Number of observed days of flow: Equal to zero flow	Number of observed days of flow: Less than or equal to 7Q10	Average annual unit flow [(ft^3/s)/mi^2]	Low-flow characteristics (ft^3/s): 7Q10	Low-flow characteristics (ft^3/s): 30Q2	Low-flow characteristics (ft^3/s): W7Q10	Low-flow characteristics (ft^3/s): 7Q2	Flow regulation	Method of analysis
21	02124149	Mallard Creek below Stony Creek near Harrisburg	34.6	PR	0	20	1.0	1.4	4.4	3.6	2.9	U	C
40	0212433550	Rocky River above Irish Buffalo Creek near Rocky River[a]	278	PR	0	72	1.0	25.2	40.6	35.2	33.4	R	C
68	02124471	Dutch Buffalo Creek at NC 49 near Mount Pleasant	45.1	PR	15	47	1.0	0.7[b]	3.3	2.2	1.9	U	C
80	02124692	Goose Creek at Fairview[c]	24.0	PR	0	15	1.0	0.3	1.4	1.0	0.8	U	C
85	02124742	Rocky River near Stanfield[a]	628	PR	0	117	1.0	42.3	103	87.3	80.5	R	C
113	02125000	Big Bear Creek near Richfield[c]	55.6	Apr 1954–Mar 2002	686	686	1.0	0	0.4	0.2	0.2	U	LP
146	02125500	Richardson Creek near Marshville	163	PR	37	60	0.9	0.5[d]	3.0	1.6	1.6	U	C
152	02125557	Gourdvine Creek near Olive Branch	8.75	PR	121	121	0.9	0	0	0	0	U	C
157	02125696	Lanes Creek near Trinity	4.92	PR	557	557	0.9	0	0	0	0	U	C
159	02125699	Wicker Branch near Trinity	5.83	PR	4	4	0.9	0	< 0.05	< 0.05	0	U	C
165	02125816	Lanes Creek near Marshville	87.7	PR	67	67	0.9	0[e]	0.3	0.05	< 0.05	U	C
169	02126000	Rocky River near Norwood[a]	1,372	Apr 1930–Mar 2002	0	152	1.0	45.8	113	77.6	78.2	R	LP

[a] Includes effects of major NPDES discharge(s) upstream from gaging station.

[b] Low-flow characteristics determined at other sites (65, 69, and 73) on Dutch Buffalo Creek suggest the existence of a losing reach in the downstream reaches.

[c] Low-flow characteristics previously published in Giese and Mason (1993); where different, estimates in this report supersede previous estimates.

[d] Low-flow characteristics reflect flow conditions prior to the opening of the water-treatment plant on Stewarts Creek just upstream from Richardson Creek in 1972 and the wastewater-treatment plant on Richardson Creek in 1965. See low-flow characteristics for other locations on Richardson Creek (sites 124, 132, 139, 145, and 154 in table 6). Low-flow characteristics for this site (and any discontinued sites) cannot be interpreted as reflective of current low-flow characteristics in the absence of more recent data. In basins where significant land-use changes have occurred, available low-flow characteristics may be useful in the understanding of natural-flow conditions during periods of low flows prior to changes in the basin.

[e] Low-flow characteristics for this site suggest the existence of a losing reach on Lanes Creek (see low-flow characteristics for site 157 in this table and site 161 in table 6).

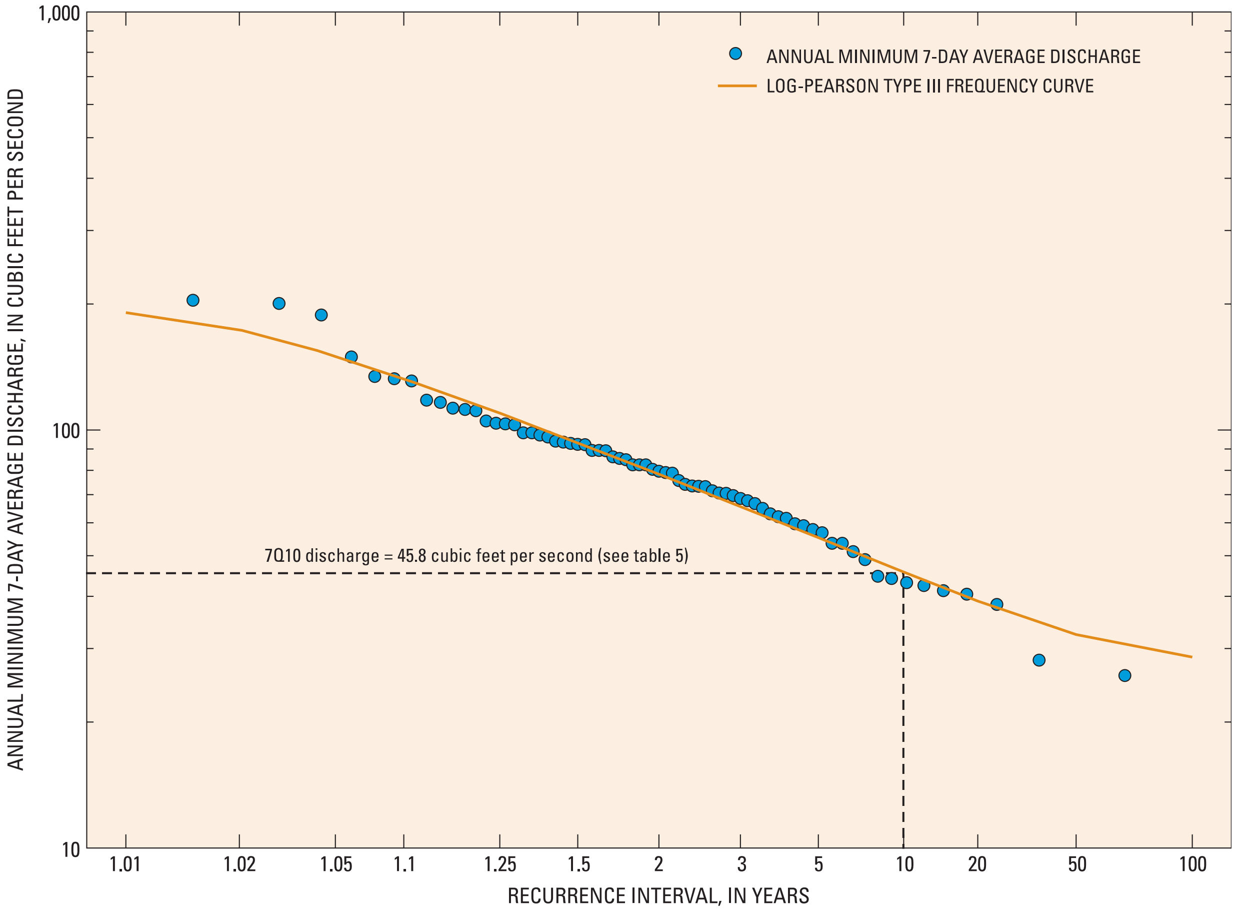


Figure 4. Low-flow frequency curve of annual minimum 7-day average discharges using log-Pearson Type III frequency distribution at Rocky River near Norwood, North Carolina (site 169).

which began in the late 1970's and early 1980's. At site 40 near Rocky River, the drainage area is 278 mi^2. The combined drainage areas at the two major point-source discharge locations on Dye Branch and Mallard Creek (table 2) is nearly 43 mi^2 (equivalent to about 15 percent of the drainage area at site 40). In other words, the intervening drainage area, where the flows are not known to be affected by any other major diversions or regulation, between site 40 and the locations of the two NPDES discharge points is 85 percent of the total area upstream from site 40. However, during the period April 2000 through September 2002, the combined point-source discharges at these two locations averaged about 26 percent of the flows at site 40.

Similarly, the drainage area at site 85 near Stanfield is 628 mi^2. The combined drainage areas upstream from the three major point-source discharges on Dye Branch, Mallard Creek, and Rocky River (discharges by Cabarrus County, table 2) is 321 mi^2, or about 51 percent of the drainage area at site 85. During the period April 2000 through September 2002, however, the combined point-source discharges averaged about 34 percent of the flows at site 85.

The drainage area between the gaging stations near Stanfield (site 85) and near Norwood (site 169) increases from 628 to 1,372 mi^2, a 118 percent increase. In this same reach, the 7Q10 discharge between the gaging stations increases from 42.3 to 45.8 ft^3/s, an 8.3 percent increase. However, the unit 7Q10 discharge between Stanfield and Norwood decreases by about 50 percent in this same reach. The reach of the river and its tributaries between these two locations is underlain by the Carolina Slate Belt, a geologic region that is characterized by streams having very little to no potential for sustained base flow.

At the gaging station near Norwood (site 169), the combined drainage areas upstream from the three major point-source discharges is about 23 percent of the drainage area at the gaging station, and the combined discharges averaged about 22 percent of the streamflows at the gaging station during April 2000 through September 2002. The actual effects of the diversions on the flows at the gaging station near Norwood (site 169) are more difficult to ascertain because of the added effect of a possible losing reach downstream from the gaging station near Stanfield (site 85).

A losing reach occurs when streamflow in a channel discharges to the ground. During low-flow periods, streams are sustained by base flows, meaning the water table is higher than the channel bottom allowing ground water to discharge from the adjacent banks to the stream. However, if the water table is below the channel bottom, streamflow in the channel discharges to the water table, resulting in a stream with declining flows. Most streams in North Carolina are recognized as gaining reaches meaning that ground-water discharge to the stream aids the accumulation of flow in the downstream direction. Although a losing reach is characterized by declining flows, it is not characterized by decreasing unit low-flow discharges in the downstream direction. Where the unit flows between two points on a stream decrease by a substantial percentage, however, it is possible that the stream could be a losing reach if there are no major water-supply diversions between the two points. Conversely, the presence of a major water-supply withdrawal between two sites on the same stream requires caution in assessing the existence of a losing reach.

During the investigation, efforts were made to estimate low-flow characteristics at the Rocky River (site 40) and Stanfield (site 85) gaging stations that would be considered reflective of natural-flow conditions (that is, without the presence of the major NPDES discharges upstream from the site). Records of daily discharge for the period April 2000 through September 2002 were adjusted to account for the upstream point-source discharges to Dye Branch, Mallard Creek, and Rocky River (table 2). At site 40, the estimated 7Q10 discharge based on streamflows unaffected by the two upstream point-source discharges was 10.5 ft^3/s, or about 0.04 $(ft^3/s)/mi^2$. At site 85, the 7Q10 discharge based on streamflows unaffected by the three point-source discharges was estimated to be 23 ft^3/s, or likewise about 0.04 $(ft^3/s)/mi^2$. The natural-flow estimates (in terms of unit discharges) are about 40 to 50 percent of the estimated 7Q10 discharges based on the presence of the point-source discharges (table 5). These comparisons highlight the effect of these major flow diversions in the basin.

The estimated 7Q10 discharge (10.5 ft^3/s) at site 40 based on unaffected streamflows is 25 percent lower than a previous 7Q10 discharge of 14 ft^3/s determined for site 39, a discontinued partial-record measuring site located almost immediately upstream from site 40. Considering that two independent sets of streamflow records from differing periods of record were used to determine these 7Q10 discharges, these values could be regarded as fairly comparable. Thus it is likely that the natural-flow 7Q10 discharge for the Rocky River above Irish Buffalo Creek may be about 10 to 15 ft^3/s. Because the short period of record used in the analysis for site 40 reflects drought conditions, it is also possible that subsequent estimates of the natural-flow 7Q10 discharge may increase if additional periods of data collection reflect normal conditions.

Partial-Record Sites

Using the techniques discussed by Riggs (1972), low-flow characteristics were determined for 44 of the 161 partial-record sites in the Rocky River basin (table 6). In general, sites having 10 or more discharge measurements were included in the analysis. Exceptions included sites where low-flow characteristics previously have been published. Sites on the Rocky River for which low-flow discharges were necessary to develop discharge profiles also were included in the analysis of low-flow characteristics.

Among the 161 partial-record sites having 10 or more measurements, low-flow characteristics were not determined for 18 sites: (1) sites 10, 17, and 140 had mostly crest-gage (peak flood) partial-record measurements, (2) site 23 is immediately downstream from a major NPDES point-source discharge, (3) site 39 is adjacent to a continuous-record station, (4) sites 114 and 153 had discharge records that were combined with those at an adjacent site for subsequent analysis, and (5) sites 1, 42, 44–50, 79, and 106 had uncharacteristically high unit low-flow discharges either because of fairly high discharge records or apparent upstream diversions.

The periods of record (and correspondingly, the number of discharge measurements) varied among the partial-record measuring sites, ranging from as little as a few years to more than several decades. Due to the varying periods of records, no common period of record could be identified for use in the analysis. Doing so would have removed some sites from the compilation of low-flow characteristics or limited the amount of data available for inclusion in the analyses. Thus data based on the available period of record through the 2001 water year were included in the analyses for partial-record measuring sites. Exceptions to this occurred in the analyses for two sites (3 and 60) on the Rocky River where only data for periods since the start of major upstream NPDES point-source discharges were used.

Discharge measurements at the partial-record sites were correlated with concurrent flows at nearby index sites (typically continuous-record gaging stations) where low-flow characteristics had been determined (fig. 5). Index sites used in the correlation analysis of concurrent flows were, to the extent possible, selected based on proximity of the partial-record and index sites, and similarity of relevant basin characteristics such as drainage area, topography, soils, and hydrogeology, which may include sites outside of the Rocky River basin.

Defining the relation between concurrent flows usually is accomplished with either statistical techniques or graphical interpretation based on a visually fitted line drawn through the concurrent flows (Riggs, 1972; U.S. Geological Survey, 1985). In this investigation, graphical interpretation was used to establish the relation between the concurrent flows for many of the sites.

At most partial-record sites, correlations of the discharge measurements with concurrent flows at multiple index sites yielded several relations from which estimates of low-flow discharges could be determined. Overall estimates of low-flow discharges (7Q10, 30Q2, W7Q10, and 7Q2) for each partial-record site were determined as the average of the individual estimates derived from each correlation. However, individually derived estimates from correlations that could not be satisfactorily defined (generally due to substantial scatter of observations) were not included in the average for overall estimates.

Low-flow characteristics for the partial-record measuring sites generally reflect unregulated conditions in the study area. However, discharge measurements at some sites on the Rocky River reflect effects of flow diversions made by several major upstream point-source discharges. In addition, some tributary streams, such as Mallard Creek, Long Creek, and Richardson Creek, also are affected by flow diversions on these streams (pl. 1). With the exception of sites 3 and 60 on the Rocky River where only measurements made since the start of major point-source discharges were used, the presence of regulation and(or) minor flow diversions was not quantified and adjusted for in the records of discharge measurements at the partial-record measuring sites (table 6).

In addition to the losing reach on the Rocky River downstream from the gaging station near Stanfield (site 85), the compilation of low-flow characteristics also indicates the possibility of losing

Table 6. Magnitude and frequency of annual low-flow characteristics at selected partial-record measuring sites in the Rocky River basin in North Carolina

[USGS, U.S. Geological Survey; mi^2, square miles; water year, the annual period from October 1 to September 30 and identified by the year in which the period ends; $(ft^3/s)/mi^2$, cubic feet per second per square mile; ft^3/s, cubic feet per second; 7Q10, 7-day, 10-year low flow; 30Q2, 30-day, 2-year low flow; W7Q10, winter 7-day, 10-year low flow; 7Q2, 7-day, 2-year low flow; SR, secondary road; <, less than; N/A, not available; NPDES, National Pollutant Discharge Elimination System. Unless otherwise noted, low-flow characteristics typically reflect flow conditions unaffected by major diversions and(or) regulation]

Site index no. (pl. 1)	USGS downstream order number	Station name	Drainage area (mi^2)	Period of analysis (water years)	Number of measurements: Flow	Number of measurements: Zero flow	Average annual unit flow [$(ft^3/s)/mi^2$]	Low-flow characteristics (ft^3/s): 7Q10	30Q2	W7Q10	7Q2
3	02123881	Rocky River near Davidson	13.4	1982–99, 2000, 2002	100[a]	0	1.05	4.6	7.6	6.9	6.4
5	02123932	South Prong West Branch Rocky River near Cornelius	4.98	1969–71, 1973–74	11	0	1.1	0.5	1.1	0.9	0.9
6	02123953	Rocky River near Caldwell[b]	39.0	1948, 1952-53, 1961-62, 1971, 1973–74	16[c]	0	1.1	6.1	11.1	9.3	9.1
9	02124050	South Prong Clarke Creek near Huntersville	5.75	1969–71, 1973, 1975	12	0	1.1	0.6	0.9	0.8	0.7
12	02124080	Clarke Creek near Harrisburg[d]	21.9	1951–71, 1988	45	0	1.1	1.0	3.0	2.3	2.1
15	02124110	Rocky River near Roberta Mill[b]	87.2	1952–58, 1961–62, 1967, 1973–74, 1979, 2002	27	0	1.1	6.6	16.2	11.7	11.8
18	02124140	Toby Creek near Newell	3.6	1969–71, 1973, 1975	12	0	1.1	0.1	0.4	0.3	0.3
20	0212414860	Stony Creek at U.S. Highway 29 near Harrisburg	6.71	1969–71, 1973, 1975	10	0	1.1	0	0.1	< 0.05	< 0.05
24	0212418255	Rocky River at SR 1304 near Harrisburg[b]	134	1956, 1961–62, 1970–73, 1975, 2002	12[e]	0	1.1	9.0	25.5	18.3	17.9
28	02124230	Coddle Creek near Concord[f]	57.9	1949–58, 1961–63	22	0	1.05	5.6	12.7	9.0	9.2
34	0212430295	Reedy Creek at SR 2804 near Wilgrove[d]	12.7	1969–71, 1973, 1975	12	0	1.05	1.3	2.9	2.2	2.1
36	0212430645	McKee Creek at SR 2808 near Wilgrove[d]	4.08	1969–71, 1973, 1975	11	0	1.05	0.2	0.7	0.4	0.4
37	02124320	Reedy Creek at Rocky River[d]	30.9	1955–63, 2002	26	0	1.05	1.6	3.8	3.0	3.0
51	02124374	Irish Buffalo Creek near Faggarts Crossroads	45.5	1974–84, 1986–99, 2000, 2002	87	0	1.05	3.1	9.8	8.2	7.1
60	02124401	Rocky River near Flows Store	392	1980-99, 2000, 2002	54[g]	0	1.05	34.9	84.4	68.2	63.2
65	02124460	Dutch Buffalo Creek near Rimer[d]	33.8	1964–71, 1988	18	0	1.05	0.6	2.6	1.6	1.6
69	02124500	Dutch Buffalo Creek at Mount Pleasant	65.4	1953, 1955, 1961–62, 1970–71, 1973, 1975	10	0	1.05	1.1	4.7	2.9	2.8
73	02124596	Dutch Buffalo Creek at Georgeville	98.2	1948, 1952–53, 1961–62, 1986–96, 2002	33	0	1.0	N/A[h]	4.4	3.0	2.3
86	02124745	North Fork Crooked Creek near Fairview[d]	16	1961–62, 1965–69, 1971	16	1	1.0	0	0.5	0.2	0.1
92	02124776	Rock Hole Creek at Stanfield	7.55	1970–71, 1973–75	10	0	0.95	0	0.1	< 0.05	< 0.05

Table 6. Magnitude and frequency of annual low-flow characteristics at selected partial-record measuring sites in the Rocky River basin in North Carolina—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; water year, the annual period from October 1 to September 30 and identified by the year in which the period ends; $(ft^3/s)/mi^2$, cubic feet per second per square mile; ft^3/s, cubic feet per second; 7Q10, 7-day, 10-year low flow; 30Q2, 30-day, 2-year low flow; W7Q10, winter 7-day, 10-year low flow; 7Q2, 7-day, 2-year low flow; SR, secondary road; <, less than; N/A, not available; NPDES, National Pollutant Discharge Elimination System. Unless otherwise noted, low-flow characteristics typically reflect flow conditions unaffected by major diversions and(or) regulation]

Site index no. (pl. 1)	USGS downstream order number	Station name	Drainage area (mi^2)	Period of analysis (water years)	Number of measurements		Average annual unit flow [$(ft^3/s)/mi^2$]	Low-flow characteristics (ft^3/s)			
					Flow	Zero flow		7Q10	30Q2	W7Q10	7Q2
94	02124781	Rocky River at State Highway 200 near Stanfield[b]	708	1971, 1973–77, 2002	22	0	0.95	47.8	96.4	77.8	70.8
97	02124798	Rocky River at State Highway 205 near Oakboro[b]	744	1971, 1973-74	5	0	0.95	N/A[i]	95.0	64.0	62.0
98	02124813	Rocky River near Oakboro[b]	763	1961-62, 1970-71, 1973-74, 2002	13	0	0.95	46.0	91.7	68.0	66.7
99	02124823	Long Creek at SR 1454 near Richfield	5.29	1974–84	54	7	1.0	0	< 0.05	< 0.05	< 0.05
101	02124835	Long Creek near Plyler[d]	27.5	1955-56, 1961-62, 1964-67	10	0	1.0	0.2	1.3	0.7	0.7
102	02124841	Long Creek at Albemarle	33.1	1970–71, 1973–75	10	1	1.0	0.05[j]	0.7	0.3	0.2
104	02124869	Little Long Creek at SR 1903 near Albemarle	29	1970–71, 1973–75	10	0	1.0	0.4	1.7	1.1	1.0
108	02124944	Little Bear Creek at Saint Martin[d]	12.4	1961–62, 1970–71, 1973, 1975	11	0	0.95	0	0.5	0.3	0.2
115	02125023	Big Bear Creek near Saint Martin[d]	73.9	1949–54, 1961–62, 1964, 1967–69, 1975–77	63[k]	0	0.95	0.06	1.3	0.5	0.4
118	02125091	Stony Run tributary at SR 1975 near Oakboro	1.6	1970–71, 1973–75	11	0	0.95	< 0.05	0.1	0.07	0.06
121	02125126	Long Creek near Oakboro	198	1970–71, 1973–77, 1979–99, 2000, 2002	88	0	0.95	2.6	14.1	9.6	8.4
123	02125139	Rocky River near Aquadale[b]	973	1971, 1973	3	0	0.95	44.7	130.3	86.0	84.8
124	0212514705	Richardson Creek at SR 2139 near Waxhaw	3.22	1974–77	19	0	0.9	0	< 0.05	< 0.05	< 0.05
132	02125223	Richardson Creek at SR 1751 near Monroe	54.6	1970–73, 1975	13	0	0.9	0.3	0.7	0.5	0.5
139	02125310	Richardson Creek near Wingate	89	1953–54, 1956–59, 1970–74, 1976–77	25	0	0.9	0.9	3.9	2.3	2.1
142	02125462	Meadow Branch at Wingate	4.62	1970–73, 1975	8	3	0.9	0[l]	N/A[l]	N/A[l]	N/A[l]
144	02125464	Meadow Branch near Wingate	6.70	1970–73, 1975–77	16	1	0.9	0	0.1	0.06	< 0.05
145	02125482	Richardson Creek near Fairfield	153	1961-62, 1981-84, 1986-99, 2000, 2002	70	0	0.9	4.2[m]	8.7	6.8	6.4
147	02125538	Salem Creek at U.S. Highway 74 near Marshville	1.44	1954, 1961, 1970-74	9	7	0.9	0[n]	0[n]	0[n]	0[n]
150	02125546	Salem Creek at SR 1002 near Hamilton Crossroads	15.0	1953–54, 1957–58, 1970–75	13	0	0.9	0	0.2	< 0.05	< 0.05
151	02125549	Salem Creek near Fairfield	23.6	1961–62, 1970–77	18	2	0.9	0	0.2	0.05	< 0.05

Table 6. Magnitude and frequency of annual low-flow characteristics at selected partial-record measuring sites in the Rocky River basin in North Carolina—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; water year, the annual period from October 1 to September 30 and identified by the year in which the period ends; $(ft^3/s)/mi^2$, cubic feet per second per square mile; ft^3/s, cubic feet per second; 7Q10, 7-day, 10-year low flow; 30Q2, 30-day, 2-year low flow; W7Q10, winter 7-day, 10-year low flow; 7Q2, 7-day, 2-year low flow; SR, secondary road; <, less than; N/A, not available; NPDES, National Pollutant Discharge Elimination System. Unless otherwise noted, low-flow characteristics typically reflect flow conditions unaffected by major diversions and(or) regulation]

Site index no. (pl. 1)	USGS downstream order number	Station name	Drainage area (mi^2)	Period of analysis (water years)	Number of measurements		Average annual unit flow [$(ft^3/s)/mi^2$]	Low-flow characteristics (ft^3/s)			
					Flow	Zero flow		7Q10	30Q2	W7Q10	7Q2
154	02125591	Richardson Creek near Cottonville	234	1967, 1974–75, 1981, 1982–84, 2002	23[o]	0	0.9	0.8	6.6	3.9	3.2
161	02125720	Lanes Creek at Sturdivants	56.9	1961, 1964–69	13	0	0.9	0[p]	0.5	0.1	0.09
162	02125771	Beaverdam Creek near Marshville	14.9	1953, 1961-62, 1971	6	5	0.9	0[n]	0[n]	0[n]	0[n]

[a] Low-flow characteristics reflect NPDES discharges from the city of Mooreville wastewater-treatment plant, operated since 1981 on Dye Branch just upstream from its mouth where it empties into the Rocky River. Records of discharge prior to 1981 were not included in low-flow analyses for this site.

[b] Low-flow characteristics for this site were not used in the low-flow discharge profiles presented in this report. The low-flow characteristics are based on records of discharge collected prior the late 1970's and early 1980's when NPDES discharges from three wastewater-treatment plants began (town of Mooresville, Charlotte-Mecklenburg Utilities, and Cabarrus County; see table 2).

[c] Based on combined discharge records at partial-record measuring sites 02123953 (site 6), 02123989 (site 7), and 02123994 (site 8). Sixteen measurements were available in the combined record of discharges; discharges at sites 7 and 8 were adjusted by drainage area prior to analysis.

[d] Low-flow characteristics previously published in Giese and Mason (1993); where different, estimates in this report supersede previous estimates.

[e] Low-flow characteristics are based on combined discharge records at partial-record measuring sites 0212418255 (site 24) and 02124183 (site 25). Twelve measurements were available in the combined record of discharges; discharges at site 25 were adjusted by drainage area prior to analysis.

[f] This site is downstream from Lake Howell (formerly Coddle Creek Reservoir), which was completed in 1993. Records of discharge available for this site reflect flow conditions prior to completion of the lake. However, Coddle Creek was used as a source of water supply for Concord prior to the lake, and low-flow characteristics for this site reflect the effects of the water-supply diversions. At present, the effects of the Lake Howell on downstream low-flow characteristics cannot be assessed because no additional records of discharge have been collected at site 28 since the opening of the lake, which has a drainage area of approximately 47 mi^2, or about 81 percent of the drainage area at site 28.

[g] Low-flow characteristics reflect NPDES discharges from Cabarrus County wastewater-treatment plant, operated since 1979. Records of discharge prior to 1980 were not included in low-flow analyses for this site.

[h] Low-flow characteristics for this site suggest the existence of a losing reach on Dutch Buffalo Creek (see other low-flow characteristics for sites 65, 68, and 69). However, part of the reduction in low-flow yields between sites 65 and 69 may be a reflection of a water-supply withdrawal from Dutch Buffalo Creek by the town of Mount Pleasant. Estimate of 7Q10 discharge at site 73 could not be determined with reasonable level of certainty, but is likely in the range of 0.5 to 1.0 ft^3/s.

[i] Estimate of 7Q10 discharge could not be determined with reasonable level of certainty.

[j] Site is just downstream from Long Lake west of Albemarle. The decrease in low-flow characteristics from partial-record measuring site 02124135 (site 101) to this site apparently is affected by the lake. Low-flow characteristics for this site are presented as an example of the change in low-flow characteristics caused by an impoundment and should not be regarded as reflective of the entire drainage basin upstream from the site.

[k] Based on combined discharge records at partial-record measuring sites 02125020 (site 114) and 02125023 (site 115). Sixty-three measurements were available in the combined record of discharges; discharges at site 114 were adjusted by drainage area prior to analysis.

[l] Estimates for all low-flow characteristics cannot be determined based on available data; however, multiple observations of zero flow at site and(or) zero flow 7Q10 discharge at downstream site allow estimate of zero flow 7Q10 discharge at indicated site.

[m] Low-flow characteristics for site location on Richardson Creek are relatively high (in terms of low-flow yields) compared to other locations on Richardson Creek (sites 124, 132, 139, and 154 in this table; site 146 in table 5). These characteristics reflect flow conditions since the opening of the water-treatment plant on Stewarts Creek just upstream from Richardson Creek in 1972 and the wastewater-treatment plant on Richardson Creek in 1965.

[n] Due to multiple zero-flow discharge measurements at this site, low-flow characteristics are likely zero flow for the indicated statistic.

[o] Based on combined discharge records at partial-record measuring sites 02125588 (site 153) and 02125591 (site 154). Twenty-three measurements were available in the combined record of discharges. Both sites have identical drainage areas (233 mi^2). Low-flow characteristics for this site suggest the existence of a losing reach on Richardson Creek (see other low-flow characteristics for site 145).

[p] Low-flow characteristics for this site suggest the existence of a losing reach on Lanes Creek (see other low-flow characteristics for sites 157 and 165 in table 5).

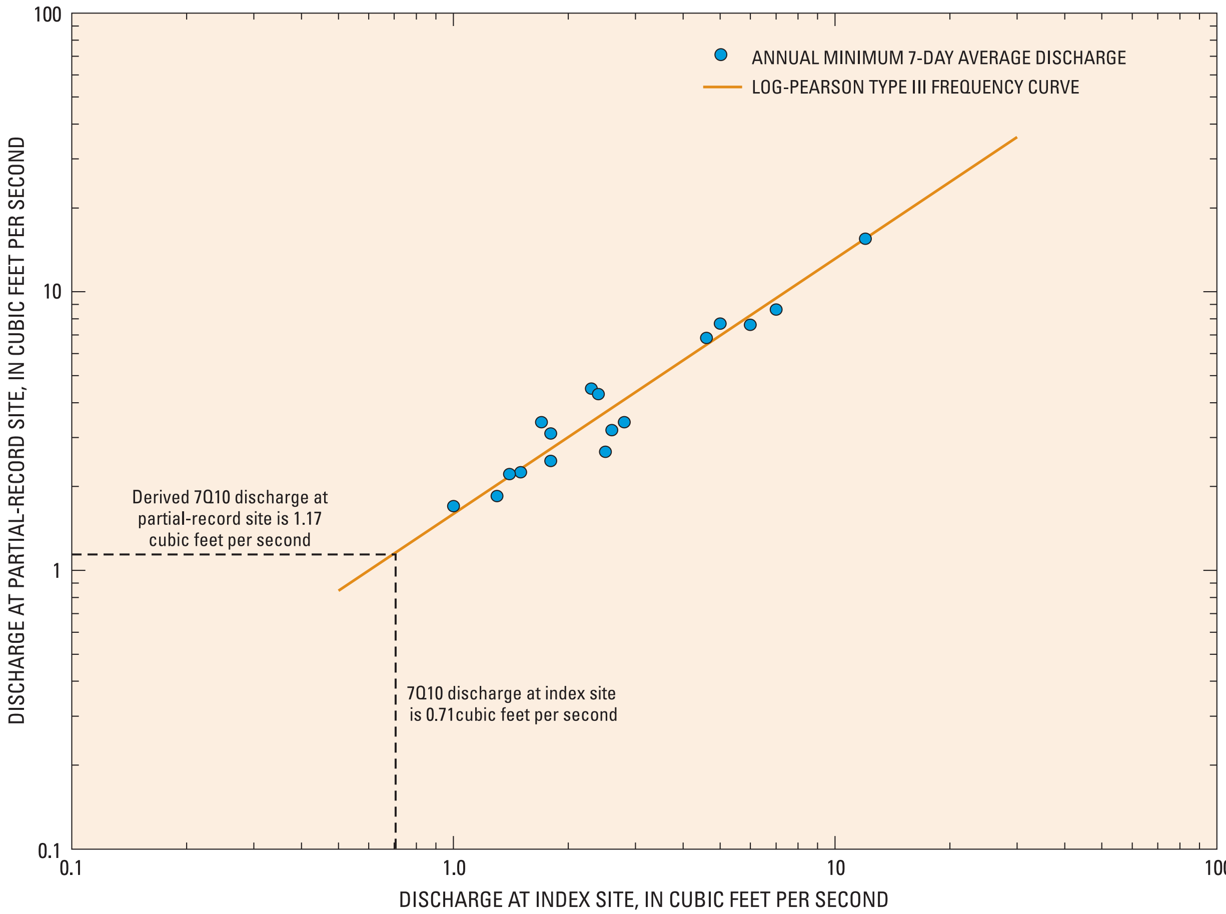


Figure 5. Correlation of concurrent discharge at the partial-record site at Clarke Creek near Harrisburg (site 12) and at the index station at Long Creek near Paw Creek (Catawba River basin).

reaches on several tributaries to the main stem. One such stream is Dutch Buffalo Creek (sites 65, 68, 69, and 73; tables 5 and 6), which is located primarily in northeastern Cabarrus County (pl. 1). Unit low-flow discharges at the three upstream sites (65, 68, and 69) are comparable. However, between sites 69 and 73, the unit low-flow discharges decrease by an average of about 37 percent (based on 30Q2, W7Q10, and 7Q2 discharges; table 6). The basin drained by Dutch Buffalo Creek is mainly in the Charlotte Belt. However, it is possible that close proximity of the downstream reaches to the Carolina Slate Belt could result in the decreased unit low-flow discharges. The presence of a water-supply withdrawal from Dutch Buffalo Creek by the town of Mount Pleasant between sites 65 and 68 was initially considered as a possible explanation for the decrease in unit low-flow discharges. However, the presence of comparable unit low-flow discharges at the three upstream sites (65, 68, and 69) indicates that such a decrease is apparently not the result of a diversion. Because the last discharge measurement at site 69 was made in 1975 as opposed to more current data (1980's through 1990's) collected at site 73, further explanation of this possible losing reach cannot be determined without additional data, including data at other locations between sites 69 and 73.

Other possible losing reaches were noted on Richardson Creek and Lanes Creek in Union and Anson Counties, respectively. These streams are located well within the Carolina Slate Belt geologic region and have a number of sites—some with drainage areas over 50 mi^2—with zero-flow 7Q10 discharges.

The possibility of a losing reach in Richardson Creek is recognized through the low-flow discharges at site 146 (table 5), which was operated for a brief period in the early 1940's. The low-flow discharges for three upstream sites (132, 139, and 145; table 6) on Richardson Creek are based on periods of record that reflect streamflows affected by diversions in the vicinity of Monroe. However, a number of tributaries to Richardson Creek indicate zero 7Q10 discharges, which suggest the possibility of losing reaches in streams downstream from Stewart Creek (a tributary to Richardson Creek).

On Lanes Creek, the low-flow discharges at site 165 (table 5) identify this stream has having losing reaches, particularly in the upper part of the basin where a number of sites having zero 7Q10 discharges were noted (tables 5, 6). Insufficient data are available to assess low-flow discharges downstream from site 165; therefore, the possibility of a losing reach cannot be assessed.

A comparison was made of low-flow characteristics based on regional equations presented by Giese and Mason (1993) at five sites in HA9 in the Rocky River basin (table 7) with those based on analysis of streamflow data as previously outlined (tables 5 and 6). The five sites presented in table 7 were part of those used by Giese and Mason (1993) to develop the regional equations for estimating low-flow characteristics at ungaged sites. Percentage differences between the regional equation estimates and data estimates vary among the sites. Four of the five sites (12, 36, 37, and 65; table 7) have regional estimates that are higher than the data estimates, with percentage differences ranging from zero percent (7Q10 discharge at site 12) to 175 percent (winter 7Q10 at site 65). At site 34, the regional estimates are lower than the data estimates with percentage differences ranging from -42.3 percent (7Q10 discharge) to -9.1 percent (winter 7Q10 discharge; table 7). For most sites, differences between the low-flow characteristics can be attributed to the general nature of residual errors associated with the use of a statistical regression to compute estimates. Still, the regional equations provided by Giese and Mason (1993) are useful for computing estimates at locations where no other data are available to assess low-flow characteristics. Given the standard errors identified for the HA9 regional equations (ranging from 49 to 92 percent; Giese and Mason, 1993), it is possible the data estimates (table 7) occur within the ranges specified by the standard errors.

Among the 44 partial-record measuring sites for which low-flow characteristics were compiled (table 6), the varying lengths of records along with the differing periods during which the measurements were obtained must be considered when assessing the reliability of the characteristics determined for each site. The length of record is expressed by the number of water years in which measurements were obtained for a given site. Among these 44 sites, the length of record ranged from 2 to 30 years (sites 123 and 121 with 3 and 88 measurements, respectively) with a median equal to

Table 7. Low-flow characteristics for selected partial-record measuring sites and regional equations in hydrologic area 9 (HA9) in the Rocky River basin in North Carolina

[USGS, U.S. Geological Survey; mi^2, square miles; water year, the annual period from October 1 to September 30 and identified by the year in which the period ends; ft^3/s, cubic feet per second; 7Q10, 7-day, 10-year low flow; 30Q2, 30-day, 2-year low flow; W7Q10, winter 7-day, 10-year low flow; 7Q2, 7-day, 2-year low flow; SR, secondary road; First line of low-flow characteristics (denoted Data under Method column) are those based on analysis of discharge records available for site and listed in table 7 (site type 1) or 8 (site type 2) depending on site type. The second line of low-flow characteristics are based on the regional equations (computed to two significant figures, denoted by hydrologic area under Method column) presented for HA9 in Giese and Mason (1993)]

Site index no. (pl. 1)	USGS downstream order number	Station name	Drainage area (mi^2)	Period of record (water years)	Low-flow characteristics (ft^3/s)				Site type	Method
					7Q10	30Q2	W7Q10	7Q2		
12	02124080	Clarke Creek near Harrisburg	21.9	1951–71, 1988	1.0	3.0	2.3	2.1	2	Data
					1.0	4.1	3.1	2.8		HA9
34	0212430295	Reedy Creek at SR 2804 near Wilgrove	12.7	1969–71, 1973, 1975	1.3	2.9	2.2	2.1	2	Data
					0.75	2.6	2.0	1.8		HA9
36	0212430645	McKee Creek at SR 2808 near Wilgrove	4.08	1969–71, 1973, 1975	0.2	0.7	0.4	0.4	2	Data
					0.41	1.0	0.82	0.76		HA9
37	02124320	Reedy Creek at Rocky River	30.9	1955–63, 2002	1.6	3.8	3.0	3.0	2	Data
					1.2	5.4	4.1	3.7		HA9
65	02124460	Dutch Buffalo Creek near Rimer	33.8	1964–71, 1988	0.6	2.6	1.6	1.6	2	Data
					1.3	5.9	4.4	3.9		HA9

about 8 years. Previous discussion indicated that 10 or more measurements are generally needed to develop low-flow characteristics for a partial-record site. More importantly, such measurements should be sought during base-flow periods that are independent of each other (e.g., during the late summer and early fall of each year). Thus in the collection of discharge measurements at partial-record sites, a minimum of 2 or 3 years of record are sought to improve the overall strength of the data available for analysis.

Measurements were obtained between 1948 and 2002 with the highest numbers of sites measured in a given year occurring between 1961 and 1975. The years during which greater than 15 sites were measured were 1961–62, 1970–71, and 1973–75. At the gaging station near Norwood (site 169), the annual mean unit flow during these 7 years ranged from 0.58 to 1.82 $(ft^3/s)/mi^2$ (1970 and 1975, respectively) with an average of 1.14 $(ft^3/s)/mi^2$. By comparison, the annual mean unit flow during the period of record (1930–2001water years) ranged from 0.32 to 1.82 $(ft^3/s)/mi^2$ (2001 and 1975, respectively) with an average annual unit flow of 0.97 $(ft^3/s)/mi^2$ for the period of record. Therefore, during 6 of the 7 years during which greater than 15 sites were measured, streamflow conditions at the gaging station near Norwood were normal or wetter than normal.

These considerations raise the possibility that some of the low-flow characteristics compiled for the partial-record sites (table 6) may be higher than true low-flow characteristics. However, in the absence of additional data collection at these and other sites, no means is available to re-assess the low-flow characteristics that would be regarded as more reflective of actual low-flow conditions. While steps can be taken to limit the inclusion of discharge measurements to those reflective of low-flow conditions, such steps would result in the removal of some sites from the overall analyses because of too few measurements and(or) would decrease the overall confidence in low-flow characteristics determined from a smaller number of measurements for a given site.

No ranges of statistical accuracy are provided for the low-flow characteristics presented in tables 5 and 6. While ranges of accuracy (e.g., 95-percent confidence intervals, standards errors) can be determined for results based on statistical techniques such as the MOVE.1 relation, the low-flow characteristics for many of the partial-record measuring sites and short-term, continuous-record sites are based in part on correlation analyses using the graphical fit. The statistical accuracy of discharges determined from graphical correlations cannot be assessed. However, an alternate means of assessing the possible range in low-flow characteristics is to examine the unit low-flow discharges at nearby sites. Knowledge of the range in unit low-flow discharges can be used with the drainage area for an ungaged site to compute a range in the estimated low-flow discharges.

Occurrence of Zero or Minimal 7Q10 Discharges

Estimated 7Q10 discharges at 18 of the 56 sites (12 continuous-record and 44 partial-record, tables 5 and 6) in the study area were determined to be zero, and one site had a 7Q10 discharge estimated to be less than 0.05 ft^3/s. In previously published reports on the low-flow characteristics in the Roanoke River basin and the Deep River basin (tributary to the Cape Fear River), Weaver (1996, 1997) defined minimal 7Q10 discharges as those reported to be less than 0.1 ft^3/s, a threshold used by Giese and Mason (1993) in reporting low-flow characteristics for streams across North Carolina. In the reports on low-flow characteristics in the Neuse River basin (Weaver, 1998) and Cape Fear River basin (Weaver and Pope, 2001), minimal 7Q10 discharges were re-defined to a lower threshold of 0.05 ft^3/s, the minimum flow allowed by the DWQ in its evaluation of NPDES permits for point-source discharges. In this report, minimal 7Q10 discharges continue to be defined as those reported to be less than 0.05 ft^3/s.

The 19 sites in the Rocky River basin having zero or minimal 7Q10 discharges were plotted on a map to determine which factors could account for the low potential to sustain base flow. Initial examination of the map indicated that 18 of the 19 sites were in the lower half of the basin downstream from the gaging station near Stanfield (site 85). Although common factors can be identified to explain the occurrence of zero or minimal 7Q10 discharges, all the factors that result in zero or minimal flows at one site may not be the same factors that cause zero or minimal flows at other sites. Thus, it is difficult to establish absolute thresholds of drainage areas at or below which 7Q10 discharges are assured of having zero or minimal flows. The determination of such drainage-area thresholds are subjective, requiring some interpretation and judgment. Although no drainage-area thresholds could be determined in the upper part of the basin (pl. 1), it does not mean that zero or minimal 7Q10 discharges do not occur on some streams in the area. Rather, only one occurrence of zero 7Q10 discharge in this area was identified from the data used in this analysis; thus, no drainage-area thresholds could be specified. Based on an assessment of 38 sites, Giese and Mason (1993) specified a drainage-area threshold of 1 mi^2 for HA9, which covers much of the upper Rocky River basin (fig. 2; pl. 1).

The area of the Rocky River basin where 18 of the 19 occurrences of zero or minimal 7Q10 discharges were noted is underlain by the geologic rock units of the Carolina Slate Belt. Rocks in this area include metamorphosed mudstone, argillite, and graywacke, and metavolcanic flows and tuffs. All sites in the basin downstream from the gaging station near Stanfield (site 85) were arranged in ascending order by drainage area to determine if there was a maximum drainage area below which 7Q10 discharges generally are zero. Within this area, drainage areas for sites having zero or minimal 7Q10 discharges ranged from 1.44 (site 147) to 87.7 mi^2 (site 165). Of the 18 sites in this area, 15 had drainage areas less than or equal to 23.6 mi^2 (site 151), suggesting that ungaged sites in the Carolina Slate Belt having drainage areas less than about 25 mi^2 likely will have zero or minimal 7Q10 discharges.

Aside from site 165, other sites in the Carolina Slate Belt having larger drainage areas where zero or minimal 7Q10 discharges were noted are Big Bear Creek (site 113, drainage area 55.6 mi^2, tributary to Long Creek) and Lanes Creek (site 161, drainage area 56.9 mi^2). Well yields estimated by Daniel (1989) in this part of the study area were determined to be among the lowest for the hydrogeologic units in the Piedmont and Blue Ridge Provinces. Soils in this area typically are thin and have little water-storage capacity to sustain streams during base-flow periods (Charles Daniel, U.S. Geological Survey, oral commun., September 2000). The drainage-area threshold of 25 mi^2 is higher than that identified by Giese and Mason (1993) for HA8 (fig. 2), which covers most of the lower half of the Rocky River basin. Based on their investigation of nine sites in HA8 (argillite zone), they established a drainage-area threshold of 12 mi^2. The sites used in their investigation were not known to be affected by significant regulation and(or) diversions upstream from the sites (Giese and Mason, 1993).

LOW-FLOW DISCHARGE PROFILES FOR THE ROCKY RIVER

Discharge profiles of low flows were developed for the Rocky River to depict changes in low-flow discharges along most of its length. A drainage-area profile also was developed to document the relation between basin size and river miles. River miles shown on the profiles were determined by using the USEPA's River Reach files, which are geographic information system (GIS) coverages of rivers and streams, digitized from 1:100,000-scale USGS topographic maps. River miles computed for the Rocky River begin at zero at the mouth and increase upstream.

The drainage-area profile for the Rocky River (fig. 6) reflects the shape of the entire river basin (pl. 1). Between the river's initial reaches near Mooresville in Iredell County and Reedy Creek (tributary to the main stem) in Cabarrus County, the distance is about 31 mi, or about 33 percent of the river's length. However, the accumulated drainage area in this reach is about 234 mi^2, or about 17 percent of the total drainage area at the mouth of the Rocky River. In this reach between the headwaters and Reedy Creek, drainage-area contributions from tributary streams generally are less than 80 mi^2 and include West Branch Rocky River (22.8 mi^2), Clarke Creek (28.2 mi^2), Mallard Creek (41.2 mi^2), Coddle Creek (78.8 mi^2), and Reedy Creek (43.0 mi^2). In the reach between Reedy Creek and the mouth of the Rocky River, drainage-area increases are larger as a result of some of the major tributaries that drain to the Rocky River, which include Irish Buffalo/Coldwater Creeks (110 mi^2), Dutch Buffalo Creek (99 mi^2), Long Creek (200 mi^2), Richardson Creek (234 mi^2), and Lanes Creek (135 mi^2). Between the partial-record site near Oakboro (site 98, river mile 22.4, or about 25 percent of the river length) and the mouth of the Rocky River, the drainage area increases by 650 mi^2, or 46 percent of the total drainage area. The Long Creek, Richardson Creek, and Lanes Creek tributaries drain to the Rocky River in this lowest reach.

Discharge profiles are presented for the 7Q10, 30Q2, W7Q10, and 7Q2 discharges (figs. 7–10) for the segment of the Rocky River between a partial-record site near Davidson (site 3, river mile 85.8) and the long-term continuous-record gaging station near Norwood (site 169, river mile approximately 11.8). Low-flow characteristics at three continuous-record gaging stations (sites 40, 85, and 169; table 5) and two partial-record sites (sites 3 and 60, table 6) on the Rocky River

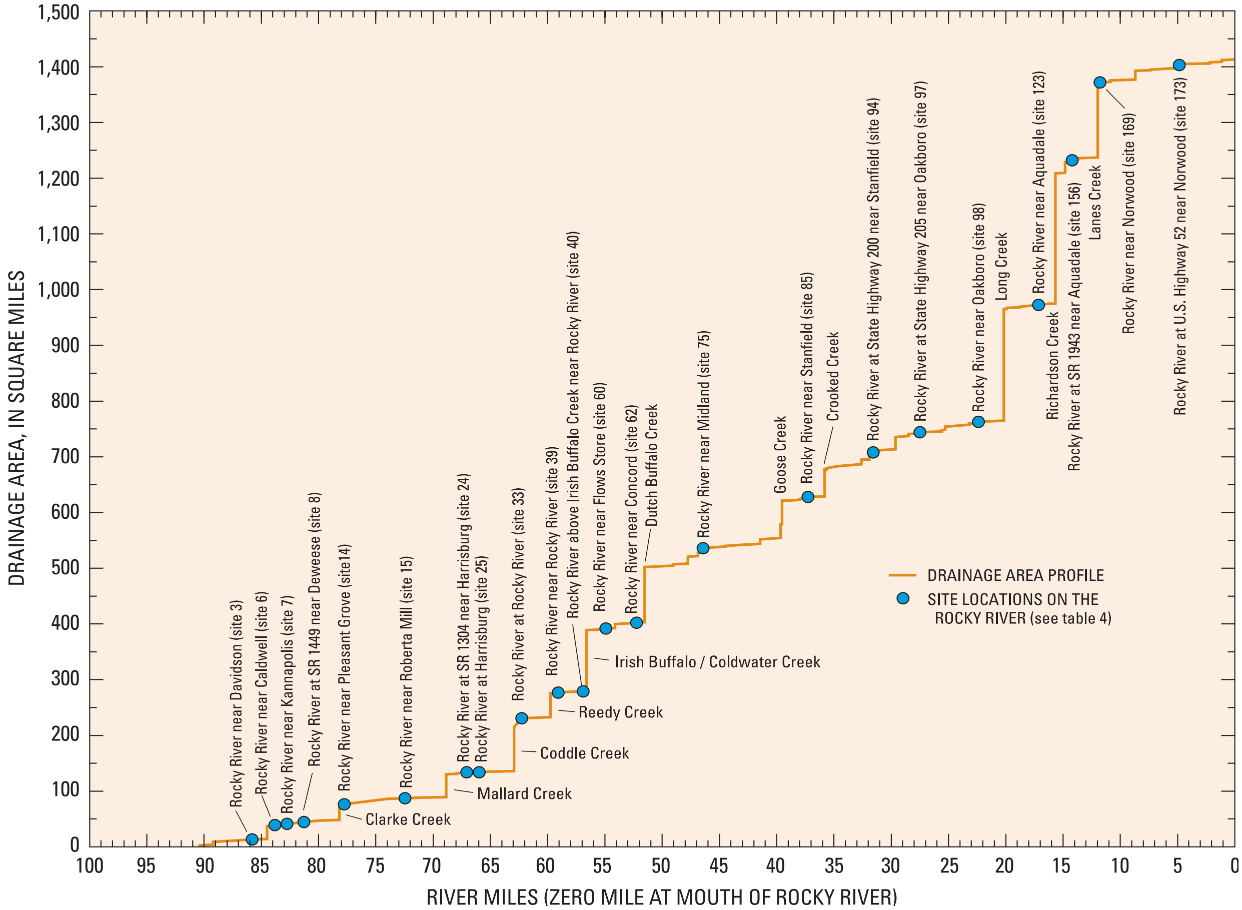


Figure 6. Relation of river miles to drainage area for the Rocky River in North Carolina.

served as “anchor” points in the discharge profiles for estimating low-flow discharges at upstream and downstream locations. Low-flow discharges at the ungaged sites in the profile were estimated by using unit flows prorated on the basis of drainage areas for nearby upstream or downstream anchor points. Contributions of low flows from tributaries to the Rocky River were estimated when the drainage area from a tributary was 5 percent or greater than the drainage area of the main stem directly upstream from the tributary, with the exception of Coddle Creek, as discussed below.

The low-flow characteristics for the sites used as anchor points in the profiles reflect flow conditions since the start of three major NPDES point-source discharges in the upper half of the basin in the late 1970’s and early 1980’s (Dye Branch, Mallard Creek, and Rocky River discharge by Cabarrus County; table 2). Low-flow characteristics for seven partial-record sites (6, 15, 24, 94, 97, 98, and 123; table 6) were not used in the profiles because discharge records available at these sites reflect streamflow conditions prior to start of the three major point-source discharges. During the investigation, attempts were made to develop profiles showing estimated low-flow discharges based on flow conditions not affected by the major NPDES point-source discharges. Records of discharge at the gaging stations above Irish Buffalo Creek (site 40) and near Stanfield (site 85) were adjusted to remove the effects of the major diversions; however, the variations in unit low-flow discharges at these sites precluded the development of reliable profiles for assessing the low-flow characteristics based on minor diversions.

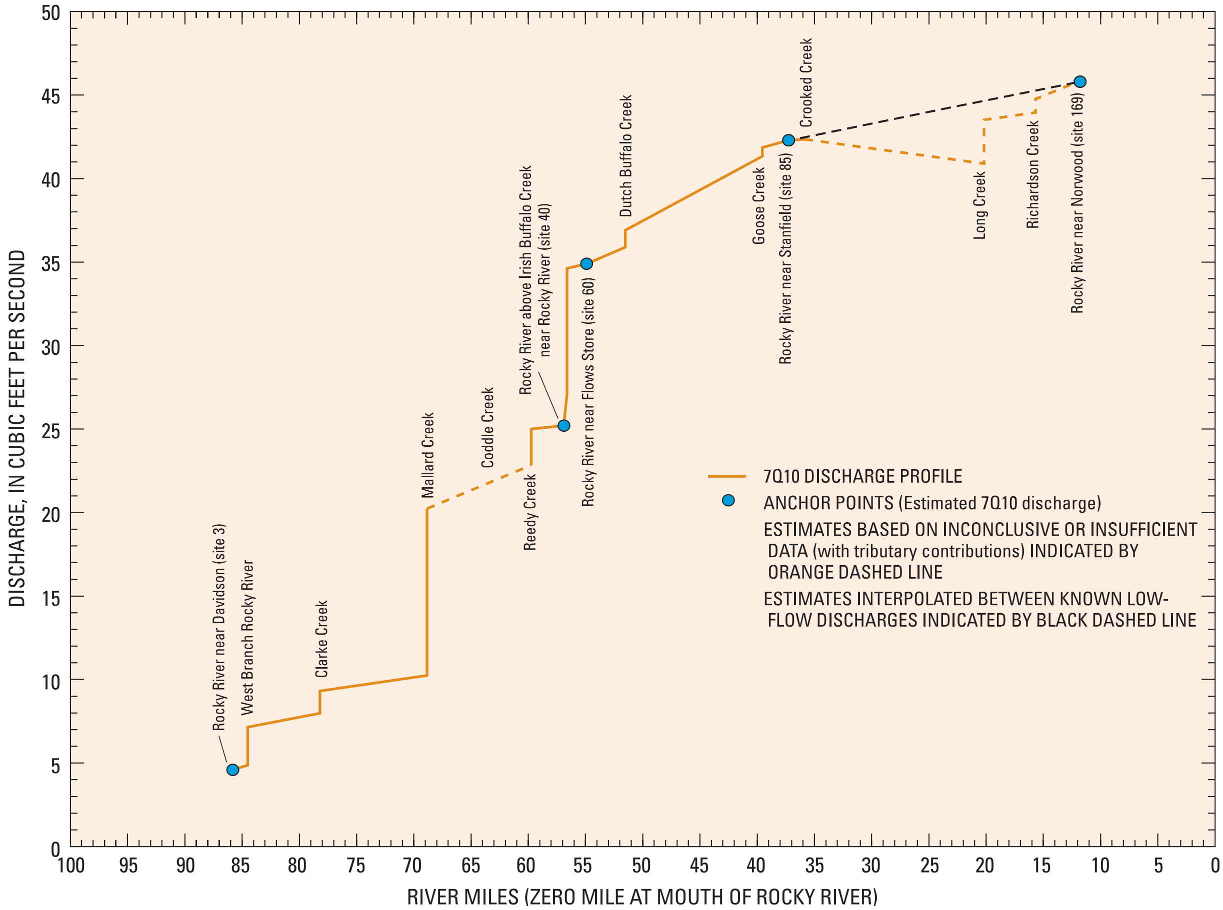


Figure 7. Relation of river miles to annual 7-day, 10-year (7Q10) low-flow discharge for the Rocky River in North Carolina.

Low-flow discharge profiles for the Rocky River suggest different potentials for sustained base flow. Between sites 3 and 40, the 7Q10 discharge increases from 4.6 to 25.2 ft^3/s (tables 5 and 6). Expressed in terms of the unit 7Q10 discharge (as cubic feet per second per square mile drainage area), this corresponds to a decrease from 0.34 to 0.09 $(ft^3/s)/mi^2$. At site 3, the unit 7Q10 discharge of 0.34 $(ft^3/s)/mi^2$ reflects the point-source discharge on Dye Branch (table 2) and is not reflective of natural-flow characteristics. Previous low-flow investigations in North Carolina have shown that 7Q10 discharges having unit flows in the range of 0.3 $(ft^3/s)/mi^2$ or higher typically occur in the Sand Hills region in the Coastal Plain (HA3, fig. 2) or in the higher elevations of the mountains region (HA10, fig. 2).

Downstream from site 40, the 7Q10 discharge increases to 42.3 and 45.8 ft^3/s at the gaging stations near Stanfield (site 85) and Norwood (site 169), respectively (table 5). Expressed as unit 7Q10 discharges, this corresponds to a further decrease to about 0.07 and 0.03 $(ft^3/s)/mi^2$, respectively, at these sites. The 30Q2, W7Q10, and 7Q2 discharges (as well as the corresponding unit low-flow discharges) exhibited similar trends between these sites (table 5).

Because low-flow discharges at locations between the anchor points are estimated by using the unit flows at these points along with estimates of tributary contributions, the development of discharge profiles for two particular reaches were identified as having a higher level of uncertainty than the other reaches (indicated by the dashed lines in figs. 7–10). The first reach is between Mallard Creek and Reedy

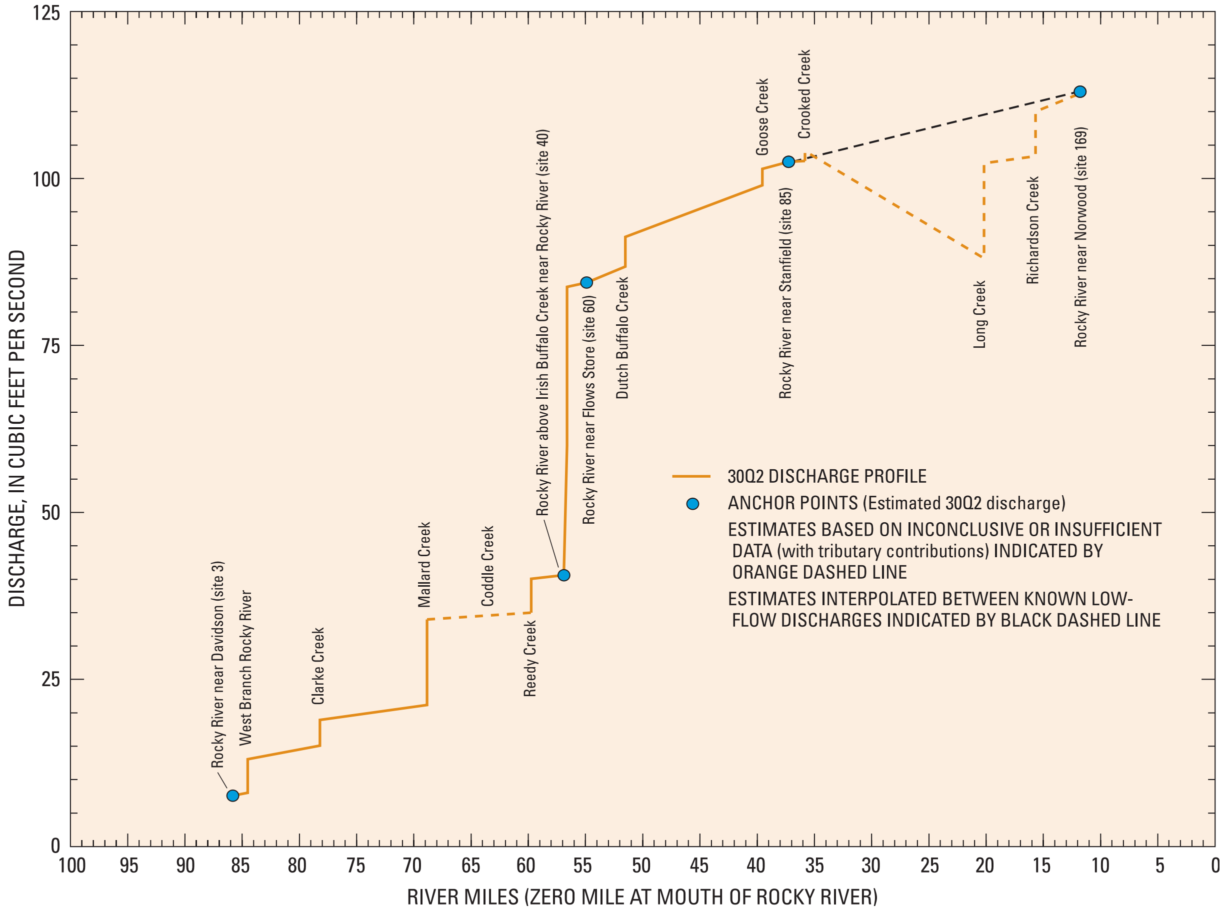


Figure 8. Relation of river miles to annual 30-day, 2-year (30Q2) low-flow discharge for the Rocky River in North Carolina.

Creek, and includes the area drained by Coddle Creek (fig. 7). The development of the profile is made difficult by the presence of the three major point-source discharges (table 2) on the Rocky River since the late 1970's. In addition, the effects of Lake Howell on low-flow characteristics in Coddle Creek downstream from the lake cannot be quantified because discharge records are unavailable for locations between the dam and the mouth of the stream since the opening of the lake in 1993. Hence, the low-flow discharge profiles do not show any tributary contributions from Coddle Creek and are depicted with a dashed line to designate a reach where changes in low-flow characteristics are regarded as being more uncertain than other locations on the profiles. Despite the uncertainty associated with low-flow characteristics in the reach upstream and downstream from Coddle Creek, continual increases occur in the estimated low-flow discharges overall between Davidson and Stanfield, partly attributed to the three major point-source discharges.

The second reach where changes in low-flow profiles are considered uncertain is between gaging stations near Stanfield (site 85) and Norwood (site 169, fig. 7). Results of profile development indicate the presence of a possible losing reach, and support of this observation is available from three lines of evidence.

The first line of evidence is based on changes in the unit low-flow discharges. As previously stated, the 7Q10 discharge increases from 42.3 to 45.8 ft^3/s between the gaging stations near Stanfield and Norwood (sites 85 and 169, table 5). However, because the drainage area between these two sites increases from 628 to 1,372 mi^2, the unit 7Q10 discharge results in a 57-percent decrease (from 0.07 to 0.03 $(ft^3/s)/mi^2$).

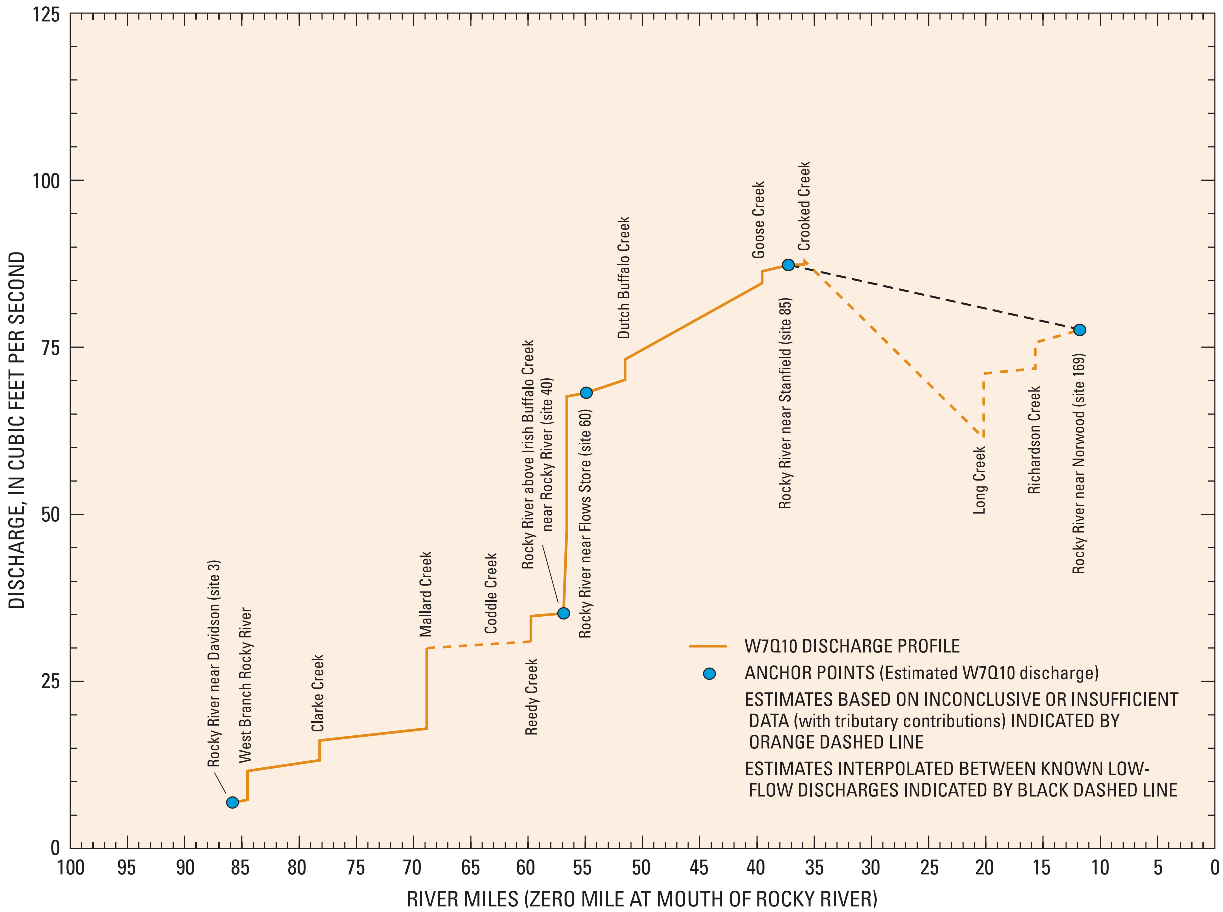


Figure 9. Relation of river miles to winter 7-day, 10-year (W7Q10) low-flow discharge for the Rocky River in North Carolina.

Likewise, the 30Q2 discharge increases from 103 to 113 ft^3/s between the gaging stations (sites 85 and 169, table 5), representing a decrease in the unit 30Q2 discharge from 0.16 to 0.08 $(ft^3/s)/mi^2$, or a 50-percent decrease between the two sites. While decreasing unit flows alone are not indicators of a losing reach, the magnitude of the decrease in unit low flows between Stanfield and Norwood provides support in the identification of the losing reach. Upstream from Stanfield, most of the basin is underlain by the Charlotte Belt, the geologic unit within which streams have been observed to have moderate potential for sustained base flows. The transition from the Charlotte Belt is depicted as being rather sudden (North Carolina Geological Survey; 1985, 1991), meaning that much of the Rocky River basin between Stanfield and Norwood is underlain by the Carolina Slate Belt. Thus, the decrease in the unit low-flow discharges is primarily attributed to the underlying Carolina Slate Belt, a geologic unit within which streams have been observed as having little to no potential for sustained base flows.

The second line of evidence is based on the spatial distribution of sites having 7Q10 discharges less than minimal flow (defined as being 0.05 ft^3/s or less) or zero flow (tables 5 and 6). Of the 19 sites having 7Q10 discharges less than minimal flow or zero flow, 18 sites are on tributaries draining to the Rocky River in the reaches downstream from Stanfield, particularly in the basins drained by Long Creek, Richardson Creek, and Lanes Creek, which contribute a combined 40 percent of the total drainage area for the Rocky River. Compilations of the low-flow characteristics (tables 5 and 6) indicated that losing reaches may exist in several tributaries to the Rocky River, including Richardson

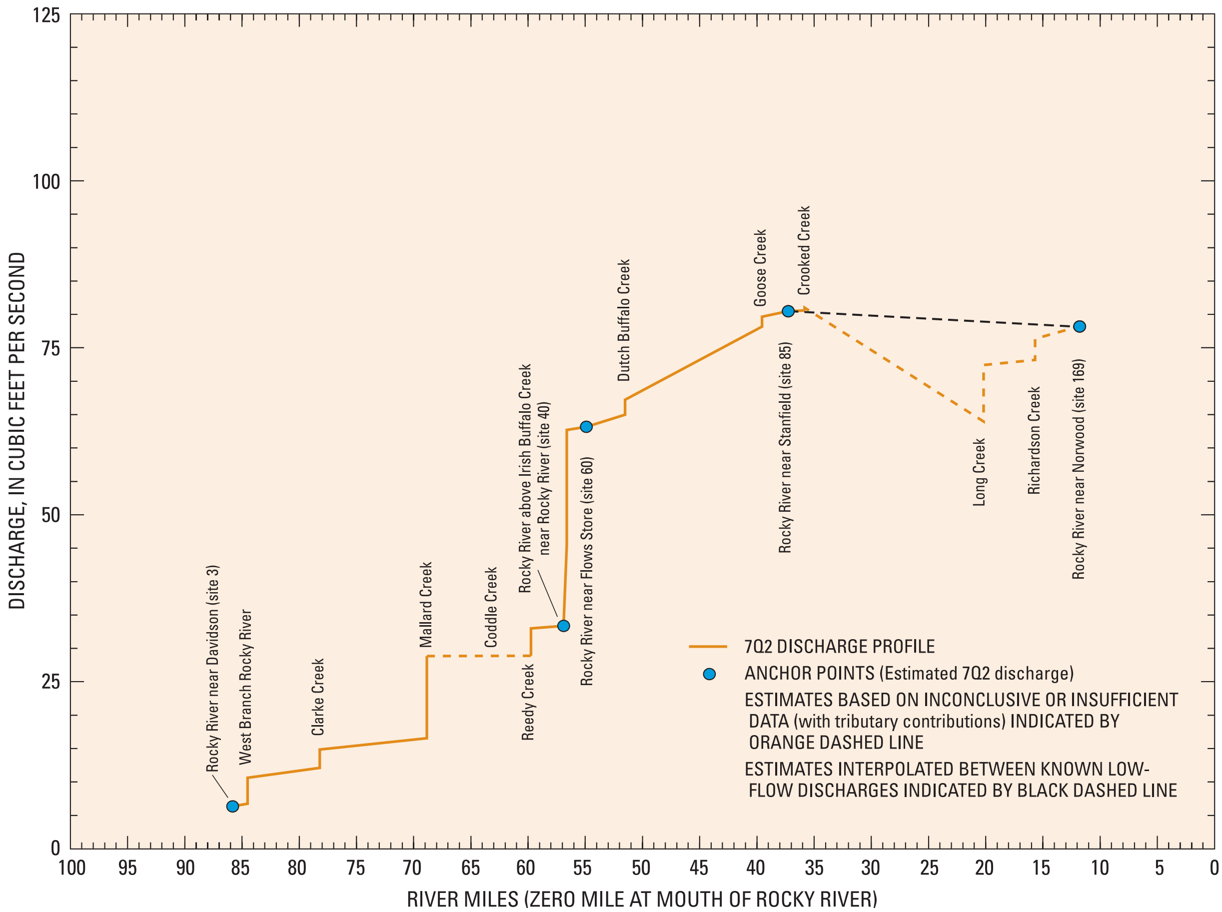


Figure 10. Relation of river miles to annual 7-day, 2-year (7Q2) low-flow discharge for the Rocky River in North Carolina.

and Lanes Creeks (see discussion in preceding section Low-Flow Characteristics in the Rocky River Basin).

A third line of evidence to support a losing reach in the Rocky River downstream from Stanfield is found in the results of synoptic discharge measurements that were made at selected locations in the Rocky River basin during November 7–8, 2001 (fig. 11; table 8). On November 7, the range of discharges recorded at site 169 and the measured discharge at site 173 were lower than the measured discharge at the partial-record measuring site near Stanfield (site 94). Likewise on November 8, measurements made at two sites (85, 98) were lower than the discharge measured at a partial-record site near Midland (site 75), indicating the losing reach may possibly extend upstream from Stanfield to Midland (fig. 11). In addition, while the discharge measured at the gaging station near Norwood (site 169) was higher in value, the unit flow of 0.06 $(ft^3/s)/mi^2$ at this location was less than half of the unit flow of 0.13 $(ft^3/s)/mi^2$ at the site near Midland (site 75, table 8).

Hydrographs of the discharges and stages at the three gaging stations (sites 40, 85, and 169) were checked to see if variations in measured flows could be accounted for by a wave of higher flow moving down the river during the 2-day period. No high flows were noted during the measurement period. The only variations noted in the hydrographs were daily fluctuations that apparently were reflective of the upstream point-source discharges. However, the magnitudes of the fluctuations did not account for the decreases in the measured discharges.

Given the three lines of evidence to support the possibility of a losing reach in the Rocky River, an

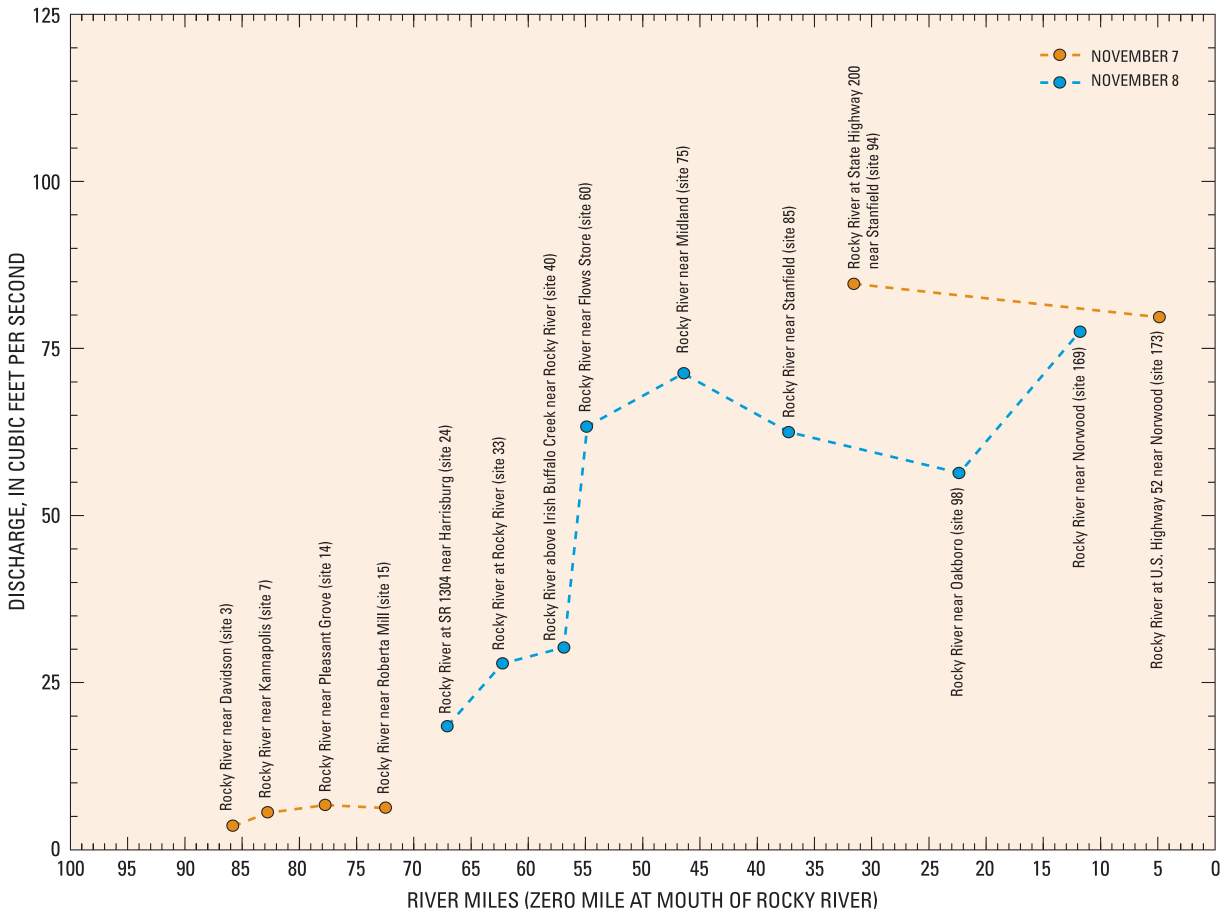


Figure 11. Relation of river miles to synoptic discharge measurements made on November 7–8, 2001, at selected sites on the Rocky River, North Carolina.

assessment of the diversions in the lower half of the basin was necessary to determine if the losing reach might be the result of a major water-supply withdrawal. Downstream from Stanfield, no major water-supply withdrawals occur on the Rocky River. The only major withdrawal is made by the city of Monroe, which withdrew an average of 7.5 Mgal/d (11.6 ft^3/s) in 2001 (table 2) and returned a combined 7.5 Mgal/d (11.6 ft^3/s) to Richardson Creek during the same period resulting in no overall change to flows in the stream. Another major diversion occurs in the form of a return point-source discharge to Long Creek by the city of Albemarle, which discharged an average of 9.6 Mgal/d (14.9 ft^3/s) in 2001 (table 2). This diversion, however, occurs upstream from the partial-record site near Bloomington (site 105; table 4) where the drainage area is approximately 66 mi^2 (the drainage area at the mouth of Long Creek is 200 mi^2). Given no other major diversions, particularly water-supply withdrawals, on the Rocky River downstream from Stanfield, the presence of a losing reach can be attributed to natural factors instead of human-induced effects to the river.

The estimated low-flow discharges depicted in the profiles for the reach between Stanfield and Norwood are shown by two dashed lines (figs. 7–10). The orange dashed line depicts the estimated discharges with tributary contributions from Long Creek, Richardson Creek, and Lanes Creek. Estimated contributions from Lanes Creek are zero flow for 7Q10 discharge and minimal flows for the 30Q2, W7Q10, and 7Q2 discharges and, thus, are not visible on the profiles. The black dashed line depicts straight-line interpretation between the low-flow characteristics at Stanfield (site 85) and Norwood (site 169). Because of the uncertainty associated with the estimated low-flow discharges in this reach with tributary contributions, estimated discharges based on the black line may serve as the more reasonable estimates in the absence of additional data and(or) analyses that would further clarify the variations of low-flow characteristics in this reach.

Table 8. Summary of synoptic discharge measurements obtained at selected sites in the Rocky River basin in North Carolina, November 7–8, 2001

[USGS, U.S. Geological Survey; mi^2, square miles; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; SR, secondary road; N/A, not applicable. Shading indicates a stream that is tributary to the Rocky River]

Site index no. (pl. 1)	USGS downstream order number	Station name	Latitude	Longitude	Drainage area (mi^2)	Discharge (ft^3/s)	Unit discharge [$(ft^3/s)/mi^2$]	Time of measurement (2400 hour time)	Comment
				November 7					
3	02123881	Rocky River near Davidson	35° 28'29"	80° 46'48"	13.4	3.63	0.2709	10:00 – 10:30	
7	02123989	Rocky River near Kannapolis	35° 26'31"	80° 45'08"	40.9	5.62	0.1374	11:47 – 12:22	
13	02124091	Clarke Creek at Pleasant Grove	35° 23'12"	80° 43'46"	28.2	0.38	0.0135	13:27 – 13:43	
14	02124101	Rocky River near Pleasant Grove	35° 22'59"	80° 43'18"	76.8	6.72	0.0875	14:19 – 14:52	
15	02124110	Rocky River near Roberta Mill	35° 21'33"	80° 40'31"	87.2	6.28	0.0720	15:52 – 16:22	
23	02124160	Mallard Creek at Harrisburg	35° 20'02"	80° 40'05"	41.1	12.8	0.3114	17:04 – 17:35	
40	0212433550	Rocky River above Irish Buffalo Creek near Rocky River	35° 19'22"	80° 32'17"	278	30	0.1079	N/A	Estimated daily discharge for November 7 based on discharge records.
84	0212471905	Goose Creek at SR 1547 near Faiview	35° 10'33"	80° 30'40"	41.4	0.6	0.0145	14:45 – 15:40	
85	02124742	Rocky River near Stanfield	35° 10'10"	80° 28'24"	628	63	0.1003	N/A	Estimated daily discharge for November 7 based on discharge records.
89	0212476710	Crooked Creek at SR 1547 near Fairview	35° 08'41"	80° 28'18"	47.3	3.06	0.0647	13:40 – 14:24	
94	02124781	Rocky River at State Highway 200 near Stanfield	35° 09'55"	80° 23'51"	708	84.7	0.1196	11:00 – 13:00	
154	02125591	Richardson Creek near Cottonville	35° 09'27"	80° 14'07"	234	7.52	0.0321	15:41 – 16:20	
169	02126000	Rocky River near Norwood	35° 08'54"	80° 10'33"	1,372	78	0.0569	N/A	Estimated daily discharge for November 7 based on discharge records.
173	02126201	Rocky River at U.S. Highway 52 near Norwood	35° 11'39"	80° 06'49"	1,403	79.7	0.0568	12:53 – 13:23	

Table 8. Summary of synoptic discharge measurements obtained at selected sites in the Rocky River basin in North Carolina, November 7–8, 2001—Continued

[USGS, U.S. Geological Survey; mi^2, square miles; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; SR, secondary road; N/A, not applicable. Shading indicates a stream that is tributary to the Rocky River]

Site index no. (pl. 1)	USGS down-stream order number	Station name	Latitude	Longitude	Drainage area (mi^2)	Discharge (ft^3/s)	Unit discharge [$(ft^3/s)/mi^2$]	Time of measurement (2400 hour time)	Comment
November 8									
24	0212418255	Rocky River at SR 1304 near Harrisburg	35° 20'06"	80° 37'41"	134[a]	18.5	0.1381	07:52 – 08:21	
29	02124237	Coddle Creek near Harrisburg	35° 20'32"	80° 36'45"	74.3	5.89	0.0793	09:21 – 09:58	
33	02124277	Rocky River at Rocky River	35° 18'59"	80° 35'43"	231	27.9	0.1208	11:55 – 12:45	
37	02124320	Reedy Creek at Rocky River	35° 18'12"	80° 35'41"	30.9	2.21	0.0715	10:45 – 11:17	
40	0212433550	Rocky River above Irish Buffalo Creek near Rocky River	35° 19'22"	80° 32'17"	278	30.3	0.1090	14:42 – 15:19	
51	02124374	Irish Buffalo Creek near Faggarts Crossroads	35° 20'50"	80° 32'52"	45.5	5.15	0.1132	13:36 – 14:00	Irish Buffalo Creek and Coldwater Creek merge prior to the confluence with Rocky River.
59	02124394	Coldwater Creek near Concord	35° 20'41"	80° 31'41"	63.4	2.2	0.0347	14:37 – 15:08	Irish Buffalo Creek and Coldwater Creek merge prior to the confluence with Rocky River.
60	02124401	Rocky River near Flows Store	35° 19'26"	80° 30'59"	392	63.3	0.1615	13:58 – 16:00	
73	02124596	Dutch Buffalo Creek at Georgeville	35° 18'51"	80° 27'52"	98.2	1.76	0.0179	16:50 – 17:40	
75	02124644	Rocky River near Midland	35° 15'16"	80° 28'22"	536	71.3	0.1330	11:30 – 12:45	
77	02124668	Clear Creek at Brief	35° 11'40"	80° 31'46"	22.5	0.56	0.0249	08:45 – 10:30	Sum of two measurements, including tributary to Clear Creek.
85	02124742	Rocky River near Stanfield	35° 10'10"	80° 28'24"	628	62.5	0.0995	11:49 – 13:00	
98	02124813	Rocky River near Oakboro	35° 11'42"	80° 16'48"	763	56.4	0.0739	10:28 – 11:03	
121	02125126	Long Creek near Oakboro	35° 13'05"	80° 15'28"	198	13.8	0.0697	08:49 – 09:20	
145	02125482	Richardson Creek near Fairfield	35° 04'16"	80° 24'25"	153	8.9	0.0582	15:04 – 15:36	
169	02126000	Rocky River near Norwood	35° 08'54"	80° 10'33"	1,372	77.5	0.0565	11:00 – 11:54	

[a]Approximate drainage area.

The Rocky River exemplifies the difficulty in understanding and quantifying the factors that affect low-flow discharges. Topographic, geologic, and climatic factors usually can be understood more readily because, within a given region, the effects of these factors on low-flow discharges generally do not change, other than in areas of rapid development where topographic changes may occur in conjunction with land-use changes. Likewise, climate characteristics for a given area are fairly well understood with the availability of historic climatological records. However, human-induced flow modifications resulting from impoundments and flow diversions—withdrawals and point-source discharges—and the absence of long-term streamflow records throughout the basin complicate the quantification of low-flow characteristics. In particular, the extent to which flow diversions affect low-flow characteristics can be difficult to quantify; in some instances, the presence of flow diversions upstream from a given location can only be acknowledged. Because of the complexity associated with the flow modifications as well as the losing reaches identified in the lower half of the basin, the opportunities for increased understanding of the low-flow characteristics in the Rocky River basin can best be achieved with the addition of streamflow monitoring sites, preferably for long-term periods.

SUMMARY

This report describes low-flow characteristics for the Rocky River basin in North Carolina. Low-flow characteristics were compiled for selected continuous-record gaging stations and partial-record measuring sites in the study area, and drainage-area and low-flow discharge profiles were developed for the Rocky River. The low-flow characteristics and profiles in this report were developed in cooperation with the Water and Sewer Authority of Cabarrus County, Charlotte-Mecklenburg Utilities, and Union County.

In 1991, the North Carolina Department of Environment and Natural Resources began using a basinwide approach in its assessment of water-quality conditions in North Carolina; part of the assessment includes the simultaneous evaluation of National Pollution Discharge Elimination System (NPDES) permits for point-source discharges into streams in the basin. This report was prepared using the basinwide approach to compile low-flow characteristics for selected sites in the Rocky River basin and to develop drainage-area and low-flow discharge profiles for the Rocky River.

The Rocky River basin has a drainage area of 1,413 mi^2 and merges with the Yadkin River in eastern Stanly County to form the Pee Dee River. Located in south-central North Carolina, the entire basin lies within the Piedmont Physiographic Province and is characterized by rolling and hilly topography. The Rocky River is nearly 91 mi long from the headwaters to the mouth of the river. The Rocky River begins near the town of Mooresville in Iredell County and flows southeast through Iredell and Cabarrus Counties, turning south in southeastern Cabarrus County, and then constitutes the county boundary between Stanly and Anson Counties and Stanly and Union Counties before draining into the Yadkin-Pee Dee River. Overall, land use in the Rocky River basin is rural; about 91 percent of the basin is covered by forested and agricultural areas. Urban land uses occupy about 7 percent of the basin.

Approximately 175 impoundments with dams having structural heights exceeding 15 ft were identified in the Rocky River basin. The vast majority of these impoundments have relatively small surface areas at the spillway level and are used primarily for sources of irrigation, sediment reduction, recreational activities, and(or) landscape features. Seven of these impoundments were identified as causing widespread inundation upstream from the dam. The largest impoundment is Lake Don T. Howell (formerly known as Coddle Creek Reservoir), which has a surface area of 1,300 acres in Cabarrus County. This impoundment is the only one having a required minimum-flow release, which is 6.0 ft^3/s. However, releases as low as 2.0 ft^3/s were permitted to occur during the recent 1998–2002 drought, and a tiered set of lower minimum-flow releases currently (2003) is being investigated for use during low-flow periods.

Withdrawals and return discharges were paired for 16 municipalities or other entities that use streams in the Rocky River as a source for withdrawals and(or) as the receiving stream for return point-source discharges. The largest withdrawals were made by the cities of Concord and Kannapolis, which withdrew an average of 9.8 and 6.1 Mgal/d, respectively, in 2001 from Lake Howell and other smaller impoundments. The largest return point-source discharge in the basin is made by Cabarrus County, which treated and discharged an average of 16.3 Mgal/d in 2001 for Concord, Kannapolis, and several other smaller

municipalities in Cabarrus County. Other substantial return discharges in the basin occur on Mallard Creek in Mecklenburg County and on Dye Branch in Iredell County near the town of Mooresville (6.0 and 2.4 Mgal/d, respectively, in 2001). Aside from withdrawals made by Concord and Kannapolis, additional sources of water supply for other municipalities in the Rocky River basin are Mountain Island Lake (Charlotte-Mecklenburg) and Lake Norman (Mooresville) located west of the study area in the Catawba River basin, and Tuckertown and Narrows Reservoir (Albemarle) and Lake Tillery (Norwood) located east of the study area.

Soils and underlying hydrogeologic units in the Rocky River basin were examined to determine their effects on low flows. The Rocky River basin spans two of the major geologic belts in North Carolina—the Charlotte Belt in the upper half of the basin and the Carolina Slate Belt in much of the lower half. Streams in the Charlotte Belt are recognized as having moderate potential for sustained base flows, and streams in the Carolina Slate Belt are recognized as having little to no potential for sustained base flows, patterns that were observed in the compilations of low-flow characteristics at selected sites in the basin.

Twelve major soil series are present along the river's course and directly adjacent to the Rocky River and its tributaries. The soils generally reflect the underlying geologic parent material with a mixture of soils derived from crystalline rock and soils derived from fine-grained Carolina Slate rock present throughout the basin. Loam is the dominant soil texture throughout the 12 soil series. Loam combination soil textures predominate in the basin, including sandy loam, silt loam, and clay loam, with silt loam most common. Two of the 12 series are clay soils. In general, all of the soils are considered to be moderately permeable (0.6 to 2 in. per hour). Streams in areas of clay soils have little or no source for sustained base flow during drought conditions.

The Rocky River basin includes 12 of 18 hydrogeologic units identified for the Blue Ridge and Piedmont Provinces in North Carolina. Of these 12 hydrogeologic units, 7 have average well yields below the mean average yield of 18.2 gal/min for hydrogeologic units in the Blue Ridge and Piedmont Provinces. When combined, these seven units make up nearly 64 percent of the Rocky River basin. The largest hydrogeologic unit in the basin is characterized by argillite rocks and covers nearly 48 percent of the basin, primarily in the lower half of the basin. This same unit has an average well yield of 14.6 gal/min, significantly below the average well yield for the Blue Ridge and Piedmont Provinces.

Records of surface-water data were identified and compiled for 173 sites in the study area. Low-flow characteristics (7Q10, 30Q2, W7Q10, and 7Q2) were determined for 56 sites (12 continuous-record and 44 partial-record). Discharge records available at the continuous-record gaging stations through the 2002 water year and at the partial-record measuring sites through the 2001 water year were used in the analyses of low-flow characteristics. At the continuous-record sites, the records were extended during the latter stages of the investigation to include discharges for the 2002 water because of the 1998–2002 drought.

Of the 56 sites where low-flow characteristics were developed, 19 sites had minimal (defined as 0.05 ft^3/s or less) or zero 7Q10 discharges. The spatial distribution of these 19 sites was examined to determine if any drainage-area thresholds could be established for the basin. Eighteen of the 19 sites were present in the part of the basin underlain by the Carolina Slate Belt. Drainage areas among the 18 sites ranged from 1.44 to 87.7 mi^2 with 15 sites having drainage areas less than 23.6 mi^2, suggesting that 7Q10 discharges at ungaged sites in the Carolina Slate Belt with drainage areas less than about 25 mi^2 likely will have zero or minimal discharges. Because only one site in the upper part of the basin (underlain by the Charlotte and Milton Belts) had a zero 7Q10 discharge, no drainage-area thresholds were established for this area.

Drainage-area and low-flow discharge profiles were developed for the Rocky River. The drainage-area profile shows increases in basin size for the entire reach of the Rocky River. Major tributaries draining to the Rocky River include Clarke Creek (28.2 mi^2) and Mallard Creek (41.2 mi^2) in Mecklenburg and Cabarrus Counties; Coddle Creek (78.8 mi^2) in Iredell, Rowan, and Cabarrus Counties; Irish Buffalo/ Coldwater Creek (110 mi^2) and Dutch Buffalo Creek (99 mi^2) in Rowan and Cabarrus Counties; Long Creek (200 mi^2) in Stanly County; and Richardson Creek (234 mi^2) and Lanes Creek (135 mi^2) in Union and Anson Counties.

The low-flow discharge profiles depict the 7Q10, 30Q2, W7Q10, and 7Q2 discharges for the Rocky

River between a partial-record site near Davidson and a continuous-record gaging station near Norwood. Five sites on the Rocky River (two continuous-record and three partial-record sites) were used to estimate the low-flow discharges depicted in the profiles. The profiles indicate different potentials for sustained base flow between the upper and lower reaches of the main stem. In the upper reach between Davidson and Stanfield, flow profiles show continual increases in low-flow characteristics as a result of flow contributions from tributaries during base-flow conditions as well as several major point-source discharges. In the reach downstream from Stanfield, the profiles show a substantial decrease in the potential for sustained base flow as a result of little to no flow contributions from tributaries. Correspondingly, the profiles indicate the presence of a losing reach between Stanfield and Norwood. The presence of a losing reach is attributed to the soils and underlying rock types of the Carolina Slate Belt, which do not allow storage in surficial aquifers. Many streams in the lower parts of the basin have minimal (less than 0.05 ft^3/s) or zero 7Q10 discharges.

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Table 4. Summary of continuous-record gaging stations and partial-record measuring sites in the Rocky River basin in North Carolina where gage height and streamflow data were collected

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Site index no. (pl. 1)	USGS downstream order number	Station name	Latitude	Longitude	County	USGS topographic quadrangle	Drainage area (mi^2)	Tributary to	Hydrologic unit code	Site type	Period of record	Number of measurements for partial-record sites: Flow	Number of measurements for partial-record sites: Zero flow
1	02123844	Dye Branch near Mooresville	35° 32'14"	80° 47'41"	Iredell	Mooresville	3.96	Rocky River	03040105	2	1970–75	12	0
2	0212384510	Dye Branch at SR 1142 near Mooresville	35° 31'29"	80° 46'54"	Iredell	Mooresville	4.82	Rocky River	03040105	2	1973	1	0
3	02123881	Rocky River near Davidson	35° 28'29"	80° 46'48"	Mecklenburg	Cornelius	13.4	Pee Dee River	03040105	2	1970–99, 2000, 2002	138	0
4	02123917	West Branch Rocky River near Cornelius	35° 28'21"	80° 47'33"	Mecklenburg	Cornelius	13.6	Rocky River	03040105	2	1955, 1961–62	3	0
5	02123932	South Prong West Branch Rocky River near Cornelius	35° 28'23"	80° 49'02"	Mecklenburg	Cornelius	4.98	West Branch Rocky River	03040105	2	1969–71, 1973–74	11	0
6	02123953	Rocky River near Caldwell	35° 27'18"	80° 45'43"	Cabarrus	Cornelius	39.0	Pee Dee River	03040105	2	1948, 1952–53, 1961–62	7	0
7	02123989	Rocky River near Kannapolis	35° 26'31"	80° 45'08"	Cabarrus	Cornelius	40.9	Pee Dee River	03040105	2	1948, 1961–62, 2002	4	0
8	02123994	Rocky River at SR 1449 near Deweese	35° 25'27"	80° 44'28"	Cabarrus	Kannapolis	44.4	Pee Dee River	03040105	2	1971, 1973–74	8	0
9	02124050	South Prong Clarke Creek near Huntersville	35° 24'21"	80° 48'06"	Mecklenburg	Cornelius	5.75	Clarke Creek	03040105	2	1969–71, 1973, 1975	12	0
10	02124060	North Prong Clarke Creek near Huntersville	35° 25'11"	80° 47'53"	Mecklenburg	Cornelius	3.63	Clarke Creek	03040105	2	1960–73	17	0
11	02124077	Ramah Creek near Huntersville	35° 25'26"	80° 45'56"	Mecklenburg	Cornelius	6.19	Clarke Creek	03040105	2	1961–62	2	0
12	02124080	Clarke Creek near Harrisburg	35° 24'50"	80° 45'08"	Cabarrus	Cornelius	21.9	Rocky River	03040105	2	1951–71, 1988	45	0
13	02124091	Clarke Creek at Pleasant Grove	35° 23'12"	80° 43'46"	Cabarrus	Kannapolis	28.2	Rocky River	03040105	2	1952–53, 1961–62, 1967, 2002	8	0
14	02124101	Rocky River near Pleasant Grove	35° 22'59"	80° 43'18"	Cabarrus	Kannapolis	76.8	Pee Dee River	03040105	2	1953, 1961–62, 2002	4	0
15	02124110	Rocky River near Roberta Mill	35° 21'33"	80° 40'31"	Cabarrus	Harrisburg	87.2	Pee Dee River	03040105	2	1952–58, 1961–62, 1967, 1973–74, 1979, 2002	27	0
16	02124122	Mallard Creek near Derita	35° 19'34"	80° 46'25"	Mecklenburg	Derita	11.9	Rocky River	03040105	2	1961–62	2	0
17	02124130	Mallard Creek near Charlotte	35° 19'05"	80° 44'14"	Mecklenburg	Harrisburg	20.6	Rocky River	03040105	2	1961–71	11	0
18	02124140	Toby Creek near Newell	35° 17'42"	80° 44'39"	Mecklenburg	Harrisburg	3.6[a]	Mallard Creek	03040105	2	1969–71, 1973, 1975	12	0
19	02124146	Mallard Creek near Newell	35° 19'12"	80° 43'54"	Mecklenburg	Harrisburg	26.1	Rocky River	03040105	2	1954–55, 1961–62, 1971	6	0

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20	0212414860	Stony Creek at U.S. Highway 29 near Harrisburg	35° 20'02"	80° 43'11"	Mecklenburg	Harrisburg	6.71	Mallard Creek	03040105	2	1969–71, 1973, 1975	10	0
21	02124149	Mallard Creek below Stony Creek near Harrisburg	35° 19'57"	80° 42'58"	Mecklenburg	Harrisburg	34.6	Rocky River	03040105	1	Dec 1994–Sept 2002	N/A	N/A
22	0212414950	Mallard Creek near Charlotte	35° 20'03"	80° 42'19"	Mecklenburg	Harisburg	36[a]	Rocky River	03040105	2	1969, 1971	4	0
23	02124160	Mallard Creek at Harrisburg	35° 20'02"	80° 40'05"	Cabarrus	Harrisburg	41.1	Rocky River	03040105	2	1955–65, 1971, 1973–81, 2002	50	0
24	0212418255	Rocky River at SR 1304 near Harrisburg	35° 20'06"	80° 37'41"	Cabarrus	Harrisburg	134[a]	Pee Dee River	03040105	2	1970–73, 1975, 2002	9	0
25	02124183	Rocky River at Harrisburg	35° 19'57"	80° 37'42"	Cabarrus	Harrisburg	136	Pee Dee River	03040105	2	1956, 1961–62	3	0
26	02124194	Coddle Creek near Deweese[b]	35° 28'51"	80° 42'58"	Cabarrus	Kannapolis	32.2	Rocky River	03040105	2	1961–62, 1970, 1982	4	0
27	02124206	Coddle Creek at NC 73 near Concord	35° 26'12"	80° 41'52"	Cabarrus	Kannapolis	47.5	Rocky River	03040105	2	1973	1	0
28	02124230	Coddle Creek near Concord	35° 24'29"	80° 40'29"	Cabarrus	Kannapolis	57.9	Rocky River	03040105	2	1949–58, 1961–63	22	0
29	02124237	Coddle Creek near Harrisburg	35° 20'32"	80° 36'45"	Cabarrus	Concord	74.3	Rocky River	03040105	2	1961–62, 2002	3	0
30	02124269	Back Creek above SEO near Harrisburg	35° 18'33"	80° 40'25"	Cabarrus	Harrisburg	7.45	Rocky River	02040105	2	1970–71	4	0
31	02124270	Back Creek below SEO at Harrisburg	35° 18'48"	80° 39'10"	Cabarrus	Harrisburg	9[a]	Rocky River	03040105	2	1970–71, 1973–75	7	0
32	02124273	Back Creek near Harrisburg	35° 18'37"	80° 36'17"	Cabarrus	Concord SE	15.3	Rocky River	03040105	2	1961–62	2	0
33	02124277	Rocky River at Rocky River	35° 18'59"	80° 35'43"	Cabarrus	Concord SE	231	Pee Dee River	03040105	2	1967, 2002	2	0
34	0212430295	Reedy Creek at SR 2804 near Wilgrove	35° 15'32"	80° 39'46"	Mecklenburg	Harrisburg	12.7	Rocky River	03040105	2	1969–71, 1973, 1975	12	0
35	02124303	Reedy Creek near Harrisburg	35° 16'48"	80° 38'46"	Cabarrus	Harrisburg	16.0	Rocky River	03040105	2	1961–62	2	0
36	0212430645	McKee Creek at SR 2808 near Wilgrove	35° 14'25"	80° 39'01"	Mecklenburg	Mint Hill	4.08	Reedy Creek	03040105	2	1969–71, 1973, 1975	11	0
37	02124320	Reedy Creek at Rocky River	35° 18'12"	80° 35'41"	Cabarrus	Concord SE	30.9	Rocky River	03040105	2	1955–63, 2002	26	0
38	02124327	Caldwell Creek near Rocky River	35° 16'06"	80° 35'32"	Cabarrus	Concord SE	5.38	Reedy Creek	03040105	2	1955, 1961–62	3	1
39	02124334	Rocky River near Rocky River	35° 19'27"	80° 33'40"	Cabarrus	Concord SE	277	Pee Dee River	03040105	2	1952–56, 1961–62, 1971, 1973	13	0

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40	0212433550	Rocky River above Irish Buffalo Creek near Rocky River	35° 19'22"	80° 32'17"	Cabarrus	Concord SE	278	Pee Dee River	03040105	1	Apr 2000–Sept 2002	N/A	N/A
41	02124337	Irish Buffalo Creek near Landis	35° 32'24"	80° 38'32"	Rowan	Enochville	5.24	Rocky River	03040105	2	1961–62, 1972	3	0
42	0212433839	Irish Buffalo Creek tributary at SR 1100 at Kannapolis	35° 30'37"	80° 37'58"	Rowan	Enochville	1.6[a]	Irish Buffalo Creek	03040105	2	1970–71, 1973–75	11	0
43	0212433840	Bleachers Creek at SR 1119 near Kannapolis	35° 30'26"	80° 38'09"	Rowan	Enochville	0.1[a]	Boiler Room Branch	03040105	2	1973–74	4	0
44	0212433843	Irish Buffalo Creek tributary at SR 1109 near Kannapolis	35° 30'34"	80° 38'48"	Rowan	Enochville	2.50	Irish Buffalo Creek	03040105	2	1970–71, 1973–75	11	0
45	0212433845	Irish Buffalo Creek at SR 1124 near Kannapolis	35° 30'30"	80° 38'53"	Rowan	Enochville	14.1	Rocky River	03040105	2	1970–75	15	0
46	0212434059	Irish Buffalo Creek at SR 1609 near Kannapolis	35° 29'16"	80° 39'13"	Cabarrus	Kannapolis	16[a]	Rocky River	03040105	2	1970–75	13	0
47	0212434410	Irish Buffalo Creek near Fisher Town	35° 28'23"	80° 39'19"	Cabarrus	Kannapolis	20.2	Rocky River	03040105	2	1970–75	14	0
48	02124357	Irish Buffalo Creek at SR 1394 near Concord	35° 24'52"	80° 36'46"	Cabarrus	Concord	32.3	Rocky River	03040105	2	1970–75	14	0
49	02124366	Irish Buffalo Creek at NC 49 near Concord	35° 22'15"	80° 33'50"	Cabarrus	Concord SE	40.9	Rocky River	03040105	2	1970–75	14	0
50	02124368	Irish Buffalo Creek near Concord	35° 21'49"	80° 33'25"	Cabarrus	Concord SE	42.2	Rocky River	03040105	2	1970–75	14	0
51	02124374	Irish Buffalo Creek near Faggarts Crossroads	35° 20'50"	80° 32'52"	Cabarrus	Concord SE	45.5	Rocky River	03040105	2	1974–84, 1986–99, 2000, 2002	87	0
52	0212437525	Coldwater Creek tributary near China Grove	35° 33'15"	80° 35'00"	Rowan	China Grove	0.2[a]	Coldwater Creek	03040105	2	1973–74	4	0
53	02124377	Coldwater Creek near Landis	35° 31'36"	80° 34'27"	Rowan	China Grove	7.66	Rocky River	03040105	2	1961–62	2	0
54	02124379	Coldwater Creek tributary at Kannapolis	35° 30'58"	80° 34'35"	Rowan	China Grove	3.99	Coldwater Creek	03040105	2	1961–62	2	0
55	02124382	Threemile Branch at Kannapolis	35° 27'14"	80° 36'33"	Cabarrus	Concord	1.76	Coldwater Creek	03040105	2	1961	2	0
56	02124383	Threemile Branch near Kannapolis	35° 26'26"	80° 35'30"	Cabarrus	Concord	2.84	Coldwater Creek	03040105	2	1952	1	0

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57	02124388	Threemile Branch at Concord	35° 24'37"	80° 34'04"	Cabarrus	Concord	5.30	Coldwater Creek	03040105	2	1953	2	0
58	02124391	Little Coldwater Creek near Concord	35° 23'26"	80° 32'15"	Cabarrus	Concord	13.5	Coldwater Creek	03040105	2	1961–62	2	0
59	02124394	Coldwater Creek near Concord	35° 20'41"	80° 31'41"	Cabarrus	Concord SE	63.4	Irish Buffalo Creek	03040105	2	1961–62, 2002	3	0
60	02124401	Rocky River near Flows Store	35° 19'26"	80° 30'59"	Cabarrus	Concord SE	392	Pee Dee River	03040105	2	1970–71, 1973–99, 2000, 2002	84	0
61	02124408	Hamby Branch near Georgeville	35° 19'29"	80° 30'13"	Cabarrus	Concord SE	6.94	Rocky River	03040105	2	1955, 1961–62	3	1
62	02124420	Rocky River near Concord	35° 18'50"	80° 28'45"	Cabarrus	Mount Pleasant	402[a]	Pee Dee River	03040105	2	1963	1[c]	0
63	02124448	Little Buffalo Creek at NC 49 near Mount Pleasant	35° 26'02"	80° 23'56"	Cabarrus	Mount Pleasant	15.6	Dutch Buffalo Creek	03040105	2	1961-62	2	2
64	02124458	Dutch Buffalo Creek near Watts Crossroads	35° 26'30"	80° 27'20"	Cabarrus	Mount Pleasant	24.5	Rocky River	03040105	2	1961-62	2	0
65	02124460	Dutch Buffalo Creek near Rimer	35° 26'30"	80° 26'38"	Cabarrus	Mount Pleasant	33.8	Rocky River	03040105	2	1964-71, 1988	18	0
66	02124468	Black Run Creek near Watts Crossroads	35° 26'23"	80° 26'18"	Cabarrus	Mount Pleasant	6.71	Dutch Buffalo Creek	03040105	2	1961, 1970	2	0
67	0212446990	Dutch Buffalo Creek above NC 49 near Mount Pleasant	35° 25'59"	80° 25'11"	Cabarrus	Mount Pleasant	43[a]	Rocky River	03040105	2	1973, 1975	3	0
68	02124471	Dutch Buffalo Creek at NC 49 near Mount Pleasant	35° 25'37"	80° 24'40"	Cabarrus	Mount Pleasant	45.1	Rocky River	03040105	1	Mar 1985 - Feb 1987	N/A	N/A
69	02124500	Dutch Buffalo Creek at Mount Pleasant	35° 23'45"	80° 25'00"	Cabarrus	Mount Pleasant	65.4	Rocky River	03040105	2	1953, 1955, 1961-62, 1970-71, 1973, 1975	10	0
70	02124524	Dutch Buffalo Creek near Mount Pleasant	35° 23'20"	80° 25'28"	Cabarrus	Mount Pleasant	66.2	Rocky River	03040105	2	1952, 1954, 1956, 1961	4	0
71	02124548	Adams Creek at Mount Pleasant	35° 23'13"	80° 26'17"	Cabarrus	Mount Pleasant	15.6	Dutch Buffalo Creek	03040105	2	1955-56, 1961	3	0
72	02124572	Dutch Buffalo Creek near Barriers Mill	35° 20'17"	80° 26'46"	Cabarrus	Mount Pleasant	94.4	Rocky River	03040105	2	1948, 1961-62	3	0
73	02124596	Dutch Buffalo Creek at Georgeville	35° 18'51"	80° 27'52"	Cabarrus	Locust	98.2	Rocky River	03040105	2	1948, 1952-53, 1961-62, 1986-96, 2002	33	0
74	02124621	Anderson Creek near Cabarrus	35° 16'00"	80° 30'08"	Cabarrus	Concord SE	11.4	Rocky River	03040105	2	1954, 1961-62	3	1

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75	02124644	Rocky River near Midland	35° 15'16"	80° 28'22"	Cabarrus	Mount Pleasant	536	Pee Dee River	03040105	2	1961-62, 2002	3	0
76	02124660	Clear Creek at SR 3181 near Mint Hill	35° 12'29"	80° 34'48"	Mecklenburg	Midland	12.6	Rocky River	03040105	2	1969-71, 1975	8	0
77	02124668	Clear Creek at Brief	35° 11'40"	80° 31'46"	Union	Midland	22.5	Rocky River	03040105	2	1954, 1961-62, 2002	4	1
78	0212466825	Clear Creek Tributary at Brief	35° 11'38"	80° 31'29"	Union	Midland	0.82	Clear Creek	03040105	2	2002	1	0
79	02124675	Goose Creek at SR 1524 near Mint Hill	35° 07'48"	80° 37'51"	Union	Midland	8.6[a]	Rocky River	03040105	2	1969-73	10	0
80	02124692	Goose Creek at Fairview	35° 09'14"	80° 32'09"	Union	Midland	24.0	Rocky River	03040105	1	Nov 1999 - Sept 2002	N/A	N/A
										2	1955, 1961-62	3	0
81	0212471765	Duck Creek tributary at NC 218 near Brief	35° 09'50"	80° 35'13"	Union	Midland	2.80	Yadkin River	03040105	2	1996	1	1
82	0212471785	Duck Creek tributary at NC 218 near Fairview	35° 09'45"	80° 34'26"	Union	Midland	0.81	Yadkin River	03040105	2	1996	1	1
83	02124718	Duck Creek at Brief	35° 10'52"	80° 32'28"	Union	Midland	12.1	Goose Creek	03040105	2	1954-55, 1961-62	4	2
84	0212471905	Goose Creek at SR 1547 near Faiview	35° 10'33"	80° 30'40"	Union	Midland	41.4	Rocky River	03040105	2	2002	1	0
85	02124742	Rocky River near Stanfield	35° 10'10"	80° 28'24"	Stanly	Stanfield	628	Pee Dee River	03040105	1	Apr 2000 - Sept 2002	N/A	N/A
										2	1961-62	2	0
86	02124745	North Fork Crooked Creek near Fairview	35° 06'32"	80° 33'43"	Union	Bakers	16[a]	Crooked Creek	03040105	2	1961-62, 1965-69, 1971	16	1
87	02124761	South Fork Crooked Creek near Unionville	35° 06'26"	80° 32'56"	Union	Bakers	18.4	Crooked Creek	03040105	2	1961-62	2	2
88	02124766	Crooked Creek at Fairview	35° 07'44"	80° 32'14"	Union	Midland	36.9	Rocky River	03040105	2	1954, 1962, 1964-65	4	1
89	0212476710	Crooked Creek at SR 1547 near Fairview	35° 08'41"	80° 28'18"	Union	Stanfield	47.3	Rocky River	03040105	2	2002	1	0
90	02124772	Grassy Creek near Fairview	35° 07'53"	80° 26'34"	Union	Stanfield	4.50	Rocky River	03040105	2	1961-62	2	2
91	02124773	Rock Hole Creek at SR 1147 near Stanfield	35° 12'58"	80° 26'34"	Stanly	Stanfield	4.27	Rocky River	03040105	2	1970-71, 1973, 1975	9	0
92	02124776	Rock Hole Creek at Stanfield	35° 12'14"	80° 25'58"	Stanly	Stanfield	7.55	Rocky River	03040105	2	1970-71, 1973-75	10	1
93	02124778	Rock Hole Creek near Stanfield	35° 10'39"	80° 24'37"	Stanly	Stanfield	11.7	Rocky River	03040105	2	1961-62	2	0

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94	02124781	Rocky River at State Highway 200 near Stanfield	35° 09'55"	80° 23'51"	Stanly	Stanfield	708	Pee Dee River	03040105	2	1971, 1973-77, 2002	22	0
95	02124789	Island Creek near Locust	35° 15'38"	80° 24'06"	Stanly	Mount Pleasant	3.10	Rocky River	03040105	2	1955, 1957, 1961-62	4	2
96	02124794	Island Creek near Stanfield	35° 11'51"	80° 22'28"	Stanly	Oakboro	19.2	Rocky River	03040105	2	1961-62	2	1
97	02124798	Rocky River at State Highway 205 near Oakboro	35° 10'09"	80° 20'44"	Stanly	Oakboro	744	Pee Dee River	03040105	2	1971, 1973-74	5	0
98	02124813	Rocky River near Oakboro	35° 11'42"	80° 16'48"	Stanly	Oakboro	763	Pee Dee River	03040105	2	1961-62, 1970-71, 1973-74, 2002	13	0
99	02124823	Long Creek at SR 1454 near Richfield	35° 28'21"	80° 17'37"	Stanly	Mount Pleasant	5.29	Rocky River	03040105	2	1974-84	54	7
100	02124827	Long Creek near Richfield	35° 26'24"	80° 16'28"	Stanly	Mount Pleasant	12.6	Rocky River	03040105	2	1961-62	2	1
101	02124835	Long Creek near Plyler	35° 22'51"	80° 14'48"	Stanly	New London	27.5	Rocky River	03040105	2	1955-56, 1961-62, 1964-67	10	0
102	02124841	Long Creek at Albemarle	35° 19'55"	80° 12'45"	Stanly	Albemarle	33.1	Rocky River	03040105	2	1970-71, 1973-75	10	1
103	02124861	Little Long Creek at Albemarle	35° 21'39"	80° 12'15"	Stanly	Albemarle	20.5	Long Creek	03040105	2	1955-56, 1961, 1964-65	5	0
104	02124869	Little Long Creek at NC 24/27 near Albemarle	35° 20'13"	80° 12'38"	Stanly	Albemarle	29[a]	Long Creek	03040105	2	1970-71, 1973-75	10	0
105	0212488455	Long Creek near Bloomington	35° 18'25"	80° 13'48"	Stanly	Albemarle	66[a]	Rocky River	03040105	2	1972-73	2	0
106	02124908	Long Creek near Hills	35° 16'57"	80° 14'52"	Stanly	Albemarle	72.4	Rocky River	03040105	2	1970-71, 1973-75	10	0
107	02124941	Little Bear Creek near Hills	35° 18'20"	80° 16'25"	Stanly	Mount Pleasant	6.99	Long Creek	03040105	2	1970-71, 1973, 1975	9	2
108	02124944	Little Bear Creek at Saint Martin	35° 16'02"	80° 16'04"	Stanly	Mount Pleasant	12.4	Long Creek	03040105	2	1961-62, 1970-71, 1973, 1975	11	0
109	02124948	Long Creek tributary near Saint Martin	35° 15'00"	80° 15'00"	Stanly	Oakboro	10.6	Long Creek	03040105	2	1961-62	2	1
110	02124958	Big Bear Creek near Finger	35° 21'56"	80° 20'55"	Stanly	Mount Pleasant	20.3	Long Creek	03040105	2	1961-62	2	2
111	02124981	Little Bear Creek near Finger	35° 23'05"	80° 22'18"	Stanly	Mount Pleasant	10.9	Big Bear Creek	03040105	2	1955-56, 1961-62	4	4
112	02124998	Little Creek near Bloomington	35° 20'10"	80° 20'10"	Stanly	Mount Pleasant	7.10	Big Bear Creek	03040105	2	1961-62	2	1
113	02125000	Big Bear Creek near Richfield	35° 20'02"	80° 20'09"	Stanly	Frog Pond	55.6	Rocky River	03040105	1	May 1954 - Sept 2002	N/A	N/A
114	02125020	Big Bear Creek near Albemarle	35° 16'49"	80° 18'10"	Stanly	Frog Pond	70.5	Long Creek	03040105	2	1949-54, 1961-62, 1964, 1967-69	47	0

Table 4. Summary of continuous-record gaging stations and partial-record measuring sites in the Rocky River basin in North Carolina where gage height and streamflow data were collected—Continued

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Site index no. (pl. 1)	USGS downstream order number	Station name	Latitude	Longitude	County	USGS topographic quadrangle	Drainage area (mi^2)	Tributary to	Hydrologic unit code	Site type	Period of record	Number of measurements for partial-record sites: Flow	Number of measurements for partial-record sites: Zero flow
115	02125023	Big Bear Creek near Saint Martin	35° 15'23"	80° 17'15"	Stanly	Frog Pond	73.9	Long Creek	03040105	2	1975-77	16	0
116	02125052	Stony Run at Red Cross	35° 17'06"	80° 20'53"	Stanly	Mount Pleasant	8.28	Big Bear Creek	03040105	2	1955, 1961-62	3	2
117	02125084	Stony Run near Red Cross	35° 16'21"	80° 19'27"	Stanly	Mount Pleasant	10.2	Big Bear Creek	03040105	2	1955, 1961-62	3	2
118	02125091	Stony Run tributary at SR 1975 near Oakboro	35° 14'54"	80° 18'45"	Stanly	Oakboro	1.6[a]	Stony Run	03040105	2	1970-71, 1973-75	11	0
119	02125116	Stony Run near Saint Martin	35° 14'53"	80° 17'34"	Stanly	Oakboro	19.7	Big Bear Creek	03040105	2	1955, 1961-62	3	2
120	02125122	Big Bear Creek near Aquadale	35° 15'18"	80° 16'27"	Stanly	Oakboro	95.5	Long Creek	03040105	2	1961-62	2	0
121	02125126	Long Creek near Oakboro	35° 13'05"	80° 15'28"	Stanly	Oakboro	198	Rocky River	03040105	2	1970-71, 1973-77, 1979-99, 2000, 2002	88	0
122	02125132	Long Creek tributary No. 2 near Aquadale	35° 13'00"	80° 15'00"	Stanly	Oakboro	2.0[a]	Long Creek	03040105	2	1961-62	2	0
123	02125139	Rocky River near Aquadale	35° 10'19"	80° 14'16"	Stanly	Aquadale	973	Pee Dee River	03040105	2	1971, 1973	3	0
124	0212514705	Richardson Creek at SR 2139 near Waxhaw	34° 54'40"	80° 35'38"	Union	Monroe	3.22	Rocky River	03040105	2	1974-77	19	0
125	02125148	Richardson Creek at NC 207 near Monroe	34° 57'14"	80° 32'42"	Union	Monroe	32.6	Rocky River	03040105	2	1955, 1961-62	3	3
126	02125181	Richardson Creek at Monroe	34° 57'37"	80° 31'23"	Union	Monroe	34[a]	Rocky River	03040105	2	1930	1	0
127	02125183	Richardson Creek above water intake near Monroe	34° 57'50"	80° 30'49"	Union	Monroe	50[a]	Rocky River	03040105	2	1971, 1975	2	0
128	02125199	Little Richardson Creek near Altan	34° 55'30"	80° 31'11"	Union	Monroe	7.01	Richardson Creek	03040105	2	1962	1	1
129	02125201	Little Richardson Creek tributary No.2 near Altan	34° 56'00"	80° 31'00"	Union	Monroe	0.9[a]	Little Richard-son Creek	03040105	2	1962	1	1
130	02125204	Little Richardson Creek tributary near Monroe	34° 56'02"	80° 30'26"	Union	Monroe	3.26	Richardson Creek	03040105	2	1961	1	1
131	02125212	Richardson Creek near Monroe	34° 58'26"	80° 30'37"	Union	Monroe	52.2	Rocky River	03040105	2	1973, 1975	7	0
132	02125223	Richardson Creek at SR 1751 near Monroe	34° 59'24"	80° 30'36"	Union	Monroe	54.6	Rocky River	03040105	2	1970-73, 1975	13	0
133	0212522625	Bearskin Creek at SR 1007 near Bakers	35° 00'10"	80° 36'34"	Union	Bakers	1.9[a]	Richardson Creek	03040105	2	1973, 1975	7	0

Table 4. Summary of continuous-record gaging stations and partial-record measuring sites in the Rocky River basin in North Carolina where gage height and streamflow data were collected—Continued

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Site index no. (pl. 1)	USGS downstream order number	Station name	Latitude	Longitude	County	USGS topographic quadrangle	Drainage area (mi^2)	Tributary to	Hydrologic unit code	Site type	Period of record	Number of measurements for partial-record sites: Flow	Number of measurements for partial-record sites: Zero flow
134	02125228	Bearskin Creek near Bakers	34° 59'00"	80° 34'00"	Union	Monroe	16[a]	Richardson Creek	03040105	2	1961-62	2	2
135	0212523050	Bearskin Creek at Hayne Street at Monroe	34° 59'24"	80° 32'57"	Union	Monroe	19[a]	Richardson Creek	03040105	2	1973, 1975	8	0
136	02125244	Bearskin Creek at Monroe	34° 59'46"	80° 31'24"	Union	Monroe	14.3	Richardson Creek	03040105	2	1973, 1975	7	0
137	02125246	Bearskin Creek near Monroe	34° 59'24"	80° 30'37"	Union	Monroe	15.0	Richardson Creek	03040105	2	1973-75	4	0
138	02125276	Flag Branch near Wingate	34° 59'00"	80° 28'00"	Union	Wingate	12.8	Richardson Creek	03040105	2	1954, 1961-62	3	2
139	02125310	Richardson Creek near Wingate	35° 01'58"	80° 28'20"	Union	Watson	89[a]	Rocky River	03040105	2	1953-54, 1956-59, 1970-74, 1976-77	25	0
140	02125410	Chinkapin Creek near Monroe	35° 02'48"	80° 29'33"	Union	Watson	8.5[a]	Richardson Creek	03040105	2	1953-71	23	1
141	02125456	Stewarts Creek near Monroe	35° 02'15"	80° 28'34"	Union	Watson	35.4	Richardson Creek	03040105	2	1954, 1961-62, 1970-71, 1973	7	6
142	02125462	Meadow Branch at Wingate	35° 00'20"	80° 26'51"	Union	Watson	4.62	Richardson Creek	03040105	2	1970-73, 1975	8	3
143	0212546245	Meadow Branch tributary at SR 1631 near Wingate	35° 00'44"	80° 26'29"	Union	Watson	0.3[a]	Meadow Branch	03040105	2	1970-71, 1975	3	2
144	02125464	Meadow Branch near Wingate	35° 01'53"	80° 27'07"	Union	Watson	6.70	Richardson Creek	03040105	2	1970-73, 1975-77	16	1
145	02125482	Richardson Creek near Fairfield	35° 04'16"	80° 24'25"	Union	Watson	153	Rocky River	03040105	2	1961-62, 1981-84, 1986-99, 2000, 2002	70	0
146	02125500	Richardson Creek near Marshville	35° 05'53"	80° 23'03"	Union	Watson	163	Rocky River	03040105	1	Apr 1940 - May 1944	N/A	N/A
147	02125538	Salem Creek at U.S. Highway 74 near Marshville	34° 59'05"	80° 24'05"	Union	Wingate	1.44	Richardson Creek	03040105	2	1954, 1961, 1970-74	9	7
148	0212553855	Salem Creek at SR 1751 near Marshville	34° 59'44"	80° 23'29"	Union	Wingate	3.25	Richardson Creek	03040105	2	1970-75	9	0
149	02125543	Salem Creek at NC 205 near Marshville	35° 00'46"	80° 22'39"	Union	Watson	7.68	Richardson Creek	03040105	2	1970-71, 1974-75	6	0

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150	02125546	Salem Creek at SR 1002 near Hamilton Crossroads	35° 02'37"	80° 21'56"	Union	Olive Branch	15.0	Richardson Creek	03040105	2	1953-54, 1957-58, 1970-75	13	0
151	02125549	Salem Creek near Fairfield	35° 04'30"	80° 22'07"	Union	Olive Branch	23.6	Richardson Creek	03040105	2	1961-62, 1970-77	18	2
152	02125557	Gourdvine Creek near Olive Branch	35° 06'02"	80° 20'11"	Union	Olive Branch	8.75	Richardson Creek	03040105	1	Jul 1978 - Dec 1982	N/A	N/A
										2	1961-62	2	0
153	02125588	Richardson Creek near Kikers	35° 09'11"	80° 14'50"	Anson	Aquadale	233	Rocky River	03040105	2	1967, 1974-75, 1981	13	0
154	02125591	Richardson Creek near Cottonville	35° 09'27"	80° 14'07"	Anson	Aquadale	234	Rocky River	03040105	2	1982-84, 2002	10	0
155	02125636	Cribs Creek near Burnsville	35° 07'55"	80° 12'17"	Anson	Aquadale	14.0	Rocky River	03040105	2	1955, 1961-62	3	0
156	02125650	Rocky River at SR 1943 near Aquadale	35° 09'52"	80° 12'22"	Stanly	Aquadale	1,232	Peedee River	03040105	2	2002	1	0
157	02125696	Lanes Creek near Trinity	34° 50'39"	80° 28'49"	Union	Pageland, SC-NC	4.92	Rocky River	03040105	1	July 1978 - Dec 1982	N/A	N/A
158	02125698	Lanes Creek near Monroe	34° 50'42"	80° 26'02"	Union	Pageland, SC-NC	12.7	Rocky River	03040105	2	1961-62	2	1
159	02125699	Wicker Branch near Trinity	34° 52'54"	80° 26'24"	Union	Wingate	5.83	Lanes Creek	03040105	1	July 1978 - Dec 1982	N/A	N/A
160	02125712	Lanes Creek near Sturdivants	34° 53'53"	80° 23'03"	Union	Wingate	43.9	Rocky River	03040105	2	1961-62	2	1
161	02125720	Lanes Creek at Sturdivants	34° 55'26"	80° 20'32"	Union	Marshville	56.9	Rocky River	03040105	2	1961, 1964-69	13	0
162	02125771	Beaverdam Creek near Marshville	34° 57'14"	80° 21'07"	Union	Marshville	14.9	Lanes Creek	03040105	2	1953, 1961-62, 1971	6	5
163	02125812	Lanes Creek at SR 1900 near Marshville	34° 58'08"	80° 18'44"	Union	Marshville	81[a]	Rocky River	03040105	2	1970-73, 1975	8	0
164	02125813	Lick Branch below SEO near Marshville	34° 58'52"	80° 19'53"	Union	Marshville	3.03	Lanes Creek	03040105	2	1970-73, 1975	8	0
165	02125816	Lanes Creek near Marshville	34° 58'31"	80° 18'14"	Union	Marshville	87.7	Rocky River	03040105	1	Mar 1985 - Feb 1987	N/A	N/A
										2	1954	1	1
166	02125861	Lanes Creek tributary near Peachland	34° 59'24"	80° 17'10"	Union	Marshville	1.08	Lanes Creek	03040105	2	1954, 1961-62	3	3
167	02125906	Lanes Creek near Polkton	35° 01'33"	80° 13'51"	Union	Polkton	110[a]	Rocky River	03040105	2	1930	1	0
168	02125951	Lanes Creek near Ansonville	35° 07'49"	80° 11'18"	Union	Aquadale	133	Rocky River	03040105	2	2002	1	0

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169	02126000	Rocky River near Norwood	35° 08'54"	80° 10'33"	Stanly	Aquadale	1,372	Pee Dee River	03040105	1	Oct 1929 - Sept 2002	N/A	N/A
170	02126088	Hardy Creek tributary above SEO near Aquadale	35° 12'53"	80° 12'27"	Stanly	Aquadale	0.5[a]	Hardy Creek	03040105	2	1970-71, 1975	6	0
171	02126091	Hardy Creek tributary near Cottonville	35° 12'29"	80° 11'04"	Stanly	Aquadale	3.09	Hardy Creek	03040105	2	1970-71, 1973, 1975	7	1
172	02126101	Hardy Creek near Cottonville	35° 10'48"	80° 10'04"	Stanly	Aquadale	15.2	Rocky River	03040105	2	1955, 1961-62	3	0
173	02126201	Rocky River at U.S. Highway 52 near Norwood	35° 11'39"	80° 06'49"	Stanly	Mount Gilead West	1,403	Pee Dee River	03040105	2	2002	1	0

[a]Approximate drainage area.

[b]Site now impounded by Lake Don T. Howell (formerly Coddle Creek Reservoir).

[c]Low-flow files for this site indicate the presence of 15 discharge measurements that were made during the 1948–54 water years. However, the files also indicate that the measurements were affected by presence of diversions and not suitable for low-flow analysis. No information is known about the specific diversions affecting flows at this site during the indicated period of record.

GLOSSARY

Base flow. The contribution of flow to a stream from ground water or spring discharge.

Climatic year. A continuous 12-month period during which a complete annual cycle occurs. The climatic year typically is from April 1 through March 31, designated by the calendar year in which the climatic year begins. For example, the 1997 climatic year is the period from April 1, 1997, to March 31, 1998. The year begins and ends during the period of increased flows so that all flows during a single dry season are included in annual values for that year.

Continuous-record gaging station. A site on a stream where continuous records of gage height are collected and for which discharge records are computed.

Drainage area. The drainage area of a stream at a specified location is the area, measured in a horizontal plane, which is enclosed by a drainage divide.

Gage height. The water-surface elevation referenced to an arbitrary gage datum, often used interchangeably with the term “stage.”

Low flow. Base flow or sustained fair-weather flow.

Partial-record measuring site. A site on a stream where periodic discharge measurements are collected, usually for a period of years. The data collected at partial-record sites are often correlated with data at nearby continuous-record gaging stations to estimate low-flow characteristics at the partial-record sites.

Recurrence interval. The average interval of time in which the magnitude of an extreme event can be expected to be equaled or exceeded once. The primary recurrence intervals used in this report are 2 years and 10 years. For example, if the 7-day, 10-year low-flow discharge is 5 cubic feet per second (ft^3/s), the annual minimum average discharge for a 7-consecutive-day period would be 5 ft^3/s or lower, on average, 1 time in 10 years, 5 times in 50 years, or 10 times in 100 years. Expressed in terms of probability, there is a 10-percent probability (inverse of recurrence interval) that the flow will be less than or equal to the 7-day, 10-year low-flow discharge in any 1 year. In a similar manner, there is a 50-percent probability that the flow will be less than or equal to the 7-day, 2-year low-flow discharge in any 1 year. While recurrence intervals indicate the average frequency of occurrence for a particular hydrologic event, it should be noted that the event could occur more than once in a given year, in consecutive years, or not at all during the period specified by the recurrence interval.

River mile. A measure of the distance upstream from the mouth of a stream.

Unit flow. Value of flow expressed in units of volume per time per square mile of drainage area. In this report, unit flow (sometimes used interchangeably with the term “yield”) is expressed as cubic feet per second per square mile [$(ft^3/s)/mi^2$].

Water year. The 12-month period October 1 through September 30, designated by the calendar year in which the period ends. For example, the 1998 water year is the period from October 1, 1997, to September 30, 1998. Average discharge and flow-duration data are computed by using the water-year time frame.

Zero-flow day. Day in which no flow occurred at a continuous-record gaging station and evidenced by a daily mean discharge of zero.