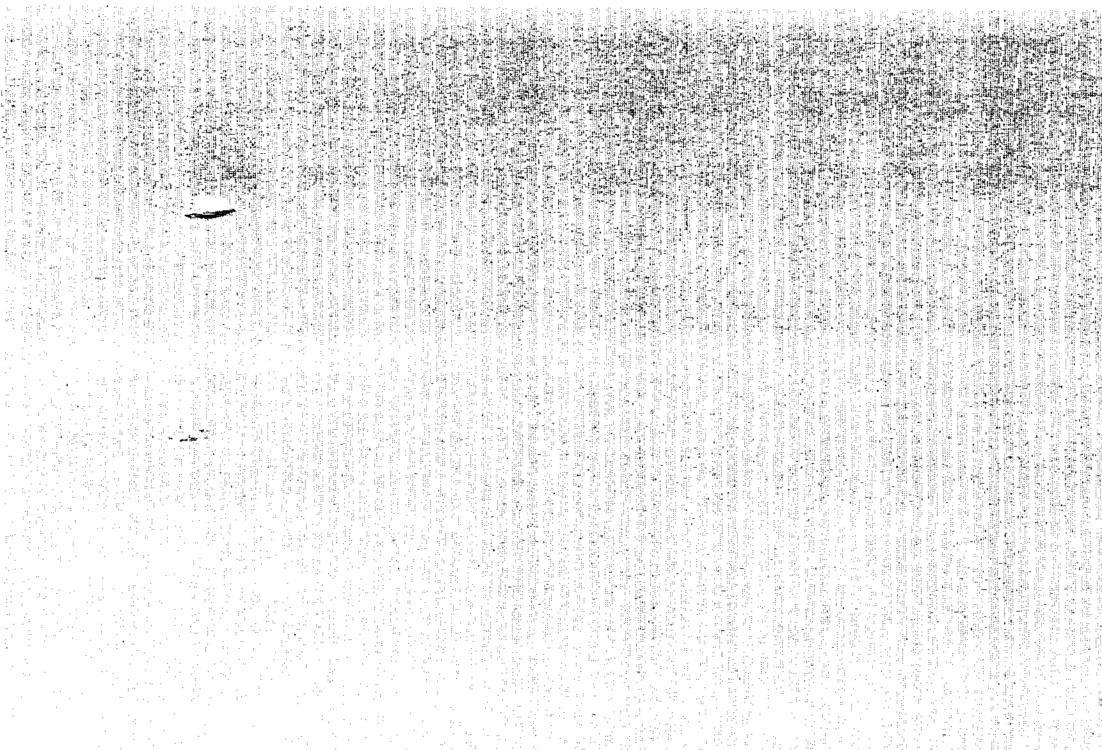
Base-Flow Characteristics of Streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia



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Base-Flow Characteristics of Streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia

By DAVID L. NELMS, GEORGE E. HARLOW, JR., and DONALD C. HAYES

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2457

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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Library of Congress Cataloging in Publication Data

Nelms, David L.
Base-flow characteristics of streams in the Valley and Ridge, the Blue Ridge, and the Piedmont physiographic provinces of Virginia / by David L. Nelms, George E. Harlow, Jr., and Donald C. Hayes.
p. cm. -- (U.S. Geological Survey water-supply paper ; 2457)
Includes bibliographical references.
Supt. of Docs. no.: I 19.13:2457
1. Streamflow--Virginia. I. Harlow, George E. II. Hayes, Donald C. III. Title. IV. Series.
GB1225.V8N45 1997
551.48'3'09755--dc21 97-1129
CIP
ISBN 0-607-86841-4

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	0.06308	liter per second
	Diffusivity and Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day
	Temperature	

degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

°F = 1.8(°C) + 32

Abbreviations: For dimensions expressed in this report, L equals distance and T equals time.

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

Base-Flow Characteristics of Streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia

By David L. Nelms, George E. Harlow, Jr., *and* Donald C. Hayes

Abstract

Growth within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia has focussed concern about allocation of surface-water flow and increased demands on the ground-water resources. The purpose of this report is to (1) describe the base-flow characteristics of streams, (2) identify the regional differences in these flow characteristics, and (3) describe, if possible, the potential surface-water and ground-water yields of basins on the basis of the base-flow characteristics.

Base-flow characteristics are presented for streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia. The provinces are separated into five regions: (1) Valley and Ridge, (2) Blue Ridge, (3) Piedmont/Blue Ridge transition, (4) Piedmont northern, and (5) Piedmont southern. Different flow statistics, which represent streamflows predominantly comprised of base flow, were determined for 217 continuous-record streamflow-gaging stations from historical mean daily discharge and for 192 partial-record streamflow-gaging stations by means of correlation of discharge measurements. Variability of base flow is represented by a duration ratio developed during this investigation. Effective recharge rates were also calculated.

Median values for the different flow statistics range from 0.05 cubic foot per second per square mile for the 90-percent discharge on the streamflow-duration curve to 0.61 cubic foot per second per square mile for mean base flow. An excellent estimator of mean base flow for the Piedmont/Blue Ridge transition region and Piedmont southern region is the 50-percent discharge on the streamflow-duration curve, but it tends to underestimate mean base flow for the remaining regions. The base-flow variability index ranges from 0.07 to 2.27, with a median value of 0.55. Effective recharge rates range from 0.07 to 33.07 inches per year, with a median value of 8.32 inches per year.

Differences in the base-flow characteristics exist between regions. The median discharges for the Valley and Ridge, the Blue Ridge, and the Piedmont/Blue Ridge transition regions are higher than those for the Piedmont regions. Results from statistical analysis indicate that the regions can be ranked in terms of base-flow characteristics from highest to lowest as follows: (1) Piedmont/Blue Ridge transition, (2) Valley and Ridge and Blue Ridge, (3) Piedmont southern, and (4) Piedmont northern. The flow statistics are consistently higher and the values for base-flow variability are lower for basins within the Piedmont/Blue Ridge transition region relative to those from the other regions, whereas the basins within the Piedmont northern region show the opposite pattern.

The group rankings of the base-flow characteristics were used to designate the potential surface-water yield for the regions. In addition, an approach developed for this investigation assigns a rank for potential surface-water yield to a basin according to the quartiles in which the

values for the base-flow characteristics are located. Both procedures indicate that the Valley and Ridge, the Blue Ridge, and the Piedmont/ Blue Ridge transition regions have moderate-to-high potential surface-water yield and the Piedmont regions have low-to-moderate potential surface-water yield.

In order to indicate potential ground-water yield from base-flow characteristics, aquifer properties for 51 streamflow-gaging stations with continuous record of streamflow data were determined by methods that use streamflow records and basin characteristics. Areal diffusivity ranges from 17,100 to 88,400 feet squared per day, with a median value of 38,400 feet squared per day. Areal transmissivity ranges from 63 to 830 feet squared per day, with a median value of 270 feet squared per day. Storage coefficients, which were estimated by dividing areal transmissivity by areal diffusivity, range from approximately 0.001 to 0.019 (dimensionless), with a median value of 0.007.

The median value for areal diffusivity decreases as potential surface-water yield of the basins increases. The ranking of areal diffusivity does not correspond with the ranking of potential surface-water yield for either the regions or the basins. Areal transmissivity generally increases as storage coefficient increases; however, basins with low potential surface-water yield generally have high values of areal transmissivity associated with low values of storage coefficient over a narrow range relative to those from basins designated as having moderate-to-high potential surface-water yield. Although the basins with high potential surface-water yield tend to have comparatively lower values for areal transmissivity, storage coefficients generally are large when compared to those from basins with similar values of areal transmissivity but different potential surface-water yield.

Aquifer properties were grouped by potential surface-water yield and were related to hydrogeologic units categorized by large, medium, and small well yields for the Valley and Ridge Physiographic Province and for the Blue Ridge and the Piedmont Physiographic Provinces. Generally, no trend is evident between areal diffusivity and the hydrogeologic units. Some of the high values of areal diffusivity are associated with basins predominantly underlain by hydrogeologic units with small well yields, especially basins with a low potential surface-water yield. Areal transmissivity and storage coefficient tend to decrease, which is the expected trend, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Valley and Ridge Physiographic Province. A similar trend is indicated for the hydrogeologic unit with medium well yields in the Blue Ridge and the Piedmont Physiographic Provinces. Areal transmissivity and storage coefficient tend to increase, which is not the expected trend, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Blue Ridge and the Piedmont Physiographic Provinces. The base-flow characteristics of a basin may provide a relative indication of the potential ground-water yield; but other factors need to be considered, such as geologic structure, lithology, precipitation, relief, and degree of hydraulic interconnection between the regolith and bedrock.

INTRODUCTION

Growth within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia has focussed concern about allocation of surface-water flow and increased demands on the ground-water resources. Hydrogeologic systems within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia are diverse and complex. Knowledge of these flow systems provides information needed to effectively manage the water resources within the study area. Base-flow characteristics of streams in these provinces were used to evaluate surface-water and ground-water flow systems. This investigation is part of the Appalachian Valley and Piedmont Regional Aquifer-System Analysis (APRASA) study, which is one of several regional investigations conducted by the U.S. Geological Survey (USGS) to assess the Nation's principal aquifer systems (Sun, 1986). The APRASA study area encompasses the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of the

Appalachian Highlands in the Eastern United States (Swain and others, 1991).

Purpose and Scope

The purpose of this report is to (1) describe the base-flow characteristics of streams within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia, (2) identify the regional differences in these flow characteristics, and (3) describe, if possible, the potential surface-water and ground-water yields of basins on the basis of the base-flow characteristics. Base-flow characteristics of streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia were used to evaluate the surface-water and ground-water-flow systems. The provinces were separated into five regions using the method described by Hayes (1991). Different flow statistics, which represent streamflows predominantly comprised of base flow, were determined for continuous-record streamflow-gaging stations from historical mean daily discharge and for partial-record streamflow-gaging stations by correlation of discharge measurements. Mean base flow and effective recharge values determined by hydrograph separation are discussed. Variability of base flow is represented by a duration ratio developed during this investigation. Regional differences in base-flow characteristics are assessed. Regions are grouped and ranked based on base-flow characteristics as an indicator of potential surface-water yield. Aquifer properties and hydrogeologic units classified on the basis of well yield are compared to potential surface-water yield to determine potential ground-water yield. Data from published reports and from streamflow records maintained by the USGS and the Virginia Department of Environmental Quality, Water Division, were used for these evaluations.

Description of Study Area

The Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces encompass approximately 29,900 mi^2 in the central part of Virginia (fig. 1). The study area is bordered by the Appalachian Plateaus Physiographic Province on the west and by the Coastal Plain Physiographic Province on the east. The entire study area is underlain by fractured rock aquifers locally covered by regolith consisting of soil, alluvium, colluvium, and residuum (commonly referred to as saprolite). Thickness of the regolith ranges from 0 to more than 150 ft throughout the study area (Swain and others, 1991, p. 12). A generalized lithologic map of the study area is shown in figure 2. In addition, the study area is divided (fig. 3) in terms of geologic province into the central and

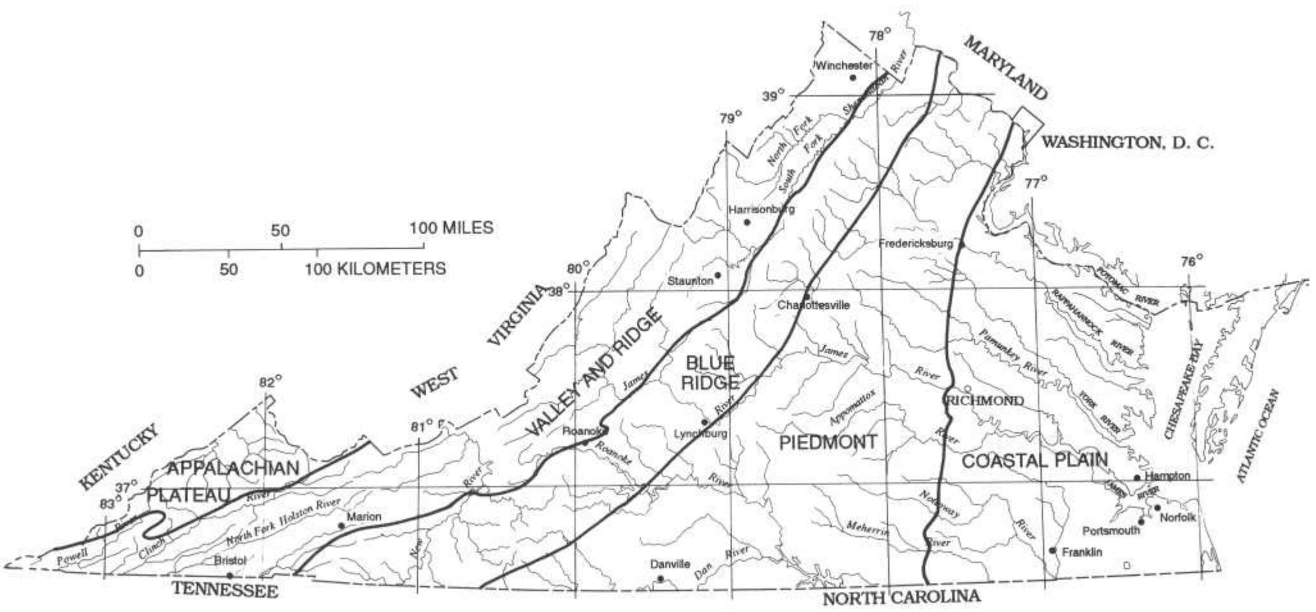


Figure 1. Physiographic provinces of Virginia. (Modified from Fenneman, 1938, pl. ii.)

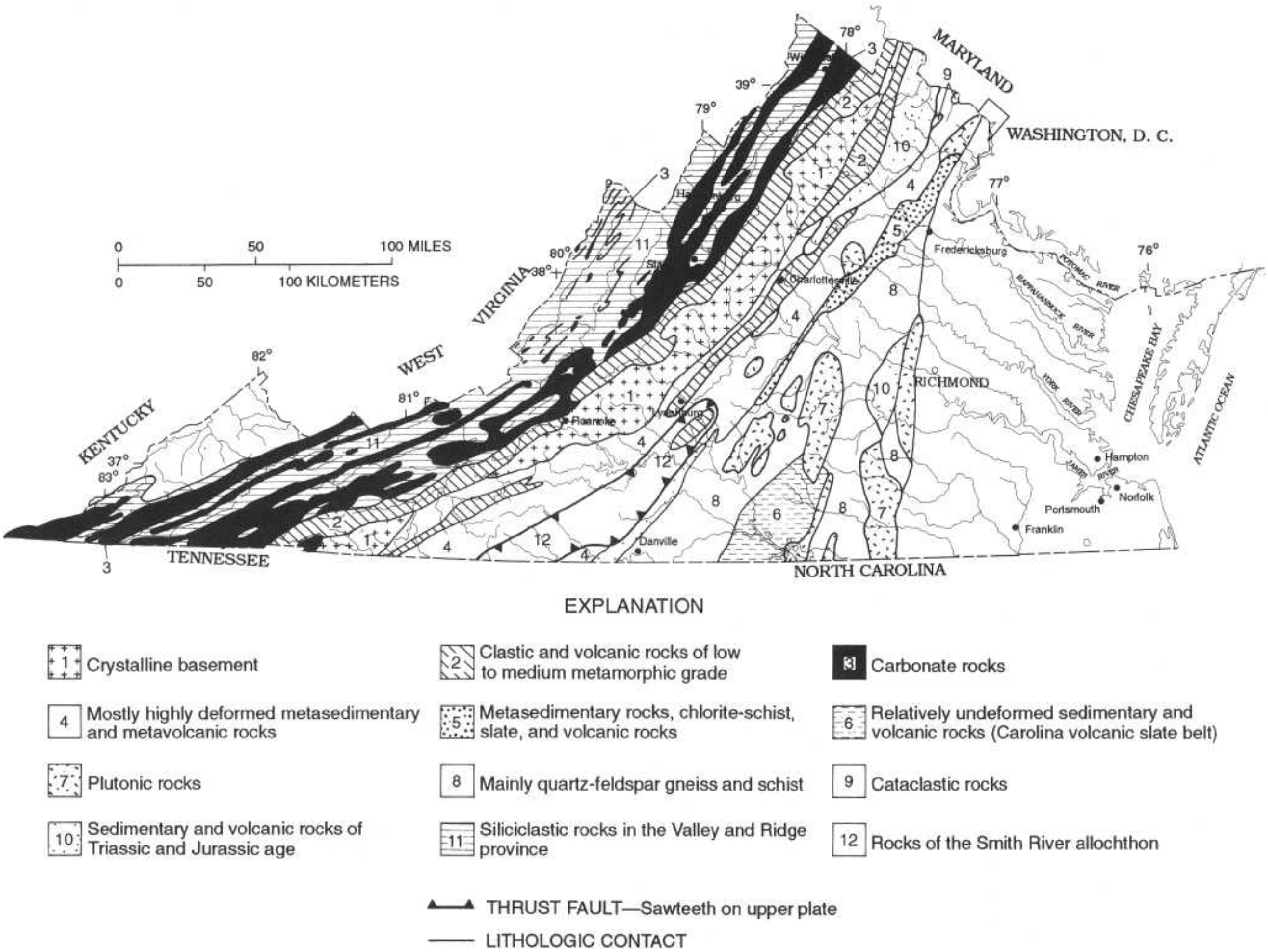
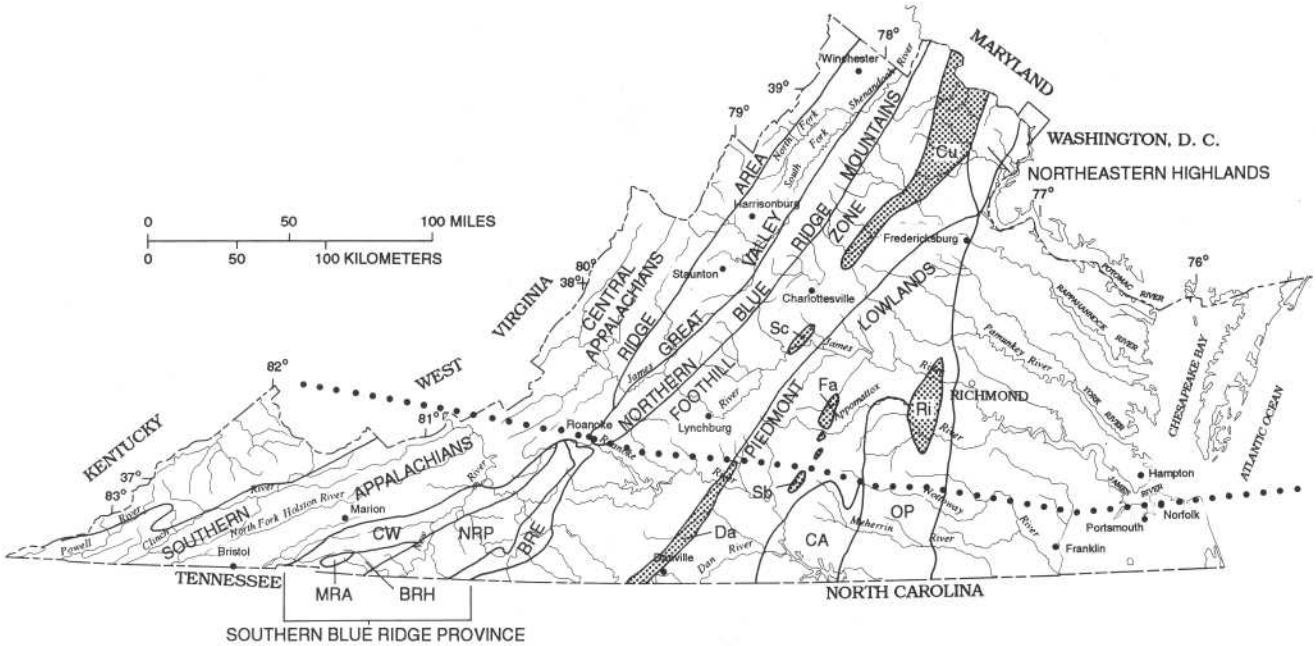


Figure 2. Generalized lithologic map of the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia. (Modified from Hack, 1982, fig. 2; Pavlides, 1981, fig. 9; Milici and others, 1963.)

southern sections of the Appalachians in the vicinity of Roanoke (Weaver, 1970, p. 125; Rast, 1989, p. 326).

The Valley and Ridge Physiographic Province encompasses approximately 10,600 mi^2 along the western part of the study area and consists of a belt of northeast/southwest trending ridges and valleys formed by the differential erosion of a thick sequence of folded and faulted Paleozoic sedimentary rocks (Pettijohn, 1970, p. 1). Elevations range from about 380 ft above sea level where the Shenandoah River flows out of Virginia into Maryland to 4,604 ft above sea level in southwestern Virginia (Butts, 1940, p. 14). North of Roanoke, the province is part of the central Appalachians and is separated into two subdivisions (fig. 3): (1) a southeastern valley area (commonly referred to as the Great Valley) underlain by Cambrian-age to Ordovician-age carbonate rocks and shales characterized by broad valleys with interspersed ridges or hills; and (2) a northwestern ridge area underlain by Silurian-age to Pennsylvanian-age sandstones and shales characterized by high ridges with interspersed narrow valleys (Hack, 1989, p. 463). Another feature of the province north of Roanoke is the presence of a thick mantle of residuum, talus, and alluvial deposits that overlie the Cambrian carbonate rocks on the eastern slope of the valley at the foot of the Blue Ridge (King, 1950, p. 54; Leonard, 1962; Hack, 1965, p. 48; Hack, 1989, p. 464). This belt of residuum termed the "Western Toe" of the Blue Ridge can exceed 600 ft in thickness (T.M. Gathright, II, Virginia Division of Mineral Resources, oral commun., 1994). South of Roanoke, the province is part of the southern Appalachians (fig. 3) and is characterized by



EXPLANATION

SUBDIVISIONS OF SOUTHERN BLUE RIDGE PROVINCE

- BRE Blue Ridge Escarpment
- BRH Blue Ridge Highlands
- CW Chilhowee-Walden Creek belt
- MRA Mount Rogers area
- NRP New River plateau

SUBDIVISIONS OF PIEDMONT LOWLANDS

- CA Carolina slate belt
- OP Outer Piedmont

MESOZOIC BASINS (dotted areas)

- Cu Culpeper
- Sc Scottsville
- Ri Richmond
- Fa Farmville
- Sb Scottsburg
- Da Danville

• • BOUNDARY BETWEEN CENTRAL AND SOUTHERN APPALACHIANS

—— SUBDIVISION BOUNDARY

Figure 3. Subdivisions within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia. (Modified from Hack, 1982, fig. 1; Rast, 1989, fig.3.)

ridges and narrow valleys, and the predominant style of deformation within the province changes from folding to thrust faulting (Hack, 1989, p. 463).

The Blue Ridge Physiographic Province encompasses approximately 3,000 mi^2 along a narrow northeast-trending belt between the Valley and Ridge and the Piedmont Physiographic Provinces and consists of a chain of mountains and highlands underlain by metamorphosed Proterozoic and Paleozoic rocks (Reed, 1970, p. 195). Elevations range from about 220 ft above sea level along the Potomac River at the State line to 5,729 ft above sea level on Mount Rogers. Generally, soils are thin and weathering profiles are shallow in the Blue Ridge Physiographic Province (Meyer and others, 1965). Hack (1982, p. 26) separated the province into two sections because the origins of the topography differ. The section north of the Roanoke River, the Northern Blue Ridge Mountains (fig. 3), is characterized by a narrow range of high mountains underlain by Precambrian-age to Cambrian-age quartzite, phyllite, metabasalt, and granodiorite that form the northwest limb of an anticlinorium. The section south of the Roanoke River, the Southern Blue Ridge Province, is much broader and was separated by Hack (1982, p. 28) into five subdivisions based on topography (fig. 3): (1) the Chilhowee-Walden Creek belt underlain by Cambrian-age quartzites and faulted carbonate rocks and shale that form long, steep ridges separated by parallel valleys along the northwest margin; (2) the Mount Rogers area underlain by Precambrian volcanic and metasedimentary rocks that form a few high ridges just north of the North Carolina/Virginia border; (3) the Blue Ridge Highlands underlain by massive Precambrian-age gneisses and amphibolites that form high mountains cut by deep valleys and basins; (4) the New River plateau, which encompasses the headwaters of the New River in North Carolina, underlain by thinly layered schist and gneiss that form a broad plateau with a few low mountains; and (5) the Blue Ridge escarpment underlain by finely laminated gneiss that form a narrow strip of land that drains southeastward to the Piedmont Physiographic Province.

The Piedmont Physiographic Province encompasses approximately 16,300 mi^2 along the eastern part of the study area and consists of a gently rolling plain underlain by polydeformed and metamorphosed Proterozoic and Paleozoic rocks (Fisher, 1970, p. 295). A thick mantle of soil and weathered rock that overlies the fractured crystalline bedrock is a characteristic feature of the province (Meyer and others, 1965; Conley, 1985, p. 1; Swain and others, 1991, p. 12). Generally, regolith developed on the crystalline rocks is thick under the hilltops and thin to absent in the stream valleys (Richardson, 1982, p. 6; Pavich and others, 1989, p. 43). Elevations range from about 200 ft above sea level along the eastern border to 1,000 ft above sea level along the western border of the province. Downfaulted Mesozoic sedimentary basins, which encompass approximately 1,340 mi^2, are located within the Piedmont Physiographic Province. These basins are underlain by shale, mudstone, sandstone, and basalt and are characterized by generally lower relief than the surrounding Piedmont (Hack, 1989, p. 461). Thin soils and shallow weathering profiles are characteristic features of the rocks in the Mesozoic Basins (Conley, 1985, p. 2; Froelich, 1985). Hack (1982, p. 3) noted that the Piedmont Physiographic Province of Virginia consists of the Foothill zone on the west, the Piedmont Lowlands on the east, and the Northeastern Highlands on the north (fig 3.). The Foothill zone also encompasses the southeastern part of the Blue Ridge Physiographic Province. The part of the Foothill zone north of the Roanoke River is underlain by resistant volcanic and metamorphic rocks that form chains of isolated hills and ridges. The part of the Foothill zone south of the Roanoke River is underlain by resistant rocks of the Smith River allochthon that form an upland (Hack, 1982, p. 24). The Piedmont Lowlands are underlain by feldspathic gneiss and schist intruded by granitic plutons with lesser amounts of metasedimentary and metavolcanic rocks that form low ridges or hills and ravines.

Climate

The climate in Virginia is moderate, with large variations in temperature and moderate variations in precipitation. Average annual temperatures range from 51°F in the Valley and Ridge and the Blue Ridge Physiographic Provinces to 57°F in the Piedmont Physiographic Province, with extremes ranging from −30 to above 100°F. Yearly precipitation is characterized by plentiful rain and snow derived from coastal cyclones and thunderstorms that move into the State from the Gulf of Mexico, the Caribbean Sea, and the Atlantic Ocean (Nuckels and Prugh, 1991, p. 543–544). Precipitation varies with location and elevation but averages 42 in/yr (fig. 4). In the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces, average annual precipitation ranges from 36 to 50 in/yr, 38 to 48 in/yr, and 40 to 46 in/yr, respectively. Rain shadows are present in both the northern and southern areas of the Valley and Ridge

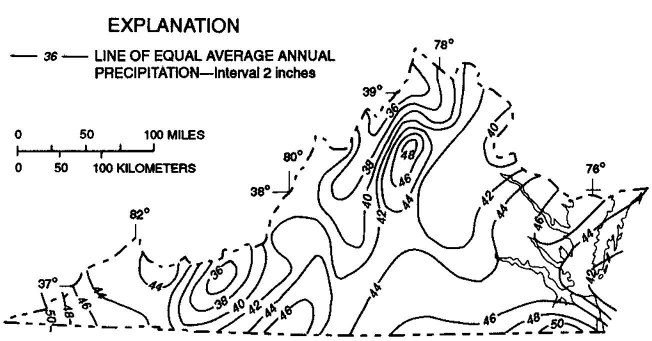


Figure 4. Average annual precipitation in Virginia. (Modified from Hayes, 1991, fig. 2.)

Methods of Study

Streamflow data for 217 continuous-record streamflow-gaging stations were used to estimate base-flow characteristics. Flow-duration statistics commonly are used in the evaluation of base-flow characteristics and are derived from a flow-duration curve, which is a cumulative frequency curve that shows the percentage of time a specified discharge is equalled or exceeded during a given period of record (Searcy, 1959). In this report, Q_x is the symbol that designates the discharge that is equalled or exceeded x-percent of the time. Values for the discharge equalled or exceeded 50 percent of the time or median discharge (Q_{50}), the discharge equalled or exceeded

90 percent of the time (Q_{90}), and the discharge equalled or exceeded 95 percent of the time (Q_{95}) on the flow-duration curve were derived from the Automated Data Processing System (ADAPS) data base maintained by the USGS (Dempster, 1990). Annual minimum average 7-consecutive-day low-flow discharges having 2-year and 10-year recurrence intervals ($7Q2$ and $7Q10$, respectively) were directly taken from Hayes (1991, appendix 1). Values for long-term mean base flow and effective recharge were estimated for 212 continuous-record streamflow-gaging stations by using a computerized streamflow-partitioning method developed for the APRASA study (Rutledge, 1992; 1993). The streamflow-partitioning method is a form of hydrograph separation that uses mean daily streamflow records to estimate base flow over a period of several years. The flow-duration statistics, mean base flow, and effective recharge were determined for the entire period of unregulated streamflow up to 1984 for each of the continuous-record streamflow-gaging stations, which duplicates the period considered by Hayes (1991).

In addition to the continuous-record streamflow-gaging stations, base-flow characteristics were estimated for 192 partial-record streamflow-gaging stations. The values for Q_{50}, Q_{90}, and Q_{95} were estimated by correlating streamflow measurements made at partial-record stations during recessional periods through a visually fitted relation line to concurrent mean daily discharge values at long-term continuous-record streamflow-gaging stations, which commonly are referred to as index stations. An example of this method is shown in figure 5, where the partial-record station is Goose Creek at Oatlands and the index station is Goose Creek at Leesburg. These base-flow characteristics were estimated by means of correlations developed by Hayes (1991), and the reader may consult Hayes (1991, p. 9–10) for further explanation. The values for $7Q2$ and $7Q10$ are from Hayes (1991, appendix 2). The streamflow-partitioning method used to compute mean base flow and effective

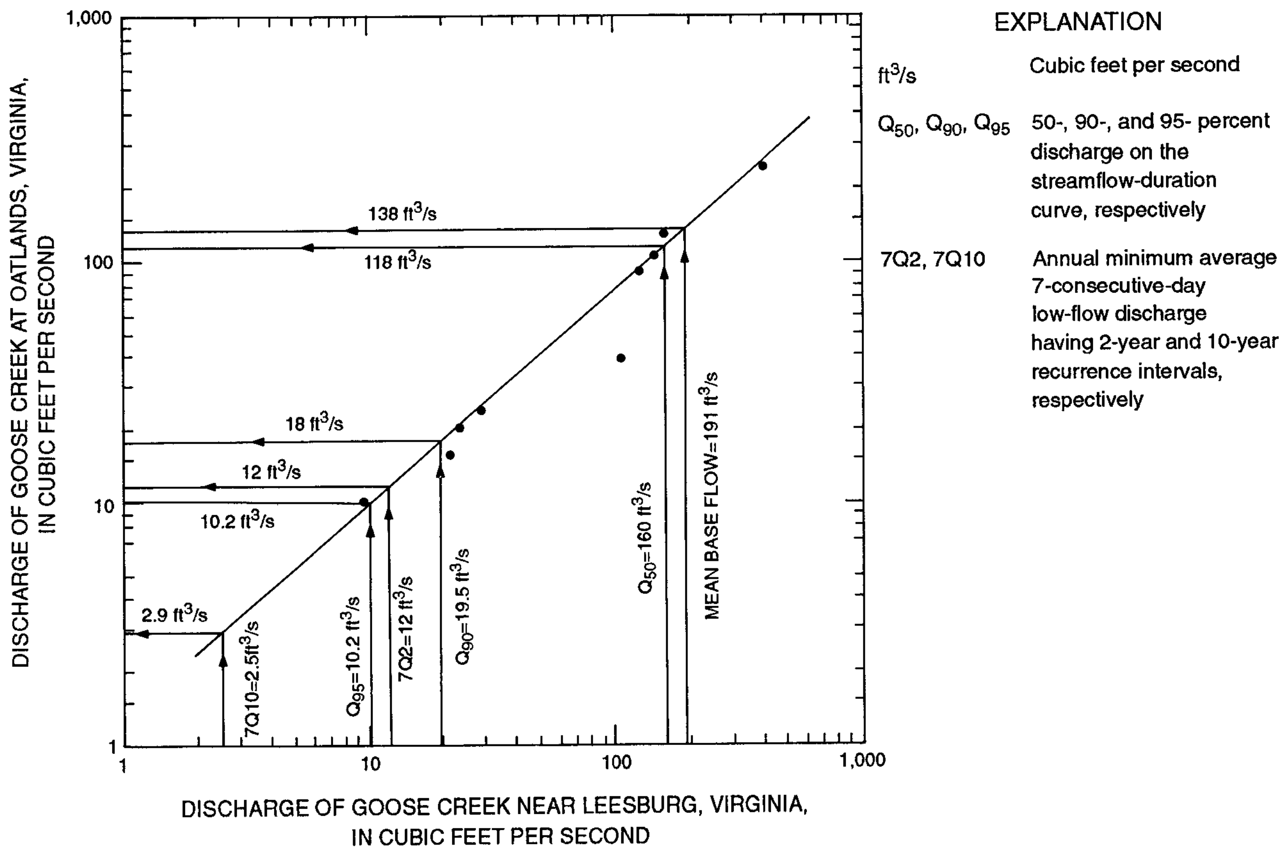


Figure 5. Relation of base flow of Goose Creek at Oatlands to concurrent mean daily discharge of Goose Creek near Leesburg.

recharge could not be applied directly to the partial-record stations because this method requires a continuous record of mean daily streamflow data. Therefore, values for mean base flow and effective recharge at 171 partial-record stations were estimated by use of the same correlations developed by Hayes (1991). The values for Q_{50} (mean base flow) and effective recharge were not estimated for some of the partial-record stations because these values required extrapolation of the relation lines established by Hayes (1991) beyond one log cycle, which was considered to be excessive. This criterion was established to improve the accuracy of the correlations for the higher flow statistics, which were not considered by Hayes (1991).

In addition to the flow characteristics previously mentioned, the $\log_{10}$ of the ratio of Q_{50} to Q_{90} was used as an index to represent the variability of base flow. This base-flow variability index is comparable to Lane's variability index (Searcy, 1959, p. 31–32), which is an index of streamflow variability from the Q_5 to Q_{95} on the flow-duration curve. The base-flow variability index, however, follows the assumption that the selected flow-duration discharges represent streamflows predominantly comprised of base flow or ground-water discharge. Arihood and Glatfelter (1991) developed a similar flow-duration ratio by dividing the Q_{20} by Q_{90}. Hely and Olmsted (1963) used the ratio of Q_{90} to average discharge as an indicator of the effects of terrestrial characteristics on base flow.

Nonparametric statistical techniques were used to perform hypothesis tests, which determine if differences in the data are by chance variability or are true statistical differences. Nonparametric techniques are less sensitive to outliers, and assumptions of equal variances or normality are not required. The hypothesis test consists of a null hypothesis which assumes that no real difference exists in the data. In this report, the alpha value (level of significance) used is 0.05, which represents the maximum probability of rejecting the null hypothesis when it is actually true at the 95-percent level of confidence. The probability for each test (p-value) represents the significance level attained by the test. In order to reject the null hypothesis, the p-value must be less than or equal to the alpha value (Hamilton and others, 1991, p. B28). Three hypothesis tests were used—Mann-Whitney, Kruskal-Wallis, and Tukey's multiple comparison. The Mann-Whitney test is a nonparametric rank-sum test that compares two groups. The Kruskal-Wallis test is a nonparametric one-way analysis of variance test that uses rank-transformed data to compare two or more groups. The Tukey's multiple comparison test (Tukey's MCT) is another nonparametric analysis of variance test performed on rank-transformed data to determine which group or groups are significantly different.

In order to facilitate a spatial analysis of the data, drainage-basin boundaries for the streamflow-gaging stations were digitized using a geographic information system by modifying the hydrologic unit coverage distributed by the Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation (DCR–DSWC). The hydrologic unit coverage is based on the USGS hydrologic unit map of Virginia at a scale of 1:500,000 (U.S. Geological Survey, 1974); however, the DCR–DSWC and U.S. Department of Agriculture, Soil Conservation Service delineated these units at a scale of 1:24,000. These hydrologic unit delineations were then digitized at the Information Support Systems Laboratory of the Department of Agricultural Engineering at Virginia Polytechnic Institute and State University.

BASE-FLOW CHARACTERISTICS

Knowledge of base-flow characteristics of streams provides insight into hydrogeologic flow systems of the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces. In order to fully define these characteristics, different flow statistics were selected to represent streamflows predominantly comprised of base flow. Mean base flow indicates the long-term average contribution of ground water to streams and is commonly referred to as either ground-water discharge or ground-water runoff. The Q_{50} is commonly selected as an approximation of mean base flow. Effective recharge is equivalent to mean base flow (by means of unit conversion) because ground-water discharge over a long period of time approximately equals ground-water recharge (Richardson, 1982, p. 12). Effective recharge is defined as the amount of precipitation that infiltrates, but is not removed by evapotranspiration, and eventually discharges to streams (U.S. Environmental Protection Agency, 1987, p. 62). Values of Q_{90}, Q_{95}, $7Q2$, and $7Q10$ represent base flow after periods of sparse recharge and are collectively termed "low-flow statistics" in this report. Although the low-flow statistics are computed differently, these statistics are indicators of base-flow characteristics for basins during periods of drought.

The rationale for using a range of flow statistics to determine base-flow characteristics is based on values reported in the literature. Flow-duration statistics commonly are used to evaluate base flow. The Q_{50} is a flow-duration statistic commonly used to estimate mean base flow (Cushing and others, 1973). The Q_{90} is a relatively stable flow-duration statistic used as a conservative estimator of mean base flow (Hely and Olmsted, 1963; Wyrick, 1968; Lichtler and Wait, 1974). Wyrick (1968) used a discharge between Q_{90} and Q_{95} as an estimate of ground-water discharge (base flow) and as an indication of water-yielding properties of rocks in the Appalachian region. Trainer and Watkins (1975) used hydrograph separation to determine mean base-flow discharges in the upper Potomac River Basin, which corresponded to discharge values on the flow-duration curve that ranged from Q_{39} to Q_{61} and averaged Q_{52}. Laczniak and Zenone (1985) used a similar method to determine that mean annual base flow in the Culpeper Basin is represented by Q_{68}.

Another important aspect of base flow is the variability of discharge exhibited by the streams in the study area. The base-flow variability index represents the average slope of the flow-duration curve from Q_{50} to Q_{90}. Streams with low variability, which indicates sustained base-flow discharges over time in response to increased ground-water storage, will have values for the base-flow variability index that are closer to zero than those for streams with higher variability.

Regions

Many basin and climatological characteristics can affect base flow, such as geology, soils, drainage area, relief, streambed elevations, and distribution of precipitation. Hayes (1991) divided the State into eight regions by grouping the residuals from regression analyses approximately along physiographic boundaries. The variability of basin and climatological characteristics is limited by the design of these regions. Hayes (1991) subdivided the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces into five regions, which were used for this investigation (pl. 1) and for which the base-flow characteristics are described below. The five regions are (1) Valley and Ridge, (2) Blue Ridge, (3) Piedmont/Blue Ridge transition, (4) Piedmont northern, and (5) Piedmont southern. Summary statistics for base-flow characteristics by region are in figure 6 and in table 1. The actual base-flow characteristics determined for the individual continuous-record and partial-record stations are listed in appendixes 1 and 2, respectively. The spatial distribution of each base-flow characteristic is presented on plate 1, where the shade patterns represent values less than the 25th-percentile (lower quartile), between the 25th- and 75th-percentiles (interquartile range), and greater than the 75th-percentile (upper quartile) for the entire study area.

Valley and Ridge Region

The Valley and Ridge region nearly encompasses the Valley and Ridge Physiographic Province (pl. 1). Drainage areas range from 0.61 to 3,768 mi^2, with a median area of 50.8 mi^2. Mean base flow for this region ranges from 0.01 to 1.51 $(ft^3/s)/mi^2$, with a median value of 0.72 $(ft^3/s)/mi^2$. The Q_{50} ranges from 0.00 to 1.35 $(ft^3/s)/mi^2$, with a median value of 0.56 $(ft^3/s)/mi^2$, which is slightly lower than the mean base flow. The difference between the median values suggests that mean base flow may be equivalent to a higher discharge on the flow-duration curve than the Q_{50}. Rutledge and Mesko (1996) determined that Q_{42} on the flow-duration curve is a reasonable estimator of mean base flow for streams in the Valley and Ridge Physiographic Province of the Eastern United States. The values for the low-flow statistics range from 0.00 to 0.60 $(ft^3/s)/mi^2$. The median discharges for the low-flow statistics range from 0.09 $(ft^3/s)/mi^2$ for $7Q10$ to 0.16 $(ft^3/s)/mi^2$ for Q_{90}. The base-flow variability index ranges from 0.18 to 2.27, with a median value of 0.55. Effective recharge in the Valley and Ridge region ranges from 0.07 to 20.55 in/yr, with a median value of 9.73 in/yr.

The subdivision of the central and southern Appalachians is approximately located near latitude 37°30'. The Mann-Whitney test indicates that the median values for the base-flow characteristics for basins north of latitude 37°30', except $7Q2$ and $7Q10$ (p=0.059 and 0.143, respectively), are significantly different from those south of this latitude. Median values for mean base flow, Q_{50}, Q_{90}, Q_{95}, effective recharge, and base-flow variability index (p-values range from <0.001 to 0.035) are higher in the southern section of the Valley and Ridge region than in the northern section (table 1). The median drainage area in the southern section of the Valley and Ridge region

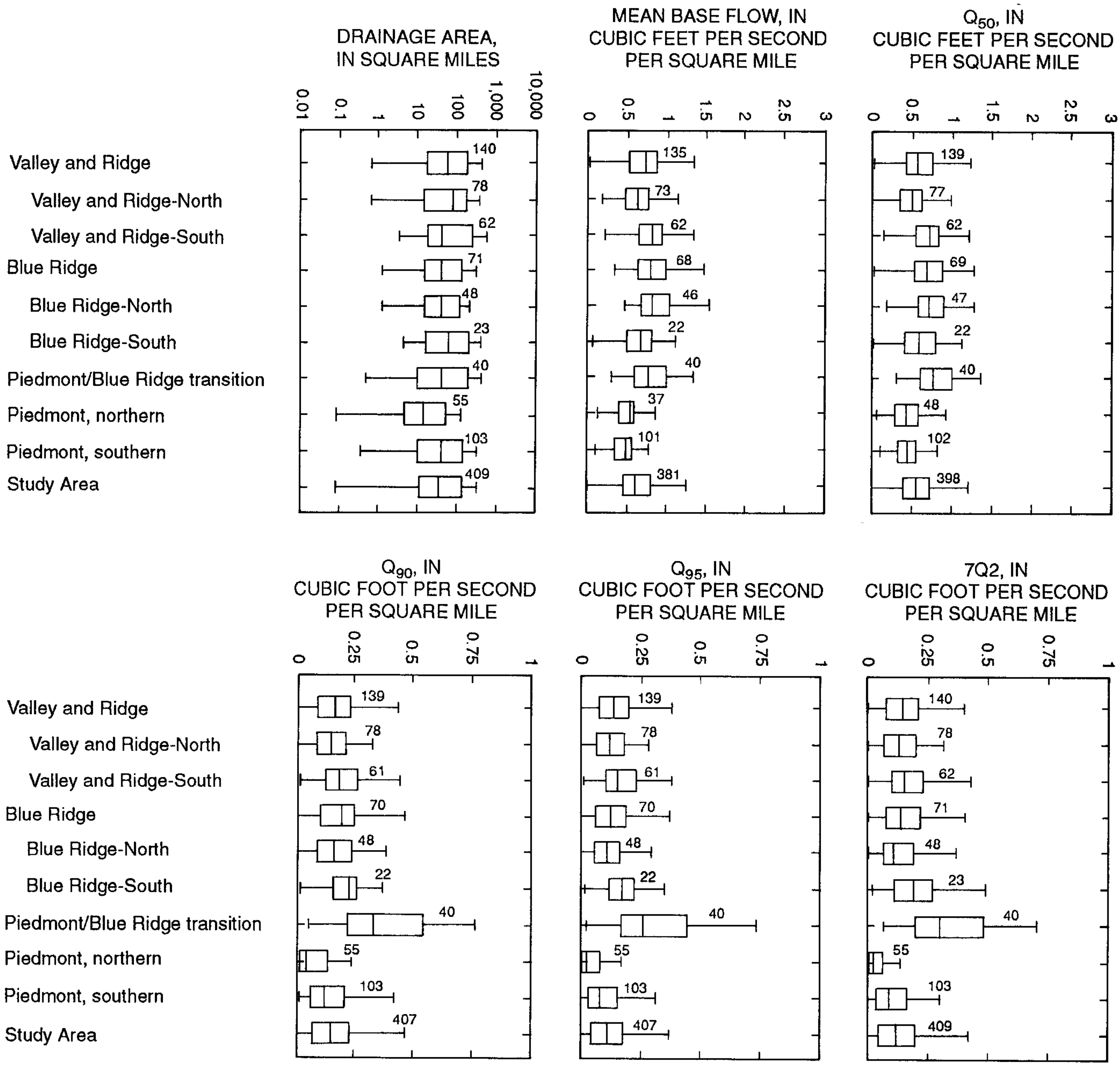
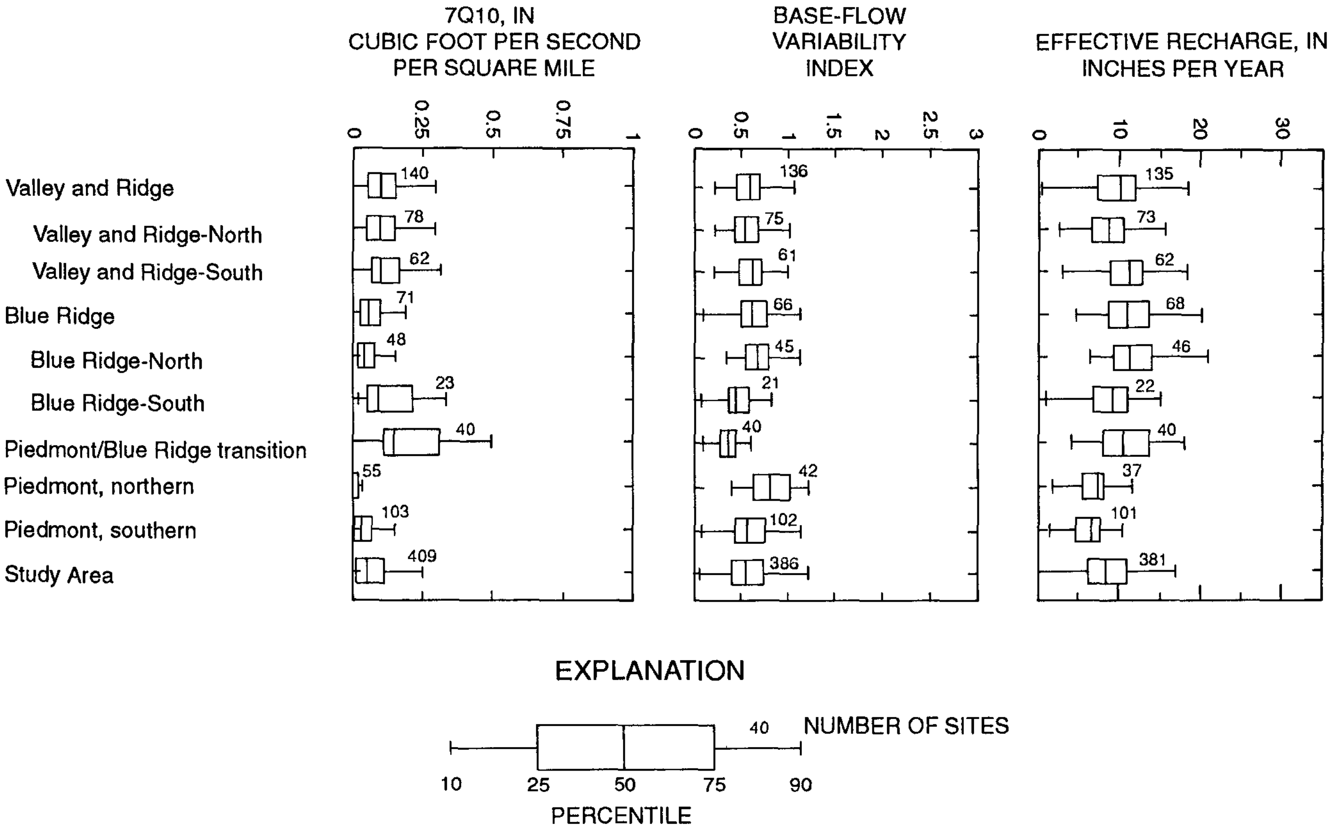


Figure 6. Summary statistics of base-flow characteristics by region.

is not significantly different from the median area in the northern section ($p = 0.461$).

The difference in base-flow characteristics between the northern and southern sections of the Valley and Ridge may be attributed to the distribution of precipitation and geology. In the northern section, the Shenandoah Valley is located in a rain shadow; where annual precipitation is the smallest recorded for a location so far south and east in the United States (Nuckels and Prugh, 1991, p. 543). Annual precipitation in the southern section generally is 10 to 14 in/yr higher than in the northern section (fig. 4). Carbonate rocks that have a high water-yielding potential, are characteristic of the southern section (fig. 2); whereas low-yielding siliciclastic rocks are characteristic of the northern section (Schneider and Friel, 1965; Cederstrom, 1972, p. 4). In addition, the differences in water-yielding potential may be related to the predominant style of deformation–faulting in the southern section and folding in the northern section. One



Q_{50}, Q_{90}, AND Q_{95}	50-, 90- AND 95-PERCENT DISCHARGE ON THE STREAMFLOW-DURATION CURVE, RESPECTIVELY
7Q2 AND 7Q10	ANNUAL MINIMUM AVERAGE 7-CONSECUTIVE-DAY LOW-FLOW DISCHARGE HAVING 2-YEAR AND 10-YEAR RECURRENCE INTERVALS, RESPECTIVELY

Figure 6.—Continued.

notable exception in the northern section is the area on the eastern margin of the Valley and Ridge just east of Staunton commonly termed the "Western Toe" of the Blue Ridge. This area is underlain by a thick sequence of unconsolidated alluvium and colluvium covering the bedrock (King, 1950; Leonard, 1962; Hack, 1965, 1989); therefore, base-flow characteristics determined for this area are not representative of consolidated rocks typically found in the Valley and Ridge region.

Blue Ridge Region

The Blue Ridge region encompasses most of the Blue Ridge Physiographic Province, except for a small section in the eastern part of the province that extends from the North Carolina/Virginia border to just north of Lynchburg (pl. 1). Drainage areas range from 1.17 to 3,259 mi^2, with a median area of 37 mi^2. Mean base flow for this region ranges from 0.02 to 2.44 $(ft^3/s)/mi^2$, with a median value of 0.79 $(ft^3/s)/mi^2$. The Q_{50} ranges from 0.01 to 2.26 $(ft^3/s)/mi^2$, with a median value of 0.67 $(ft^3/s)/mi^2$. As was the case with the Valley and Ridge region, the Q_{50} may underestimate mean base flow. Rutledge and Mesko (1996) determined that Q_{46} can serve as a surrogate for mean base flow in the Blue Ridge and the Piedmont Physiographic Provinces of the Eastern United States. The values for the low-flow statistics range from 0.00 to 0.52 $(ft^3/s)/mi^2$. The median discharges for the low-flow statistics range from 0.04 $(ft^3/s)/mi^2$ for 7Q10 to 0.19 $(ft^3/s)/mi^2$ for Q_{90}. The base-flow variability index ranges from 0.07 to 1.19, with a median value of 0.58. Effective recharge in this region ranges from 0.29 to 33.07 in/yr, with a median value of 10.71 in/yr.

Table 1. Summary statistics for base-flow characteristics by region

[mi^2, square mile; $(ft^3/s)/mi^2$, cubic foot per second per square mile; Q_{50} and Q_{90}, the 50- and 90-percent discharge on the streamflow-duration curve, respectively]

	Number of sites	Median	25th percentile	75th percentile	Minimum	Maximum
Drainage Area (mi^2)						
Valley and Ridge	140	50.8	15.9	163	0.61	3,768
North	78	71.4	12.7	157	.61	2,075
South	62	37.9	17.4	222	2.99	3,768
Blue Ridge	71	37.0	14.2	123	1.17	3,259
North	48	35.8	13.8	109	1.17	3,259
South	23	56.8	15.1	188	4.02	2,202
Piedmont/Blue Ridge transition	40	40.0	9.61	185	.46	2,415
Piedmont, northern	55	13.8	4.51	50.5	.08	1,596
Piedmont, southern	103	39.7	9.94	135	.33	7,320
Study area	409	36.3	11.5	137	.08	7,320
Mean Base Flow [$(ft^3/s)/mi^2$]						
Valley and Ridge	135	.72	.51	.86	.01	1.51
North	73	.62	.47	.75	.01	1.51
South	62	.81	.64	.93	.05	1.34
Blue Ridge	68	.79	.62	.98	.02	2.44
North	46	.82	.67	1.02	.47	2.44
South	22	.67	.50	.81	.02	1.47
Piedmont/Blue Ridge transition	40	.77	.59	1.00	.30	1.34
Piedmont, northern	37	.54	.41	.59	.07	.86
Piedmont, southern	101	.49	.35	.56	.11	.78
Study area	381	.61	.46	.81	.01	2.44
Q_{50} [$(ft^3/s)/mi^2$]						
Valley and Ridge	139	.56	.41	.74	.00	1.35
North	77	.49	.34	.61	.00	1.35
South	62	.71	.54	.82	.03	1.21
Blue Ridge	69	.67	.52	.88	.01	2.26
North	47	.70	.56	.88	.18	2.26
South	22	.59	.41	.80	.01	1.12
Piedmont/Blue Ridge transition	40	.76	.60	1.00	.30	1.36
Piedmont, northern	48	.43	.29	.58	.06	.93
Piedmont, southern	102	.44	.33	.56	.10	.83
Study area	398	.55	.39	.72	.00	2.26
Q_{90} [$(ft^3/s)/mi^2$]						
Valley and Ridge	139	.16	.09	.23	.00	.60
North	78	.14	.08	.21	.00	.60
South	61	.18	.12	.26	.01	.49
Blue Ridge	70	.19	.10	.25	.00	.52
North	48	.16	.09	.24	.00	.51
South	22	.22	.16	.26	.01	.52
Piedmont/Blue Ridge transition	40	.33	.22	.54	.05	.76
Piedmont, northern	55	.04	.02	.14	.00	.24
Piedmont, southern	103	.12	.06	.21	.01	.42
Study area	407	.15	.07	.23	.00	.76

Table 1. Summary statistics for base-flow characteristics by region—Continued

[$(ft^3/s)/mi^2$, cubic foot per second per square mile; Q_{95}, the 95-percent discharge on the streamflow-duration curve; $7Q2$ and $7Q10$, annual minimum average 7-consecutive-day low-flow discharge having 2-year and 10-year recurrence intervals, respectively]

	Number of sites	Median	25th percentile	75th percentile	Minimum	Maximum
			Q_{95} [$(ft^3/s)/mi^2$]			
Valley and Ridge	139	0.13	0.06	0.19	0.00	0.53
North	78	.11	.06	.17	.00	.53
South	61	.15	.10	.22	.01	.44
Blue Ridge	70	.12	.06	.18	.00	.43
North	48	.10	.05	.16	.00	.37
South	22	.17	.11	.22	.01	.43
Piedmont/Blue Ridge transition	40	.26	.16	.44	.02	.74
Piedmont, northern	55	.02	.01	.08	.00	.17
Piedmont, southern	103	.08	.03	.15	.00	.36
Study area	407	.11	.04	.17	.00	.74
			$7Q2$ [$(ft^3/s)/mi^2$]			
Valley and Ridge	140	.14	.07	.20	.00	.58
North	78	.13	.06	.19	.00	.58
South	62	.15	.09	.23	.00	.45
Blue Ridge	71	.13	.07	.22	.00	.49
North	48	.11	.06	.19	.00	.40
South	23	.19	.11	.27	.02	.49
Piedmont/Blue Ridge transition	40	.30	.20	.48	.07	.71
Piedmont, northern	55	.03	.01	.06	.00	.21
Piedmont, southern	103	.09	.04	.16	.00	.36
Study area	409	.12	.05	.20	.00	.71
			$7Q10$ [$(ft^3/s)/mi^2$]			
Valley and Ridge	140	.09	.04	.14	.00	.39
North	78	.08	.03	.14	.00	.39
South	62	.09	.05	.16	.00	.37
Blue Ridge	71	.04	.01	.09	.00	.33
North	48	.03	.01	.07	.00	.30
South	23	.08	.04	.21	.01	.33
Piedmont/Blue Ridge transition	40	.14	.11	.31	.00	.50
Piedmont, northern	55	.00	.00	.02	.00	.09
Piedmont, southern	103	.03	.01	.06	.00	.25
Study area	409	.05	.01	.11	.00	.50
			Base-Flow Variability Index			
Valley and Ridge	136	.55	.41	.66	.18	2.27
North	75	.50	.39	.64	.18	2.27
South	61	.59	.45	.68	.18	1.17
Blue Ridge	66	.58	.47	.74	.07	1.19
North	45	.65	.53	.76	.33	1.19
South	21	.42	.35	.57	.07	.90
Piedmont/Blue Ridge transition	40	.35	.27	.43	.09	1.29
Piedmont, northern	42	.79	.62	1.01	.39	2.10
Piedmont, southern	102	.55	.43	.74	.09	1.33
Study area	386	.55	.41	.74	.07	2.27

Table 1. Summary statistics for base-flow characteristics by region—Continued
[in/yr, inch per year]

	Number of sites	Median	25th percentile	75th percentile	Minimum	Maximum
			Effective Recharge (in/yr)			
Valley and Ridge	135	9.73	6.95	11.66	0.07	20.55
North	73	8.38	6.38	10.23	.07	20.55
South	62	10.99	8.69	12.65	.64	18.12
Blue Ridge	68	10.71	8.44	13.32	.29	33.07
North	46	11.07	9.11	13.90	6.31	33.07
South	22	9.09	6.73	10.96	.29	19.92
Piedmont/Blue Ridge transition	40	10.40	7.97	13.61	4.10	18.13
Piedmont, northern	37	7.35	5.47	8.01	.99	11.68
Piedmont, southern	101	6.61	4.76	7.65	1.43	10.54
Study area	381	8.32	6.22	10.93	.07	33.07

The subdivision of the Northern Blue Ridge Mountains and the Southern Blue Ridge Province is located in the vicinity of Roanoke. The Mann-Whitney test indicates that the median values for the base-flow characteristics are significantly different for the sections north and south of Roanoke (table 1). Median values for mean base flow and Q_{50} in the northern section are significantly higher than those in the southern section (p=0.003 and 0.028), whereas the opposite is true for the median values for the low-flow statistics (p-values range from <0.001 to 0.043). The median value for the base-flow variability index in the northern section is higher than in the southern section (p<0.001). The median value for effective recharge in the northern section is higher than in the southern section (p=0.003). The median drainage area in the northern section is not significantly different from the median area in the southern section (p=0.246).

The difference in base-flow characteristics in the Blue Ridge region may be the result of several factors. Generally, average annual precipitation is higher and average annual runoff is lower in the northern section than in the southern section (Prugh and Scott, 1986, p. 469). The combination of these two factors can explain the high median values for mean base flow and effective recharge in the northern section. Both sections have steep mountains with relief of more than 350 ft in a 5-mi^2 area; but a large part of the southern section, called the New River plateau (fig. 3), has moderate relief of 640 ft in a 50-mi^2 area (Hack, 1982, p. 26–35). Runoff generally increases with increasing relief, which reduces the amount of infiltration and recharge. Rutledge and Mesko (1996) observed a positive correlation between basin relief and mean recharge for the Blue Ridge Physiographic Province and suggested orographic effects on precipitation as a possible explanation for this correlation. Median values for the low-flow statistics, however, are higher and the median value for base-flow variability index is lower in the southern section than in the northern section, suggesting differences in ground-water storage. One possible explanation for these differences within the Blue Ridge region may be related to the abrupt change in the geologic structure in the vicinity of Roanoke from an anticlinorium represented by steep flexures in the north to large thrust faults or imbricate stacks in the south (Reed, 1970, p. 196; Wehr and Glover, 1985, p. 285; Hack, 1989, p. 461–463).

Piedmont/Blue Ridge Transition Region

The Piedmont/Blue Ridge transition region encompasses a part of the southwestern section of the Piedmont Physiographic Province and the small part of the Blue Ridge Physiographic Province not included in the Blue Ridge region (pl. 1). Drainage areas range from 0.46 to 2,415 mi^2, with a median area of 40 mi^2. Mean base flow for this region ranges from 0.30 to 1.34 (ft^3/s)/mi^2, with a median value of 0.77 (ft^3/s)/mi^2. The Q_{50} ranges from 0.30 to 1.36 (ft^3/s)/mi^2, with a median value of 0.76 (ft^3/s)/mi^2. The values for mean base flow and Q_{50} are virtually identical; therefore, Q_{50} is a reasonable estimator of mean base flow for this particular region. The values for the low-flow statistics range from 0.00 to 0.76 (ft^3/s)/mi^2. The median discharges for the low-flow statistics range from 0.14 (ft^3/s)/mi^2 for $7Q10$ to 0.33 (ft^3/s)/mi^2 for Q_{90}. The base-flow variability index ranges from 0.09 to 1.29, with a median value of 0.35.

Effective recharge in this region ranges from 4.10 to 18.13 in/yr, with a median value of 10.40 in/yr.

The Piedmont/Blue Ridge transition region approximately encompasses a fault-bounded, shallow, sheet-like synform of metasedimentary, metavolcanic, and plutonic-igneous rocks, referred to as the Smith River allochthon, which was emplaced over the Sauratown Mountains anticlinorium and eastern part of the Blue Ridge Province. The allochthon has been described as either the upper or lower limb of a detached recumbent nappe by Conley and Henika (1973, p. 50) and Henika (1977, p. 16). An alternative interpretation by Drake and others (1989, p. 158) suggests that the allochthon may represent a thrust stack. Both interpretations reveal the intensive deformation that rocks of the Smith River allochthon have undergone. The transition region is an upland with relief greater than the Piedmont but not as mountainous as the Blue Ridge (Hack, 1982, p. 24; Hayes, 1991, p. 23). The relation between the complex geologic history, geomorphic evolution, and base-flow characteristics of streams in the Piedmont/Blue Ridge transition region warrants future investigation.

Piedmont Regions

The Piedmont Physiographic Province is divided into two regions, northern and southern (pl. 1). Drainage areas in the Piedmont northern region range from 0.08 to 1,596 mi^2, with a median area of 13.8 mi^2. Mean base flow for this region ranges from 0.07 to 0.86 (ft^3/s)/mi^2, with a median value of 0.54 (ft^3/s)/mi^2. The Q_{50} ranges from 0.06 to 0.93 (ft^3/s)/mi^2, with a median value of 0.43 (ft^3/s)/mi^2. Similar to other regions, the Q_{50} may underestimate mean base flow and the Q_{46} may be a more appropriate flow-duration statistic to use (Rutledge and Mesko, 1996). The values for the low-flow statistics range from 0.00 to 0.24 (ft^3/s)/mi^2. The median discharges for the low-flow statistics range from 0.00 (ft^3/s)/mi^2 for $7Q10$ to 0.04 (ft^3/s)/mi^2 for Q_{90}. The base-flow variability index ranges from 0.39 to 2.10, with a median value of 0.79. Effective recharge in this region ranges from 0.99 to 11.68 in/yr, with a median value of 7.35 in/yr.

Drainage areas in the Piedmont southern region range from 0.33 to 7,320 mi^2, with a median area of 39.7 mi^2. Mean base flow for this region ranges from 0.11 to 0.78 (ft^3/s)/mi^2, with a median value of 0.49 (ft^3/s)/mi^2. The Q_{50} ranges from 0.10 to 0.83 (ft^3/s)/mi^2, with a median value of 0.44 (ft^3/s)/mi^2. As was the case with the Piedmont/Blue Ridge transition region, the difference between mean base flow and Q_{50} is extremely small; therefore, Q_{50} probably is a reasonable estimator of mean base flow for this region. The values for the low-flow statistics range from 0.00 to 0.42 (ft^3/s)/mi^2. The median discharges for the low-flow statistics range from 0.03 (ft^3/s)/mi^2 for $7Q10$ to 0.12 (ft^3/s)/mi^2 for Q_{90}. The base-flow variability index ranges from 0.09 to 1.33, with a median value of 0.55. Effective recharge in this region ranges from 1.43 to 10.54 in/yr, with a median value of 6.61 in/yr.

The Mann-Whitney test indicates that the median values for base-flow characteristics, except for mean base flow, Q_{50}, and effective recharge (p-values range from 0.065 to 0.349), are significantly different for the Piedmont northern and southern regions (table 1). Median values for the low-flow statistics in the southern region are significantly higher than those in the northern region ($p<0.001$). The median value for the base-flow variability index in the northern region is higher than the median index in the southern region ($p<0.001$). The median drainage area in the northern region is significantly smaller than the median area in the southern region ($p=0.007$).

The difference in base-flow characteristics between the Piedmont northern and southern regions may be the result of several factors. Large variations in base-flow characteristics may be the result of variability associated with small drainage basins, which are characteristic of the northern region. A large percentage of the total area in the Piedmont northern region is underlain by sedimentary, igneous, and metamorphic rocks of the early Mesozoic Culpeper Basin (fig. 3) that generally result in low base-flow characteristics (Trainer and Watkins, 1975; Laczniak and Zenone, 1985; Lynch and others, 1987; Hayes, 1991). In addition, the Piedmont northern region is somewhat urbanized in response to growth associated with proximity to the Washington, D.C., area. Another factor that can affect base-flow characteristics is relief. A large percentage of the Piedmont northern region is in the Foothill zone and Northeastern Highlands (fig. 3), where relief is low to moderate and ranges from 250 to 640 ft in a 50-mi^2 area. Only a small part of the Piedmont southern region is in the Foothill zone, whereas a large percentage of the area is in the Piedmont Lowlands (fig. 3), where relief is low and ranges from 130 to 250 ft in a 50-mi^2 area (Hack, 1982). This difference in topographic relief may significantly affect ground-water gradients to streams, runoff, recharge, and ground-water storage. Pavich and others (1989, p. 42–43) stated that regolith thickness is related to parent rock type and local topography. The two regions in the Piedmont have similar rock types and ranges of regolith thickness; however, the low relief in the southern region may allow for the development of a thick sequence of regolith over a large percentage of the entire region. Ground-water storage may be greater in the southern region than in the northern region in response to a possible increase in regolith thickness, which may explain the high median values for the low-flow statistics and the low base-flow variability index in the southern region.

Regional Differences

Differences in the base-flow characteristics exist between regions, as well as within regions. The distribution of median discharges for the regions is shown in figure 7. The median discharges for the Valley and Ridge, the Blue Ridge, and the Piedmont/Blue Ridge transition regions are higher than those for both of the Piedmont regions. The Kruskal-Wallis test indicates that significant differences exist ($p<0.001$) in median values for the base-flow characteristics of each region. Tukey's MCT was used to further investigate patterns within the base-flow characteristics among regions. A graphical representation of the results from the Tukey's MCT is shown in figure 8. For an individual base-flow characteristic, regions with identical group ranking have the same shade pattern in figure 8. In some cases, one region may be represented by two shade patterns for a particular base-flow characteristic, which indicates the region overlaps two group rankings and cannot be statistically separated from either group. The group rankings are only relative to the study area because basin and climatological characteristics are known to vary within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of the Eastern United States.

The Tukey's MCT indicates that the regions can be separated into three groups for mean base flow and Q_{50} ($p<0.001$). The Blue Ridge and the Piedmont/Blue Ridge transition regions are assigned the highest group ranking and the Piedmont regions are the lowest. The Valley and Ridge region is assigned the second highest group ranking; but the Piedmont/Blue Ridge transition region is not significantly different from either the Blue Ridge or the Valley and Ridge regions for mean base flow (fig. 8).

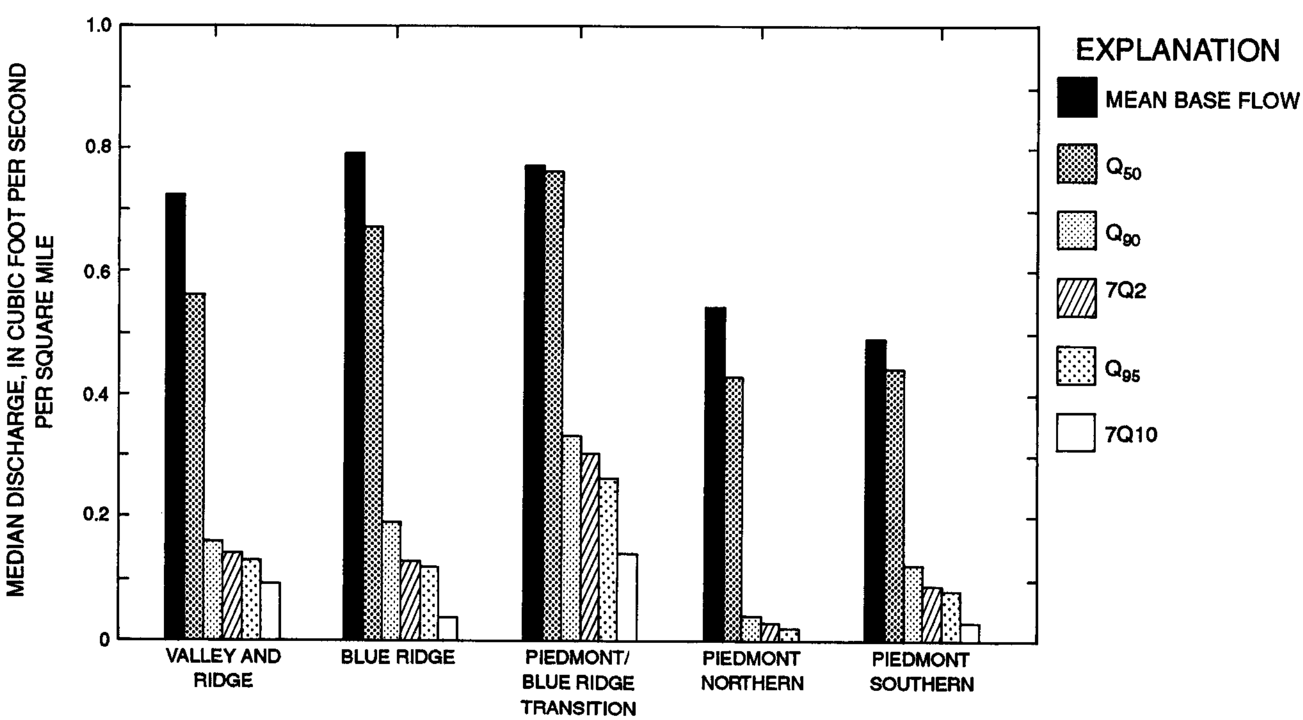


Figure 7. Distribution of median discharges for the various flow statistics by region.

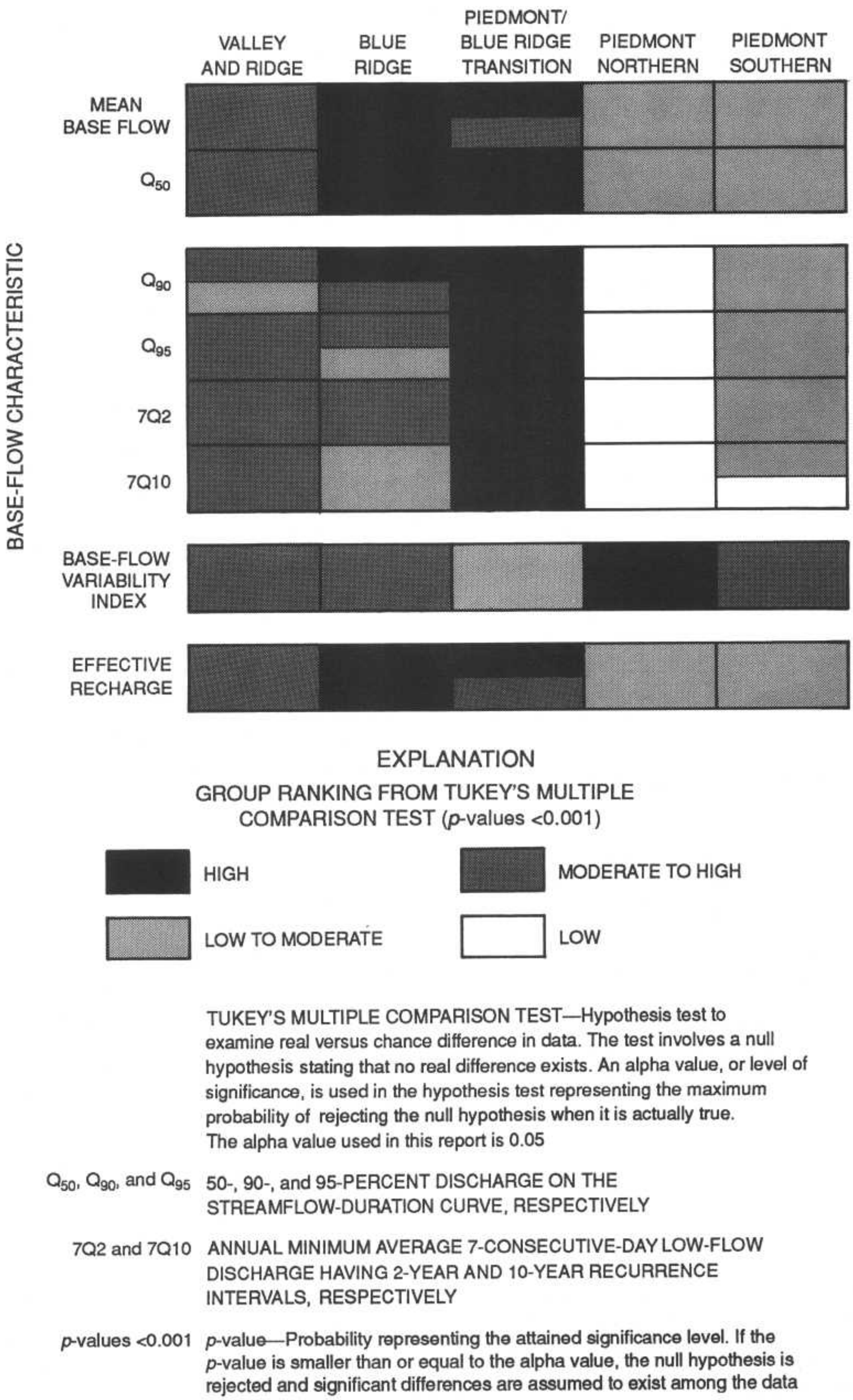


Figure 8. Group ranking from Tukey's multiple comparison test.

The Tukey's MCT indicates that the regions can be separated into four groups for the low-flow statistics ($p<0.001$). The Piedmont/Blue Ridge transition region and the Piedmont northern regions are assigned consistently the highest and lowest group rankings, respectively. The Valley and Ridge and the Blue Ridge regions are assigned generally the second highest group ranking followed by the Piedmont southern region (fig. 8).

The Tukey's MCT indicates that the regions can be separated into three groups for base-flow variability index ($p<0.001$). The Piedmont northern region is assigned the highest variability index and the Piedmont/Blue Ridge transition region is assigned the lowest variability index. The remaining regions are not significantly different with regard to the variability index and are, therefore, grouped together (fig. 8).

The Tukey's MCT indicates that the regions can be separated into three groups for effective recharge ($p<0.001$). The Blue Ridge region is assigned the highest group ranking and the Piedmont regions are the lowest. The Valley and Ridge region is assigned the second highest group ranking, but the Piedmont/Blue Ridge transition region is not significantly different from either the Blue Ridge or the Valley and Ridge regions for effective recharge (fig. 8).

Analysis of the Tukey's MCT indicates that the Piedmont/Blue Ridge transition region is assigned the highest overall group ranking for base-flow characteristics in the study area, which can be attributed to high median values for mean base flow, Q_{50}, and low-flow statistics associated with low base-flow variability and high effective-recharge rates. The Valley and Ridge and the Blue Ridge regions have similar base-flow characteristics and, thus, both regions are assigned the second highest overall group ranking. The Piedmont southern region is assigned the next overall group ranking. Finally, the Piedmont northern region is assigned the lowest overall group ranking in response to low median values for mean base flow, Q_{50}, and low-flow statistics with high base-flow variability and low effective recharge rates.

The spatial representation of these groups is shown on plate 1. The base-flow characteristics are ordered by decreasing discharge from left to right on the first two rows of the plate. The base-flow variability index and effective recharge are found on the last row. The discharges are consistently high and values for the base-flow variability index are low for the basins within the Piedmont/Blue Ridge transition region. The basins within the Piedmont northern region show the opposite pattern.

Relation to Potential Surface-Water Yield

Potential surface-water yield is a qualitative designation of the capacity of streams within a region or individual basin to sustain base flow and is based on the statistical analysis of base-flow characteristics of streams in the study area. In terms of regions, the group rankings of the base-flow characteristics were used to designate the potential surface-water yield. The Piedmont/Blue Ridge transition region is designated as having high potential surface-water yield because the median values for the flow statistics (mean base flow, Q_{50}, and low-flow statistics) and effective recharge consistently are in the groups with the highest rank, whereas the median value for the base-flow variability index is in the group with lowest rank (fig 8). The Valley and Ridge and the Blue Ridge regions are designated as having moderate-to-high potential surface-water yield because the median values for the flow statistics are in the groups with moderate-to-high ranks and the median values for the base-flow variability index are in the group with moderate rank (fig 8). The Piedmont southern region is designated as having low-to-moderate potential surface-water yield because the median values for the flow statistics are in the groups with low-to-moderate rank and the median value for the base-flow variability index is in the group with moderate rank (fig 8). The Piedmont northern region is designated as having low potential surface-water yield because the median values for the flow statistics and effective recharge consistently are in the groups with the lowest rank, whereas the median value for the base-flow variability index is in the group with highest rank (fig 8).

Although the designation of potential surface-water yield is based on the base-flow characteristics of streams in the study area, comparison with the findings of previous studies can provide insight into the relevance of these designations within the entire Appalachian Highlands. Schneider and Friel (1965) determined that streams in the Blue Ridge and the Piedmont Physiographic Provinces had high sustained flows and actually ranked these provinces higher than the Valley and Ridge Physiographic Province. The section of the Piedmont Physiographic Province in Virginia considered by Schneider and Friel (1965) is the Piedmont/Blue Ridge transition region. Extension of the transition region along strike into western North Carolina corresponds to (1) the area delineated by Schneider and Friel (1965) with the highest average annual low flows in the Appalachian region, (2) the area delineated by Wyrick (1968) with moderate to high values for ground-water discharge, and (3) the area delineated by Giese and Mason (1993, p.7) with the highest potential for sustaining low flows in North Carolina (the western Piedmont and mountains physiographic area). These areas in North Carolina have average annual precipitation values that range from 50 in/yr to more than 80 in/yr; whereas average annual precipitation in the Piedmont/Blue Ridge transition region is lower, approximately 42 in/yr (Swain and others, 1991, fig. 2; Giese and Mason, 1993, p. 7). Evidently, the Piedmont/Blue Ridge transition region represents the northernmost extent of an area in the Appalachian Highlands designated as having high potential surface-water yield associated with high annual precipitation. Median values for $7Q2$ and $7Q10$ in the western Piedmont and mountains physiographic area of North Carolina (Giese and Mason, 1993, p. 7), however, are about twice those for the Piedmont/Blue Ridge transition region. The difference in these median values demonstrates the possible effect that the amount of annual precipitation can have on the determination of potential surface-water yield. Other areas in Virginia have similar annual precipitation as the transition region but the potential surface-water yield differs, which indicates that other basin characteristics also need to be considered.

In terms of individual basins, previous investigations have used a single flow statistic or ratio to determine potential surface-water yield. For example, Trainer and Watkins (1975, p. 49–51) ranked tributary basins of the upper Potomac River Basin based on values for annual minimum average 7-consecutive-day low-flow discharges having a 20-year recurrence interval ($7Q20$) to indicate areal distribution of water-yielding potential. An alternative approach developed for this investigation assigns a rank for potential surface-water yield to a basin according to the quartiles in which the values for the base-flow characteristics are located. For example, a high rank for potential surface-water yield was assigned to a basin where values for the flow statistics are in the upper quartile and the variability index is in the lower quartile for the respective base-flow characteristic. A moderate rank was assigned to a basin where the values for the flow statistics and variability index are within the interquartile range for the respective base-flow characteristic. A low rank was assigned to a basin where values for the flow statistics are in the lower quartile and the variability index is in the upper quartile for the respective base-flow characteristic. The results from this ranking procedure are shown in figure 9. Most of the basins

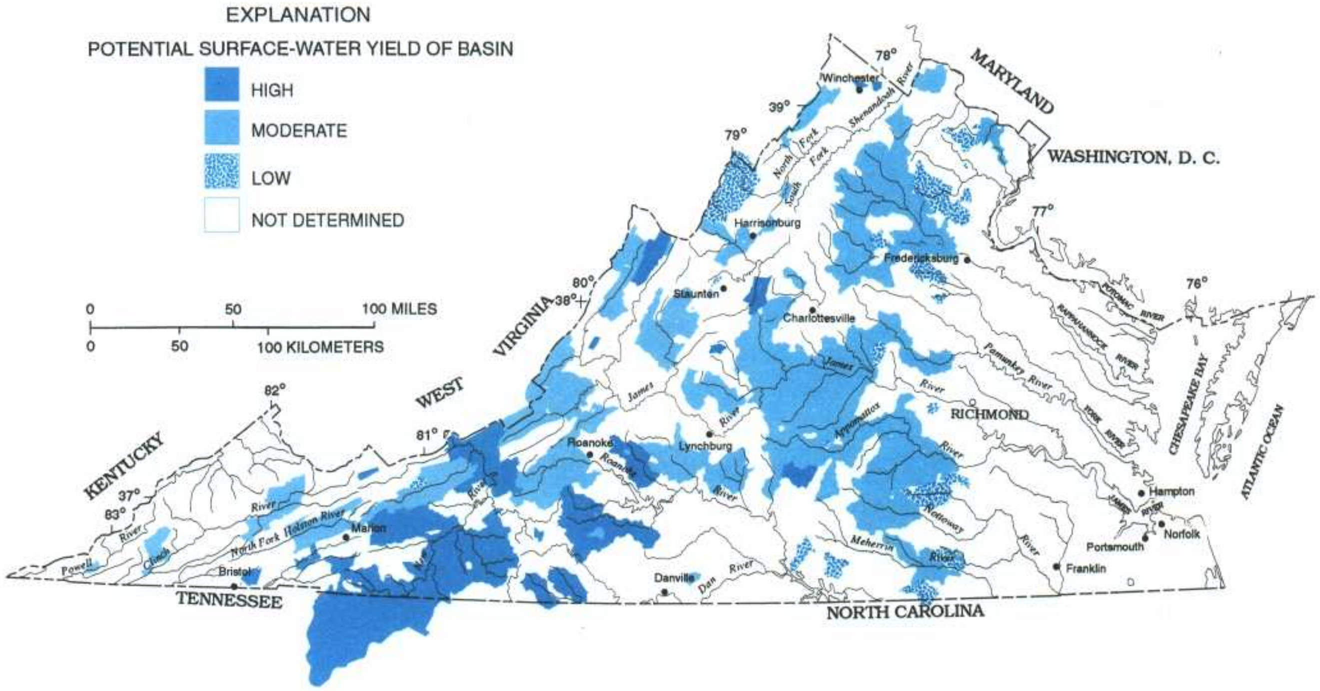


Figure 9. Spatial distribution of potential surface-water yield of basins.

with a high rank for potential surface-water yield are located in the Piedmont/Blue Ridge transition, the Valley and Ridge, and the Blue Ridge regions, and a majority of the basins that represent low-to-moderate ranks are located in the Piedmont regions (fig. 9). The differences in water-yielding potential are only relative to the study area but should be considered in the process of managing surface-water resources.

Relation to Potential Ground-Water Yield

Potential ground-water yield is the capacity of the ground-water reservoir to store and transmit water. Knopman (1990) used specific capacity data as an indicator of potential ground-water yield. An alternative approach for areas that lack sufficient specific capacity or well-yield data is to use base-flow characteristics as indicators of potential ground-water yield. Trainer and Watkins (1975, p. 50) suggested that areas with favorable potential ground-water yield, where values for transmissivity and base flow are high, could be delineated by using base flow as an indicator. However, Olmsted and Hely (1962, p. A21) stated that the relation between base flow and the amount of ground water available for development is not simple. In order to indicate potential ground-water yield from base-flow characteristics, aquifer properties for selected basins with continuous streamflow data were determined by methods that use streamflow records and basin characteristics. The basin characteristics and aquifer properties are listed in appendix 3.

Rorabaugh (1960, 1964) developed an equation that relates the slope of the master recession curve to the transmissivity and storage coefficient of the ground-water reservoir. An abbreviated form of the equation (Rorabaugh and Simons, 1966, p. 12) was used for 51 continuous-record streamflow-gaging stations to calculate areal diffusivity, which is the ratio of transmissivity to storage coefficient:

$$\frac{T}{S} = \frac{0.933a^2}{K}, \qquad (1)$$

where

T is areal transmissivity (L^2/T),
S is storage coefficient (dimensionless),
a is aquifer half-width (L), and
K is recession index (T).

The recession index (K) values were determined by Rutledge and Mesko (1996) by using a computerized method that calculates a mathematical expression of the master recession curve of streamflow recession for each station. Aquifer half-width (a) is the average distance from the stream to the hydrologic divide. The distance a for each gaged station is equal to half the reciprocal of drainage density, which is the ratio of the total length of streams in a basin to the drainage area (Horton, 1945, p. 284; Olmsted and Hely, 1962, p. A19; Carlston, 1963, p. C5; Trainer, 1969, p. C179). Summation of all stream-segment lengths upstream of each streamflow-gaging station was accomplished by applying the ARC/INFO network analysis procedure to the U.S. Environmental Protection Agency Reach File, Version 3 (RF3) coverage. In some cases, the RF3 coverage does not contain all of the stream segments within the basin; therefore, the distance a was estimated by using the mean drainage density from either the same hydrologic unit code or similar unit code.

Values of areal diffusivity range from 17,100 to 88,400 ft^2/d, with a median value of 38,400 ft^2/d (table 2), which are consistent with values reported in the literature (Olmsted and Hely, 1962; Hely and Olmsted, 1963; Trainer and Watkins, 1974, 1975). The Kruskal-Wallis test indicates that significant differences exist (p=0.037) in median values for areal diffusivity among the regions. The Tukey's MCT indicates that the Piedmont northern and southern, the Valley and Ridge, and the Blue Ridge regions do not differ significantly from each other and that the latter three regions are not significantly different from the Piedmont/Blue Ridge transition region but that the median value for areal diffusivity in the Piedmont northern region is significantly higher than in the Piedmont/Blue Ridge transition region (p=0.026). In terms of the potential surface-water yield of the basins, the Tukey's MCT indicates that the median value for areal diffusivity decreases as the group ranking increases (p<0.001). The group ranking of areal diffusivity does not correspond with the group ranking of potential surface-water yield for either the regions or the basins, which illustrates the difficulty of establishing the relation between base-flow characteristics and potential ground-water yield solely based on areal diffusivity. However, insight is provided by plotting areal diffusivity, which is grouped by potential surface-water yield, against the base-flow variability index (fig. 10). A smooth line, determined by means of a smoothing procedure (referred to as LOWESS) that uses robust least squares (Helsel and Hirsch, 1992, p. 46), suggests that areal diffusivity increases and potential surface-water yield decreases with

Table 2. Summary statistics for aquifer properties by region and potential surface-water yield of basins
[ft^2/d, feet squared per day]

	Number of sites	Median	25th percentile	75th percentile	Minimum	Maximum
Areal Diffusivity (ft^2/d)						
Region:						
Valley and Ridge	16	38,300	31,000	46,900	17,100	73,100
Blue Ridge	17	41,100	31,700	49,000	21,700	68,700
Piedmont/Blue Ridge transition	6	27,200	20,400	32,100	19,800	34,900
Piedmont northern	5	51,600	36,900	85,000	27,800	88,400
Piedmont southern	7	42,800	27,600	76,100	26,400	79,100
Potential surface-water yield:						
High	15	30,900	21,700	34,900	17,100	47,500
Moderate	30	40,300	32,000	47,400	21,600	73,100
Low	6	77,600	64,100	83,200	43,100	88,400
Study Area	51	38,400	30,600	47,500	17,100	88,400
Areal Transmissivity (ft^2/d)						
Region:						
Valley and Ridge	16	100	79	300	63	350
Blue Ridge	17	230	130	310	100	810
Piedmont/Blue Ridge transition	6	320	210	410	170	440
Piedmont northern	5	540	420	600	390	610
Piedmont southern	7	650	460	830	240	830
Potential surface-water yield:						
High	15	280	170	370	120	500
Moderate	30	230	100	410	63	830
Low	6	570	200	700	99	830
Study Area	51	270	120	440	63	830
Storage Coefficient						
Region:						
Valley and Ridge	16	.002	.002	.008	.001	.015
Blue Ridge	17	.006	.004	.008	.002	.018
Piedmont/Blue Ridge transition	6	.011	.008	.015	.008	.017
Piedmont northern	5	.008	.007	.014	.006	.016
Piedmont southern	7	.017	.008	.019	.006	.019
Potential surface-water yield:						
High	15	.008	.007	.012	.004	.019
Moderate	30	.006	.002	.012	.001	.019
Low	6	.007	.005	.009	.001	.011
Study Area	51	.007	.004	.011	.001	.019

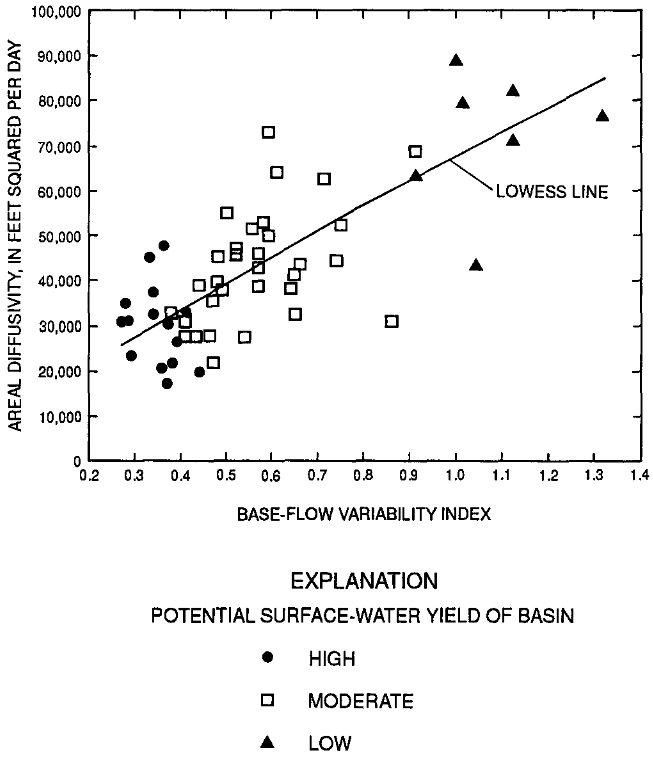


Figure 10. Relation between areal diffusivity and base-flow variability index grouped by potential surface-water yield of basins.

increasing base-flow variability. Inasmuch as transmissivity and storage coefficient determine areal diffusivity, it would seem reasonable to assume that the negative relation between areal diffusivity and potential surface-water yield is in response to differences in ground-water storage.

Ideally, areas favorable for ground-water development would have high values for both areal transmissivity and storage coefficient. Rough estimates of areal transmissivity for the 51 continuous-record streamflow-gaging stations were calculated by using the following equation from Olmsted and Hely (1962, p. A18):

$$T = \frac{R_g + ET_g}{I(2L)}, \qquad (2)$$

where

T is areal transmissivity (L^2/T),
R_g is effective recharge (L^3/T),
ET_g is riparian evapotranspiration (L^3/T),
I is average ground-water gradient from divides to streams (L/L), and
L is length of discharge areas or total stream length (L).

The effective recharge rates (R_g) determined in this investigation were nearly equal to rates calculated by Rutledge and Mesko (1996); therefore, values for riparian evapotranspiration (ET_g) determined by Rutledge and Mesko (1996) were used in equation 2. Average ground-water gradients from hydrologic divides to streams (I) were not readily available. Rough approximations for I, however, were determined using a procedure based on median basin relief and follows the assumption that the water-table profile mimics the topography of land surface. During the APRASA study, a Triangulated Irregular Network (TIN) (Environmental Systems Research Institute, 1992) was constructed to interpolate surface-elevation contours from the 30-second point-elevation data provided by the National Oceanic and Atmospheric Administration, National Geophysical Data Center. Median basin relief (in percent) is simply the median of all relief values calculated within a basin (T.O. Mesko, U.S. Geological Survey, written commun., 1994). Median basin relief values were multiplied by the values for aquifer half-width to obtain estimates for the median elevation of hydrologic divides above the streams within each basin. The median water-table elevation beneath the divides was assumed to be half the median elevation of the divides; thus, the average ground-water gradient from divides to streams (I) is equal to the median water-table elevation divided by aquifer half-width. Values for total stream length (L) were determined by the previously mentioned ARC/INFO procedure.

Values of areal transmissivity range from 63 to 830 ft^2/d, with a median value of 270 ft^2/d (table 2). Storage coefficients, which were estimated by dividing areal transmissivity by areal diffusivity, range from approximately 0.001 to 0.019 (dimensionless), with a median value of 0.007 (table 2). These values for areal transmissivity and storage coefficient are consistent with values reported in the literature (Olmsted and Hely, 1962; Hely and Olmsted, 1963; Trainer and Watkins, 1974, 1975). Median values for areal transmissivity and storage coefficient for the Piedmont and Piedmont/Blue Ridge transition regions generally are higher than those for the other regions as indicated by the Tukey's MCT; but the median value for storage coefficient for the Piedmont northern region is not significantly different from that of the other regions ($p < 0.001$). Where grouped by potential surface-water yield of the basins, median values for these properties could not be statistically separated using Tukey's

MCT (p=0.073 and 0.294). Areal transmissivity generally increases as storage coefficient increases; however, basins with low potential surface-water yield generally have high values of areal transmissivity associated with low values of storage coefficient over a narrow range relative to those from basins designated as having moderate to high potential surface-water yield (fig. 11). Similar to the earlier discussion concerning areal diffusivity and base-flow variability, values of storage coefficient can be different for the same value of areal transmissivity (fig. 11). Although the basins with high potential surface-water yield tend to have comparatively low values for areal transmissivity, storage coefficients generally are large when compared to those from basins with similar values of areal transmissivity but different potential surface-water yield. Giusti (1962, p. C129) concluded from an evaluation of floods and drought flows that differences in ground-water storage are related to variations in weathering rates and the degree of fracturing and jointing. He also stated that similar rock types can have different capacities for ground-water storage.

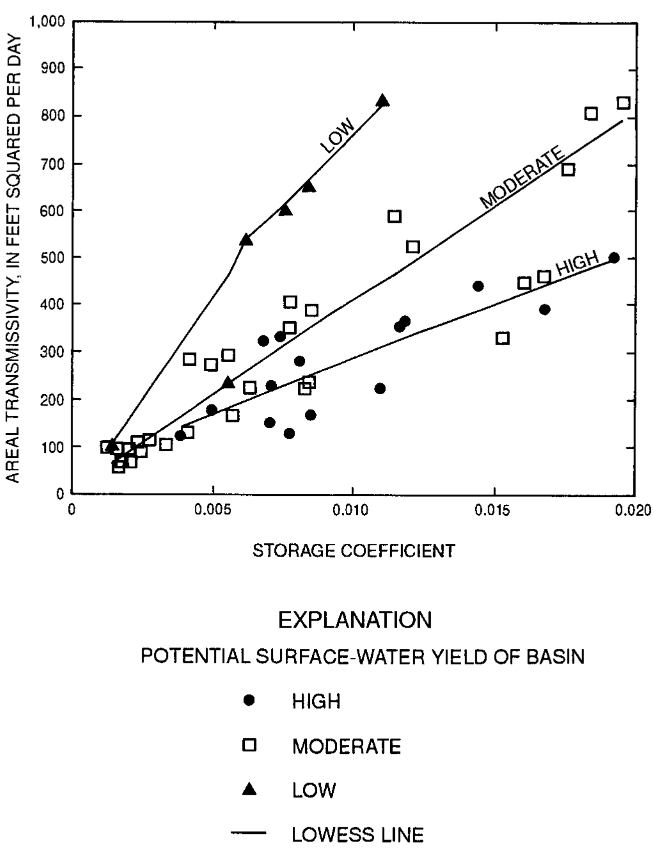


Figure 11. Relation between areal transmissivity and storage coefficient grouped by potential surface-water yield of basins.

The above discussion suggests that potential ground-water yield is directly related to potential surface-water yield. Therefore, a relation between aquifer properties, grouped by potential surface-water yield, and well yields should exist. The APRASA study developed a hydrogeologic classification system, which separates the different rock types in the study area into 13 categories representing different ranges of specific capacity and well yield (Hollyday and others, 1992; Knopman and Hollyday, 1993; Mesko, 1993). These rock categories were grouped into hydrogeologic units with large, medium, and small well yields for the Valley and Ridge Physiographic Province and for the Blue Ridge and the Piedmont Physiographic Provinces (table 3). Areal diffusivity plotted against the percentage of the area within a basin underlain by the different hydrogeologic units where the individual data points are identified by their potential surface-water yield is shown in figure 12. Generally, no trend is evident between areal diffusivity and the hydrogeologic units. Some of the high values of areal diffusivity are associated with basins predominantly underlain (greater than 50-percent) by hydrogeologic units with small well yields, especially basins with a low potential surface-water yield. Areal transmissivity and storage coefficient plotted against the percentage of the area within a basin underlain by the different hydrogeologic units where the individual data points are identified by their potential surface-water yield are shown in figures 13 and 14. Areal transmissivity and storage coefficient tend to decrease, which is the expected trend, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Valley and Ridge Physiographic Province. A similar trend is indicated for the hydrogeologic unit with medium well yields in the Blue Ridge and the Piedmont Physiographic Provinces. Areal transmissivity and storage coefficient tend to increase, which is not the expected trend, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Blue Ridge and the Piedmont Physiographic Provinces.

Explanation of the different trends between aquifer properties, grouped by potential surface-water yield, and type of hydrogeologic unit may be related to the limited number of surface-water sites selected and approximations of variables used to estimate the aquifer properties. Although the estimated values for the

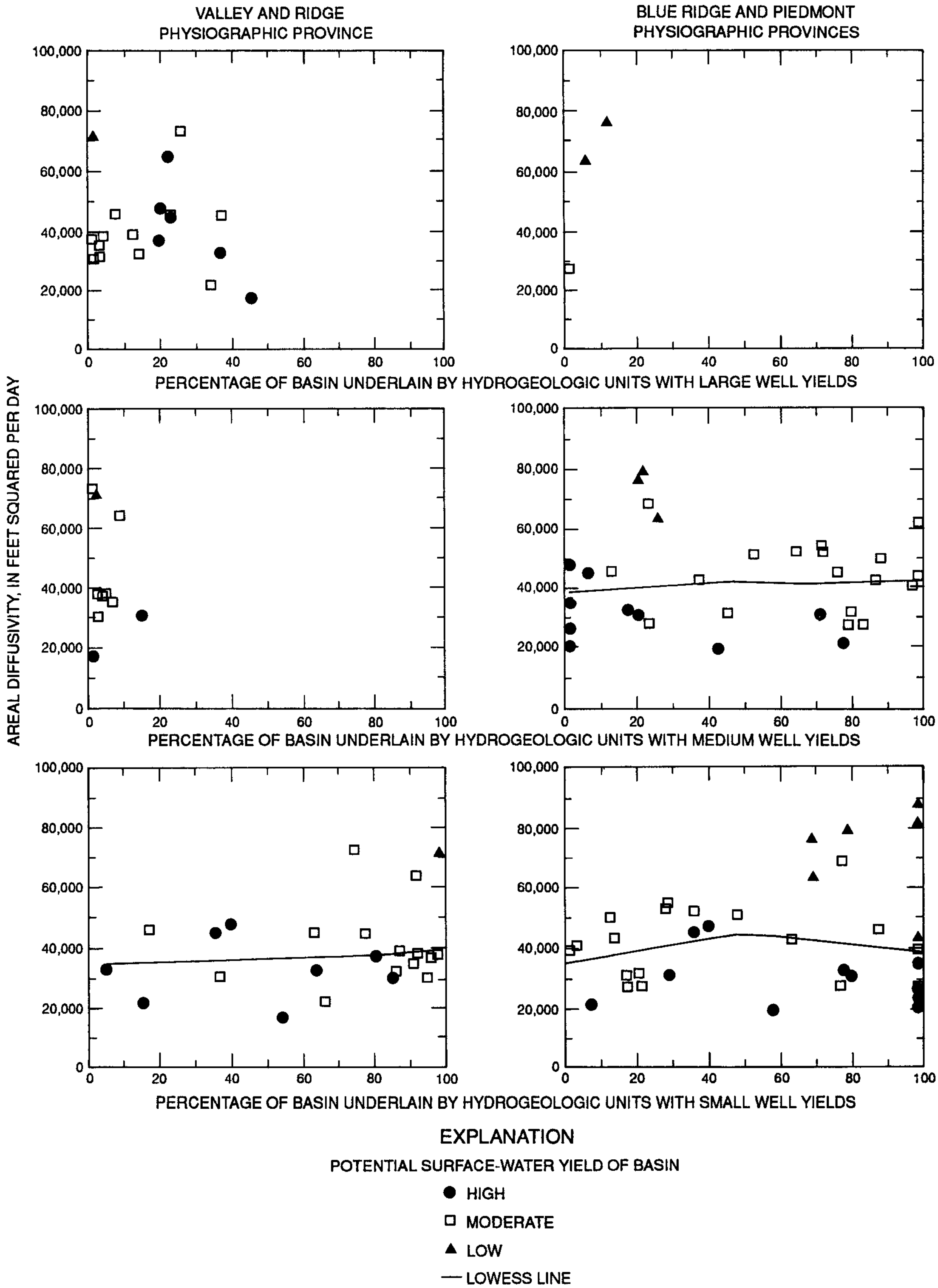


Figure 12. Relation between areal diffusivity and percentage of area within a basin underlain by different hydrogeologic units. (For explanation of the hydrogeologic unit classification system refer to table 3.)

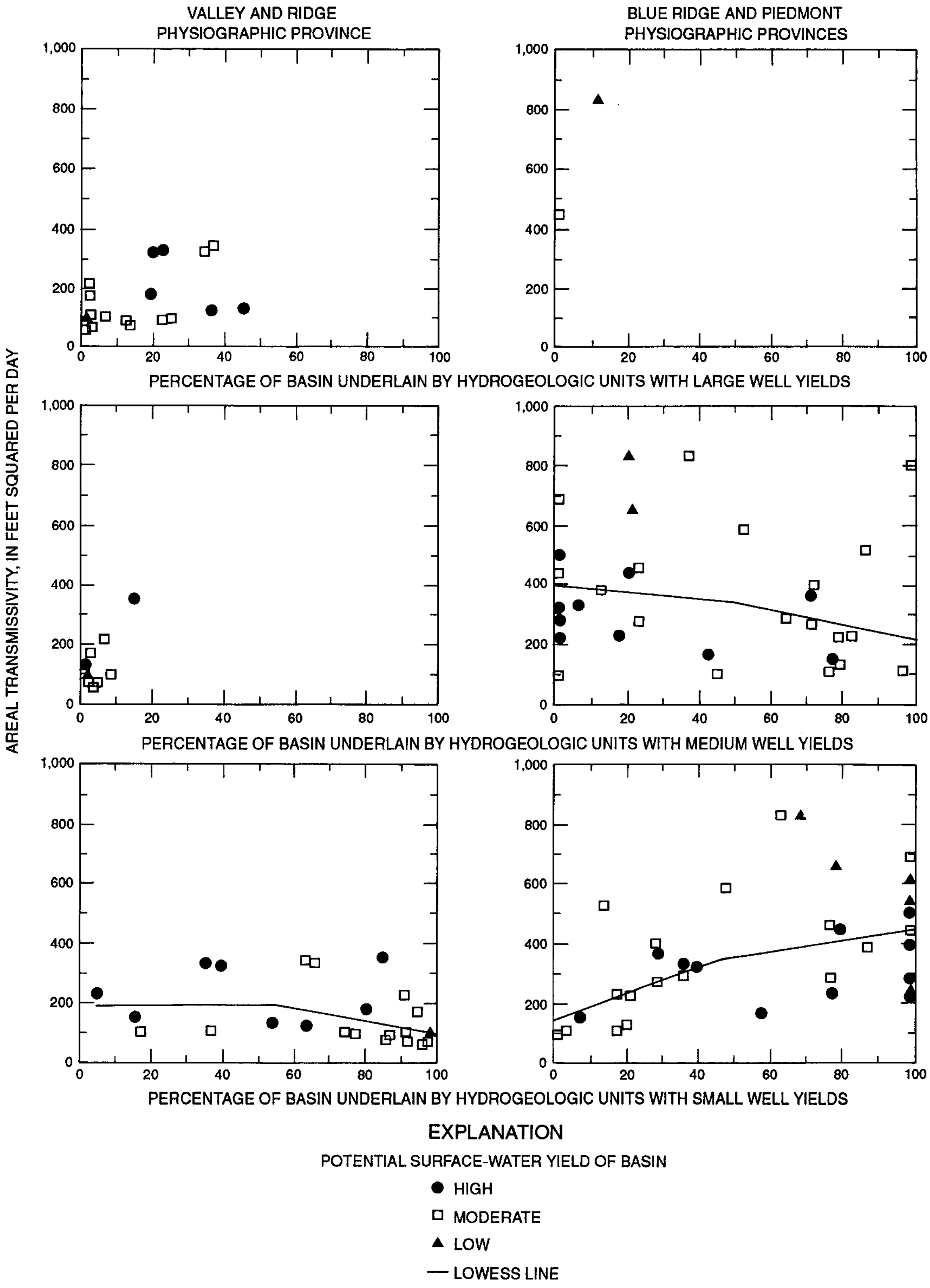


Figure 13. Relation between areal transmissivity and percentage of area within a basin underlain by different hydrogeologic units. (For explanation of the hydrogeologic unit classification system refer to table 3.)

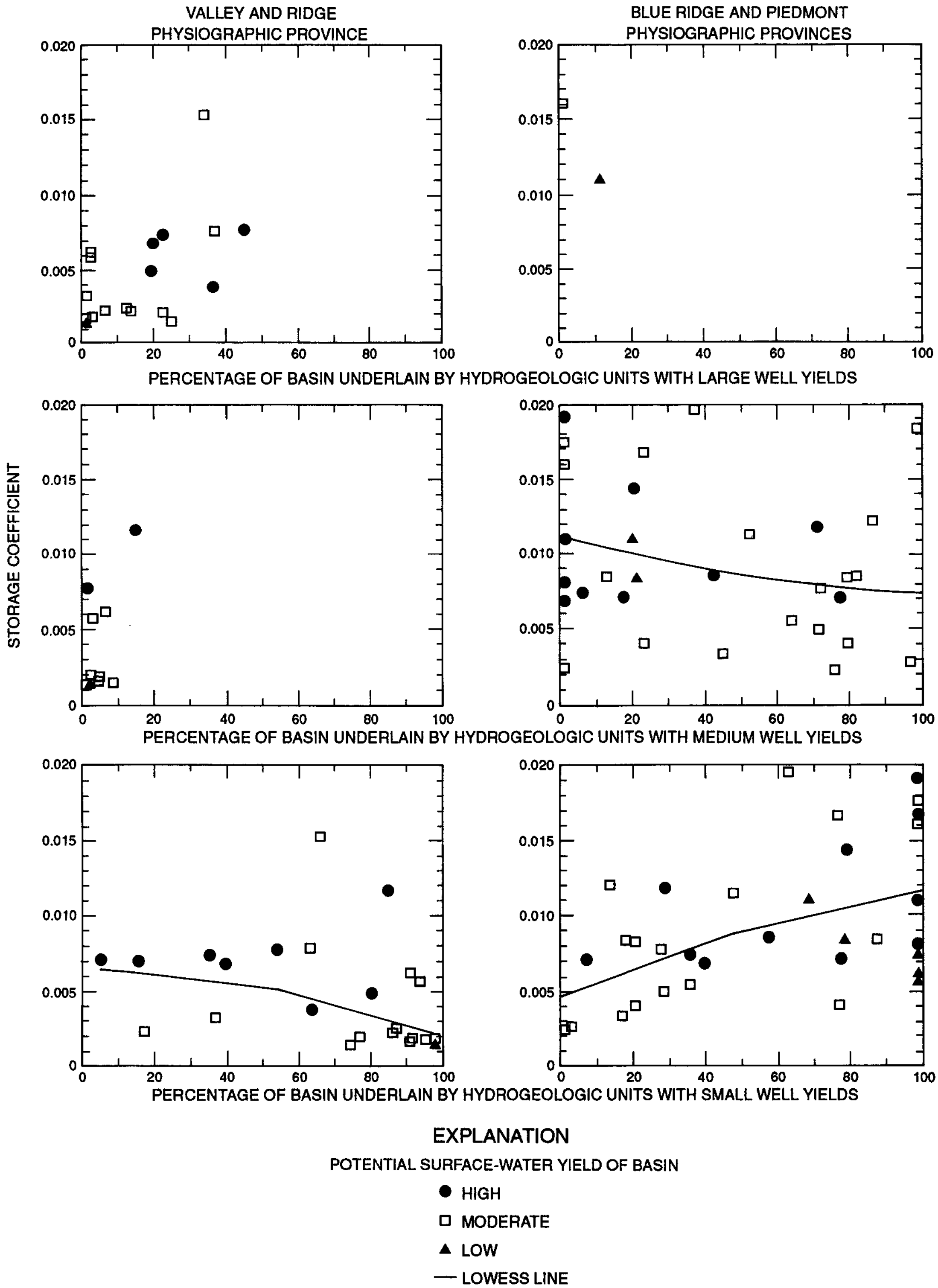


Figure 14. Relation between storage coefficient and percentage of area within a basin underlain by different hydrogeologic units. (For explanation of the hydrogeologic unit classification system refer to table 3.)

Table 3. Description of the Appalachian Valley and Piedmont Regional Aquifer-System Analysis hydrogeologic unit classification system
[gal/min, gallon per minute]

Physiographic province	Grouping variables	Hydrogeologic unit	Rock categories
Valley and Ridge	Lithology and specific capacity	Small well yields	Siliciclastics, argillaceous carbonates
		Medium well yields	Limestone
		Large well yields	Dolomite, mixtures of limestone and dolomite, alluvium
Blue Ridge and Piedmont	Well yield	Small well yields	Well yields range from 0 to 10 gal/min
		Medium well yields	Well yields range from 10 to 20 gal/min
		Large well yields	Well yields greater than 20 gal/min

aquifer properties are considered to be reasonable, additional sites and ground-water data are needed to fully evaluate potential ground-water yield. Furthermore, the estimated aquifer properties may be representative of the unconsolidated regolith and not of the fractured bedrock, especially in the Piedmont regions. In addition, most of the wells in the study area are finished in the fractured bedrock with casing extending to or below the regolith-bedrock contact; whereas the streams in the study area generally flow along or near the regolith-bedrock contact (Nutter and Otton, 1969, p. 15; Richardson, 1982, p. 6; Swain and others, 1991, p. 12). Exceptions to these explanation are (1) areas in the Valley and Ridge region underlain by carbonate rocks and sandstone with thin regolith, (2) areas in the Blue Ridge and the Piedmont regions underlain by massive or foliated crystalline rocks with thin regolith, and (3) the Mesozoic sedimentary basins in the Piedmont regions (Swain and others, 1991).

Another possible explanation is that the well-yield classification system may not account for differences on a Statewide scale, which is possible, because the classification system was developed for the entire APRASA study area. For example, a majority of the basins with high potential surface-water yield and predominantly underlain (greater than 50-percent) by the hydrogeologic unit with small well yields are in the Piedmont/Blue Ridge transition region. Well-yield data from Dawson and Davidson (1979) for high capacity wells within this region have a median value of 30 gal/min, which is characteristic of the hydrogeologic unit with large well yields in the Blue Ridge and the Piedmont Physiographic Provinces. The base-flow characteristics of a basin may provide a relative indication of the potential ground-water yield, but other factors need to be considered, such as geologic structure, lithology, precipitation, relief, and degree of hydraulic interconnection between the regolith and bedrock.

SUMMARY AND CONCLUSIONS

Growth within the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia has focussed concern about allocation of surface-water flow and increased demands on the ground-water resources. The purpose of this report is to (1) describe the base-flow characteristics of streams, (2) identify regional differences in these flow characteristics, and (3) describe, if possible, the potential surface-water and ground-water yields of basins on the basis of the base-flow characteristics.

Base-flow characteristics are presented for streams in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia. The provinces are separated into five regions: (1) Valley and Ridge, (2) Blue Ridge, (3) Piedmont/Blue Ridge transition, (4) Piedmont northern, and (5) Piedmont southern. Different flow statistics, which represent streamflows predominantly comprised of base flow, were determined for 217 continuous-record streamflow-gaging stations from historical mean daily discharge and for 192 partial-record streamflow-gaging stations by means of correlation of discharge measurements. Variability of base flow is represented by the $\log_{10}$ of the ratio of Q_{50} to Q_{90}. Effective recharge rates were also calculated.

Mean base flow ranges from 0.01 to 2.44 $(ft^3/s)/mi^2$, with a median value of 0.61 $(ft^3/s)/mi^2$. The Q_{50}, which is a flow-duration statistic commonly used to estimate mean base flow, ranges from 0.00 to 2.26 $(ft^3/s)/mi^2$, with a median value of 0.55 $(ft^3/s)/mi^2$. The Q_{50} is an excellent estimator of mean base flow for the Piedmont/Blue Ridge transition region and the Piedmont southern region, but tends to underestimate mean base flow for the remaining regions. Low-flow statistics (Q_{90}, Q_{95}, 7Q2, and 7Q10) represent base flow after periods of sparse recharge or drought and range from 0.00 to 0.76 (ft^3/s)/mi^2, with median values that range from 0.05 (ft^3/s)/mi^2 for 7Q10 to 0.15 (ft^3/s)/mi^2 for Q_{90}. The base-flow variability index ranges from 0.07 to 2.27, with a median value of 0.55. Effective recharge rates range from 0.07 to 33.07 in/yr, with a median value of 8.32 in/yr.

Differences in the base-flow characteristics exist between regions. The median discharges for the Valley and Ridge, the Blue Ridge, and the Piedmont/Blue Ridge transition regions are higher than those for the Piedmont regions. Results from statistical analysis indicate that the regions can be ranked in terms of base-flow characteristics from highest to lowest as follows: (1) Piedmont/Blue Ridge transition, (2) Valley and Ridge and Blue Ridge, (3) Piedmont southern, and (4) Piedmont northern. The flow statistics are consistently higher and the values for base-flow variability are lower for basins within the Piedmont/Blue Ridge transition region relative to those from the other regions, whereas the basins within the Piedmont northern region show the opposite pattern.

Potential surface-water yield is a qualitative designation of the capacity of streams within a region or individual basin to sustain base flow and is based on the statistical analysis of base-flow characteristics of streams in the study area. In terms of regions, the group rankings of the base-flow characteristics were used to designate the potential surface-water yield. In terms of individual basins, an approach developed for this investigation assigns a rank for potential surface-water yield to a basin according to the quartiles in which the values for the base-flow characteristics are located. Both procedures indicate that the Valley and Ridge, the Blue Ridge, and the Piedmont/Blue Ridge transition regions have moderate-to-high potential surface-water yield and the Piedmont regions have low-to-moderate potential surface-water yield.

Potential ground-water yield is the capacity of the ground-water reservoir to store and transmit water. Base-flow characteristics may provide a relative indication of the potential ground-water yield for areas that lack sufficient specific capacity or well-yield data. In order to indicate potential ground-water yield from base-flow characteristics, aquifer properties for 51 streamflow-gaging stations with continuous streamflow data were determined by methods that use streamflow records and basin characteristics. Areal diffusivity ranges from 17,100 to 88,400 ft^2/d, with a median value of 38,400 ft^2/d. Areal transmissivity ranges from 63 to 830 ft^2/d, with a median value of 270 ft^2/d. Storage coefficients, which were estimated by dividing areal transmissivity by areal diffusivity, range from approximately 0.001 to 0.019 (dimensionless), with a median value of 0.007.

Statistical analysis of median values of areal diffusivity indicate that the Piedmont northern and southern, the Valley and Ridge, and the Blue Ridge regions do not differ significantly from one another, and the latter three regions do not differ significantly from the Piedmont/Blue Ridge transition region; but, the median value of areal diffusivity in the Piedmont northern region is significantly higher than it is in the Piedmont/Blue Ridge transition region. The median value for areal diffusivity decreases as potential surface-water yield of the basins increases. The ranking of areal diffusivity does not correspond with the ranking of potential surface-water yield for either the regions or the basins, which illustrates the difficulty of establishing the relation between base-flow characteristics and potential ground-water yield solely based on areal diffusivity. Statistical analysis indicates that the Piedmont and the Piedmont/Blue Ridge transition regions generally have median values of areal transmissivity and storage coefficient that are higher than those in the other regions; but the median value of storage coefficient for the Piedmont northern region does not differ significantly from that in the other regions. Where grouped by potential surface-water yield of the basins, median values of areal transmissivity and storage coefficient could not be statistically separated. Areal transmissivity generally increases as storage coefficient increases; however, basins with low potential surface-water yield generally have high values of areal transmissivity associated with low values of storage coefficient over a narrow range relative to basins designated as having moderate-to-high potential surface-water yield. Although the basins with high potential surface-water yield tend to have comparatively low values of areal transmissivity, storage coefficients generally are large when compared to those from basins with similar values of transmissivity but different potential surface-water yield.

Aquifer properties were grouped by potential surface-water yield and were related to hydrogeologic units categorized by large, medium, and small well yields for the Valley and Ridge Physiographic Province and for the Blue Ridge and the Piedmont Physiographic Provinces. Generally, no trend is evident between areal diffusivity and hydrogeologic units. Some of the high values of areal diffusivity are associated with basins predominantly underlain by hydrogeologic units with small well yields, especially basins with a low potential surface-water yield. Areal transmissivity and storage coefficient tend to decrease, which is the expected trend, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Valley and Ridge Physiographic Province. A similar trend is indicated for the hydrogeologic unit with medium well yields in the Blue Ridge and the Piedmont Physiographic Provinces. Areal transmissivity and storage coefficient tend to increase, which is not the expected trend, as more of the basin is underlain by the hydrogeologic unit with small well yields in the Blue Ridge and the Piedmont Physiographic Provinces. Explanation of the different trends between aquifer properties and type of hydrogeologic unit may be related to the limited number of surface-water sites selected and approximations of variables used to estimate the aquifer properties. The base-flow characteristics of a basin may provide a relative indication of the potential ground-water yield; but other factors need to be considered, such as geologic structure, lithology, precipitation, relief, and degree of hydraulic interconnection between the regolith and bedrock.

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APPENDIXES

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia

[Latitude and longitude are reported in degrees, minutes, and seconds; mi², square mile; ft³/s, cubic foot per second; in/yr, inch per year; Q_{50}, Q_{90}, and Q_{95}, indicate the 50-, 90-, and 95-percent discharge on the streamflow-duration curve, respectively; 7Q2 and 7Q10, indicate the annual minimum average 7-consecutive-day low-flow discharge having 2-year and 10-year recurrence intervals, respectively; leaders (- - -) indicate value could not be determined; NB, North Branch; SB, South Branch; MF, Middle Fork; NF, North Fork; SF, South Fork; Cr., Creek; nr, near]

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi²)	Mean base flow (ft³/s)	Q_{50} (ft³/s)	Q_{90} (ft³/s)	Q_{95} (ft³/s)	7Q2 (ft³/s)	7Q10 (ft³/s)	Base-flow variability index	Effective recharge (in/yr)
01613900	Hogue Creek near Hayfield	391252	781718	1962–84	15.0	8.46	5.05	1.00	0.77	0.75	0.37	0.70	7.66
01615000	Opequon Creek near Berryville	391040	780420	1945–84	57.4	20.6	17.4	4.66	3.41	4.50	1.40	.57	4.86
01615500	Abrams Creek at Winchester	390950	781015	1946–49	5.60	4.42	3.50	2.30	2.10	1.20	.85	.18	10.71
01616000	Abrams Creek near Winchester	391040	780510	1951–84	16.5	17.8	17.1	9.02	8.25	9.60	6.50	.28	14.66
01620500	North River near Stokesville	382015	791425	1948–84	17.2	16.3	12.2	.95	.54	.68	.21	1.11	12.89
01621000	Dry River at Rawley Springs	383010	790314	1946–47	72.6	30.4	25.2	2.60	.72	.83	.12	.99	5.69
01622000	North River near Burketown	382025	785450	1928–84	379	246	201	62.9	52.6	58.0	39.0	.50	8.83
01623000	Bell Creek at St Pauls Chapel near Staunton	381000	790735	1949–55	.61	- - -	.00	.00	.00	.00	.00	- - -	- - -
01623500	Bell Creek near Staunton	381100	790705	1949–55	3.80	- - -	.00	.00	.00	.00	.00	- - -	- - -
01624000	Bell Creek at Franks Mill near Staunton	381310	790635	1949–56	9.60	- - -	.72	.10	.10	.00	.00	.86	- - -
01624300	Middle River near Verona	381436	790208	1969–84	178	134	109	43.4	36.3	39.0	28.0	.40	10.24
01624800	Christians Creek near Fishersville	380742	785941	1969–84	70.1	52.8	44.4	17.6	14.8	17.0	11.0	.40	10.23
01625000	Middle River near Grottoes	381542	785144	1929–84	375	216	185	79.5	66.9	77.0	52.0	.37	7.83
01626000	South River near Waynesboro	380327	785430	1954–84	127	105	78.5	32.0	28.5	30.0	24.0	.39	11.21
01626500	South River at Waynesboro	380340	785350	1930–52	144	109	92.0	36.4	32.1	37.0	26.0	.40	10.29
01626850	South River near Dooms	380519	785238	1976–84	149	150	122	57.0	52.7	55.0	45.0	.33	13.68
01627500	South River at Harriston	381307	785013	1926–84	212	186	156.6	68.1	58.8	66.0	48.0	.36	11.93
01628060	White Oak Run near Grottoes	381501	784457	1981–84	1.94	- - -	.43	.00	.00	.00	.00	- - -	- - -
01628150	Deep Run near Grottoes	381623	784536	1981–82	1.17	.58	.21	.03	.03	.09	.05	.85	6.75
01628500	SF Shenandoah River near Lynnwood	381921	784518	1962–84	1,084	710	595	221	188	227	147	.43	8.90
01631000	SF Shenandoah River at Front Royal	385450	781240	1956–84	1,642	1,064	898	370	318	344	235	.39	8.80
01632000	NF Shenandoah River at Cootes Store	383813	785111	1926–84	210	89.0	61.8	4.71	2.20	3.20	.77	1.12	5.75
01632900	Smith Creek near New Market	384136	783835	1962–84	93.2	55.2	45.0	14.8	11.4	14.0	8.00	.48	8.04
01633000	NF Shenandoah River at Mount Jackson	384444	783821	1945–84	506	237	187	45.4	32.1	37.0	18.0	.61	6.35
01633500	Stony Creek at Columbia Furnace	385155	783745	1947–56	79.4	42.0	32.6	8.00	6.84	5.80	3.30	.61	7.17
01634500	Cedar Creek near Winchester	390452	781947	1939–84	103	56.6	40.4	10.0	7.77	7.70	4.30	.61	7.46
01635500	Passage Creek near Buckton	385729	781601	1933–84	87.8	40.2	25.3	4.16	2.40	2.80	1.30	.78	6.22
01638480	Catoctin Creek at Taylorstown	391516	773436	1973–84	89.6	60.6	52.6	9.30	6.81	6.80	2.90	.75	9.18
01643700	Goose Creek near Middleburg	385911	774749	1967–84	123	97.1	86.0	10.6	5.96	6.00	.71	.91	10.72
01644000	Goose Creek near Leesburg	390110	773440	1931–84	332	191	160	19.5	10.2	12.0	2.50	.91	7.79

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
01644291	Stave Run near Reston	385656	772216	1972–78	0.08	---	0.02	0.00	0.00	0.00	0.00	---	---
01644295	Smilax Branch at Reston	385710	772204	1968–78	.32	---	.16	.00	.00	.00	.00	---	---
01646000	Difficult Run near Great Falls	385833	771446	1936–84	57.9	37.1	38.8	13.6	9.67	12.0	3.00	.46	8.70
01652500	Fourmile Run at Alexandria	385036	770446	1953–82	13.8	6.02	6.05	1.90	1.90	1.70	1.10	.50	5.93
01653000	Cameron Run at Alexandria	384820	770608	1957–79	33.7	14.5	15.5	4.63	3.54	3.10	1.70	.52	5.85
01654000	Accotink Creek near Annandale	384846	771343	1949–84	23.5	12.4	13.7	4.09	2.94	2.90	.43	.52	7.18
01654500	Long Beach near Annandale	384839	771407	1948–56	3.71	2.89	2.60	.88	.46	.50	.06	.47	10.58
01655000	Accotink Creek near Accotink Station	384515	771209	1950–56	37.0	20.9	20.5	4.94	2.60	3.80	.56	.62	7.68
01656000	Cedar Run near Catlett	383812	773731	1952–84	93.4	35.2	27.2	1.70	.78	.84	.00	1.20	5.11
01656100	Cedar Run near Aden	383658	773316	1974–84	155	56.7	46.0	3.68	1.70	2.50	.45	1.10	4.97
01656500	Broad Run at Buckland	384650	774022	1952–84	50.5	30.8	25.2	4.23	2.20	3.20	.92	.78	8.29
01656725	Bull Run near Catharpin	385321	773414	1971–84	25.8	13.1	11.1	.67	.15	.16	.00	1.22	6.87
01656960	Cub Run near Bull Run	384916	772757	1974–84	49.9	17.2	14.5	1.80	.95	1.60	.15	.91	4.67
01657500	Occoquan River near Occoquan	384220	771935	1914–56	570	182	182	34.7	27.7	30.0	8.40	.72	4.33
01657655	Hooes Run near Occoquan	384048	771725	1976–82	3.97	2.21	1.70	.11	.06	.10	.01	1.19	7.56
01658480	Quantico Creek near Dumfries	383422	772051	1983–84	6.90	5.02	6.41	1.00	.57	.23	.01	.81	9.87
01658500	SF Quantico Creek near Independent Hill	383514	772544	1953–84	7.64	3.15	1.90	.19	.10	.08	.00	1.00	5.60
01658550	SF Quantico Creek at Camp 5 near Joplin	383438	772436	1983–84	9.61	5.46	7.46	1.40	1.10	.52	.04	.73	7.71
01658650	SF Quantico Creek near Dumfries	383418	772057	1983–84	16.6	9.64	14.1	2.60	2.10	.94	.06	.73	7.89
01659000	NB Chopawamsic Creek near Independent Hill	383358	772548	1952–56	5.79	2.43	1.70	.19	.10	.07	.00	.95	5.69
01659500	MF Chopawamsic Creek near Garrisonville	383326	772532	1952–56	4.51	2.06	1.60	.19	.10	.07	.00	.93	6.20
01660000	SB Chopawamsic Creek near Garrisonville	383222	772530	1952–56	2.56	1.42	1.00	.18	.10	.06	.00	.74	7.55
01660400	Aquia Creek near Garrisonville	382925	772602	1973–84	34.9	19.4	19.7	1.50	.51	.90	.01	1.12	7.53
01660500	Beaverdam Run near Garrisonville	383025	772545	1952–56	12.7	---	4.62	.28	.10	.50	.00	1.22	---
01661900	Carter Run near Marshall	384758	775209	1978–82	19.5	15.5	13.7	2.70	2.20	1.80	.52	.71	10.76
01662000	Rappahannock River near Warrenton	384105	775415	1944–84	195	132	122	22.3	12.3	13.0	2.50	.74	9.21
01662500	Rush River at Washington	384250	780905	1955–77	14.7	12.5	10.1	.77	.28	.34	.00	1.12	11.55
01662800	Battle Run near Laurel Mills	383920	780427	1960–84	27.6	19.5	16.7	3.04	1.40	2.00	.34	.74	9.58
01663000	Thornton River near Laurel Mills	383741	780347	1945–56	142	109	99.2	27.7	14.4	10.5	1.40	.55	10.41
01663500	Hazel River at Rixeyville	383530	775755	1944–84	287	231	212	46.5	26.9	28.0	6.10	.66	10.94
01664000	Rappahannock River at Remington	383150	774850	1944–84	620	432	415	83.0	47.8	50.0	11.0	.70	9.46
01664500	Rappahannock River at Kellys Ford	382838	774653	1929–52	641	415	421	87.5	45.4	80.0	11.0	.68	8.79
01665500	Rapidan River near Ruckersville	381650	782025	1944–84	114	112	99.8	21.1	13.1	15.0	4.30	.67	13.33
01666500	Robinson River near Locust Dale	381930	780545	1945–84	179	154	150	41.7	27.2	31.0	9.70	.56	11.68
01667000	Rapidan River at Rapidan	381847	780350	1925–30	446	266	297	81.0	38.7	72.0	14.0	.56	8.11

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow varia-bility index	Effective recharge (in/yr)
01668000	Rappahannock River near Fredericksburg	381920	773105	1911–84	1,596	932	993	239	150	189	48.0	0.62	7.92
01670300	Contrary Creek near Mineral	380353	775245	1977–84	5.53	2.74	2.20	.44	.15	.16	.04	.70	6.72
01671100	Little River near Doswell	375221	773048	1963–84	107	54.0	50.6	6.27	2.00	3.50	.58	.91	6.85
01671500	Bunch Creek near Boswells Tavern	380154	781130	1950–79	4.37	2.29	1.70	.25	.04	.17	.00	.83	7.11
01672500	South Anna River near Ashland	374748	773257	1932–84	394	193	194	48.9	30.4	34.0	9.70	.60	6.65
01673800	Po River near Spotsylvania	381017	773542	1964–84	77.4	39.1	37.8	3.66	1.30	1.50	.22	1.01	6.86
02011400	Jackson River near Bacova	380232	795254	1976–84	158	114	88.2	29.6	25.5	26.0	20.0	.47	9.77
02011460	Back Creek near Sunrise	381443	794608	1976–84	56.7	53.0	43.2	5.92	4.35	4.30	2.10	.86	12.69
02011480	Back Creek on Route 600 near Mountain Grove	380805	795157	1975–84	85.8	74.1	62.5	9.66	6.40	5.50	2.50	.81	11.72
02011500	Back Creek near Mountain Grove	380410	795350	1953–84	134	101	80.5	12.3	8.51	7.70	3.60	.82	10.23
02012000	Falling Springs Creek near Falling Springs	375205	795645	1948–52	11.5	17.4	15.5	6.90	6.10	5.40	4.50	.35	20.55
02012500	Jackson River at Falling Spring	375236	795839	1927–79	411	316	268	89.5	78.0	81.0	64.0	.48	10.43
02013000	Dunlap Creek near Covington	374810	800250	1930–84	164	90.9	66.5	18.6	16.0	15.0	11.0	.55	7.52
02014000	Potts Creek near Covington	374344	800233	1930–84	153	114	85.3	27.3	23.4	24.0	17.0	.49	10.13
02014500	Smith Creek above Old Dam near Clifton Forge	375105	795048	1948–56	12.4	13.0	8.67	2.00	2.00	1.20	.87	.64	14.17
02015000	Smith Creek near Clifton Forge	375103	795033	1945–47	12.5	13.1	9.55	2.40	1.80	2.60	1.90	.60	14.25
02015700	Bullpasture River at Williamsville	381143	793414	1962–84	110	98.7	80.2	34.2	30.5	30.0	25.0	.37	12.18
02016000	Cowpasture River near Clifton Forge	374730	794535	1927–84	461	301	259	86.1	73.3	73.0	54.0	.48	8.87
02016500	James River at Lick Run	374625	794705	1926–79	1,373	921	830	262	230	234	185	.50	9.11
02017000	Meadow Creek at New Castle	372935	800635	1931–52	13.8	12.8	10.3	3.00	3.00	3.10	1.90	.54	12.61
02017500	Johns Creek at New Castle	373022	800625	1928–84	104	82.3	58.8	13.5	11.0	11.0	7.80	.64	10.75
02018000	Craig Creek at Parr	373957	795442	1926–84	329	239	183	49.0	41.7	43.0	31.0	.57	9.88
02018500	Catawba Creek near Catawba	372805	800020	1945–74	34.3	23.3	17.9	4.45	3.50	4.00	2.10	.60	9.22
02019000	Catawba Creek near Fincastle	373300	795005	1929–37	104	64.2	46.8	11.5	7.94	11.0	7.50	.61	8.38
02019500	James River at Buchanan	373150	794045	1912–79	2,075	1,412	1,304	410	355	378	271	.50	9.24
02020500	Calfpasture River above Mill Creek at Goshen	375916	792938	1940–84	144	85.0	62.6	7.44	4.82	4.80	1.70	.93	8.01
02021000	Calfpasture River at Goshen	375910	792938	1926–38	190	114	92.6	17.4	14.0	14.0	8.50	.73	8.15
02021500	Maury River at Rockbridge Baths	375426	792520	1930–66	329	193	139	28.5	22.7	24.0	14.0	.69	7.95
02022500	Kerrs Creek near Lexington	374932	792636	1928–84	35	22.7	17.9	7.45	6.26	6.80	4.90	.38	8.79
02023000	Maury River near Lexington	374849	792642	1928–60	487	299	252	72.6	61.1	66.0	43.0	.54	8.34
02024000	Maury River near Buena Vista	374545	792330	1940–66	646	399	317	97.0	81.9	89.0	62.0	.51	8.38
02025000	Pedlar River near Pedlar Mills	373225	791510	1944–56	91	67.7	57.7	13.1	8.51	9.80	3.00	.64	10.10
02025500	James River at Holcombs Rock	373004	791546	1928–79	3,259	2,130	2,119	649	547	572	401	.51	8.87
02026000	James River at Bent Creek	373210	784930	1926–79	3,683	2,497	2,519	832	682	730	449	.48	9.21
02026500	Tye River at Roseland	374513	785912	1929–38	68.0	95.5	73.3	14.9	7.49	15.0	3.10	.69	19.07

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
02027000	Tye River near Lovingston	374255	785855	1940–84	92.8	116	102	23.0	14.8	19.0	5.00	0.65	16.99
02027500	Piney River at Piney River	374208	790140	1951–84	47.6	73.3	60.2	11.0	6.60	7.90	3.20	.74	20.92
02027800	Buffalo River near Tye River	373620	785525	1962–84	147	124	113	32.7	22.3	28.0	7.90	.54	11.48
02028000	Tye (Buffalo) River near Norwood	373740	785250	1941–60	360	349	319	102	75.7	81.0	37.0	.49	13.17
02028500	Rockfish River near Greenfield	375210	784925	1944–84	94.6	104	88.1	19.9	12.4	15.0	4.10	.65	14.90
02029000	James River at Scottsville	374750	782930	1926–79	4,584	3,122	3,221	1,001	782	871	508	.51	9.25
02029500	Hardware River near Scottsville	375024	782828	1927–38	104	80.8	75.0	24.9	20.2	20.0	4.20	.48	10.54
02030000	Hardware River below Briery River nr Scottsville	374845	782720	1940–84	116	86.3	82.2	25.2	17.7	24.0	7.50	.51	10.09
02030500	Slate River near Arvonia	374210	782240	1927–84	226	123	128	42.2	28.6	34.0	9.50	.48	7.41
02031000	Mechums River near White Hall	380609	783535	1944–84	95.4	75.8	70.8	22.6	15.9	16.0	1.60	.50	10.78
02031500	NF Moormans River near White Hall	380825	784505	1953–84	11.4	9.72	5.89	.38	.12	.33	.00	1.19	11.58
02032000	Moormans River near White Hall	380805	784410	1945–46	18.0	11.8	10.3	.00	.00	.00	.00	---	8.88
02032400	Buck Mountain Creek near Free Union	380916	783222	1981–84	37.0	26.8	20.9	5.48	2.80	3.90	.88	.58	9.85
02032680	NF Rivanna River near Proffit	380516	782444	1971–84	176	152	150	34.6	22.0	29.4	8.17	.64	11.71
02033500	Rivanna River below Moores Cr. nr Charlottesville	380109	782713	1927–34	507	268	260	45.7	28.0	48.0	4.80	.75	7.18
02034500	Willis River at Lakeside Village	374000	781000	1927–84	262	136	130	33.4	22.6	26.8	7.19	.59	7.06
02035000	James River at Cartersville	374015	780510	1926–79	6,257	4,028	4,320	1,342	991	1,120	584	.51	8.74
02035500	Lickinghole Creek near Goochland	374131	775722	1945–46	70.0	36.8	41.6	15.5	13.1	7.40	4.70	.43	7.13
02036500	Fine Creek at Fine Creek Mills	373552	774912	1946–84	22.1	12.3	11.9	2.30	1.20	2.00	.47	.71	7.54
02038000	Falling Creek near Chesterfield	372637	773121	1957–84	32.8	20.5	18.1	2.49	1.10	1.80	.64	.86	8.46
02038850	Holiday Creek near Andersonville	372455	783810	1967–84	8.53	5.69	5.43	1.80	1.40	1.60	.52	.48	9.06
02039000	Buffalo Creek near Hampden Sydney	371525	782912	1948–84	69.7	44.9	43.4	17.6	13.2	15.0	6.00	.39	8.75
02039500	Appomattox River at Farmville	371825	782320	1927–84	303	163	168	60.9	45.4	52.0	21.0	.44	7.29
02040000	Appomattox River at Mattoax	372517	775133	1927–84	726	367	390	116	83.0	86.0	30.0	.53	6.87
02041000	Deep Creek near Mannboro	371659	775212	1948–84	158	79.8	78.5	20.0	11.3	12.0	1.40	.59	6.85
02041500	Appomattox River near Petersburg	371333	773220	1928–66	1,334	614	680	197	133.5	154	58.0	.54	6.25
02042000	Swift Creek near Chester	371855	772940	1944–49	143	85.1	82.4	13.4	8.44	4.20	.75	.79	8.08
02044000	Nottoway River near Burkeville	370440	781150	1948–84	38.7	16.6	15.4	2.20	1.10	.92	.11	.85	5.81
02044500	Nottoway River near Rawlings	365900	774800	1952–84	309	177	176	47.7	28.2	26.0	4.00	.57	7.76
02045000	Nottoway River near McKenney	365645	774355	1947–50	362	221	238	92.2	75.0	33.0	4.00	.41	8.28
02046000	Stony Creek near Dinwiddie	370401	773610	1948–84	112	58.9	52.4	6.52	2.73	4.30	.25	.91	7.14
02050500	North Meherrin River near Keysville	370305	782520	1950–61	9.20	4.81	3.30	1.10	.59	.54	.21	.48	7.10
02051000	North Meherrin River near Lunenburg	365950	782100	1948–84	55.6	22.4	21.4	4.02	2.59	2.60	.49	.73	5.46
02051500	Meherrin River near Lawrenceville	364300	774955	1930–84	552	242	256	68.0	44.8	52.0	16.0	.58	5.94
02051600	Great Creek near Cochran	364846	775519	1960–84	30.7	18.2	17.0	3.74	2.00	3.10	.35	.66	8.05

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
02052000	Meherrin River at Emporia	364124	773227	1967–84	747	372	392	101	62.8	60.0	23.0	0.59	6.76
02052500	Fountains Creek near Brink	363655	774200	1955–84	65.2	32.4	27.2	1.30	.26	.76	.00	1.32	6.75
02053800	SF Roanoke River near Shawsville	370824	801600	1962–84	110	77.4	70.2	27.2	22.4	21.0	11.0	.41	9.55
02054500	Roanoke River at Lafayette	371411	801234	1945–84	257	160	135	51.1	42.6	42.0	24.0	.42	8.43
02055000	Roanoke River at Roanoke	371530	795620	1951–84	395	229	191	68.8	56.9	58.0	35.0	.44	7.88
02055100	Tinker Creek near Daleville	372503	795608	1958–84	11.0	8.83	6.77	2.30	1.90	2.20	1.40	.47	10.89
02056650	Back Creek near Dundee	371340	795206	1976–84	56.8	39.4	32.5	8.71	6.20	5.50	2.50	.57	9.42
02056900	Blackwater River near Rocky Mount	370242	794540	1978–84	115	96.6	89.9	32.9	24.3	22.0	12.0	.44	11.40
02057000	Blackwater River near Union Hall	370235	794107	1927–63	208	160	165	71.2	55.4	66.0	26.0	.36	10.42
02057500	Roanoke (Staunton) River near Toshes	370203	793118	1927–62	1,020	668	667	273	223	246	142	.39	8.89
02058000	Snow Creek at Sago	365350	793905	1935–43	60.0	45.8	46.8	25.4	22.2	20.0	10.0	.27	10.37
02058400	Pigg River near Sandy Level	365645	793130	1965–84	350	241	254	112	86.7	96.0	47.0	.36	9.37
02058500	Pigg River near Toshes	365901	793052	1932–63	394	270	286	147	116	131	66.0	.29	9.30
02059500	Goose Creek near Huddleston	371023	793114	1956–84	188	116	109	45.0	36.9	40.0	23.0	.38	8.40
02060500	Roanoke River at Altavista	370616	791744	1932–62	1,789	1,267	1,350	552	440	492	266	.39	9.61
02061000	Big Otter River near Bedford	372150	792510	1945–60	116	98.1	91.1	27.2	19.3	17.0	7.30	.52	11.48
02061500	Big Otter River near Evington	371230	791814	1938–84	320	219	215	80.0	58.3	69.0	28.0	.43	9.28
02062000	Big Otter River near Altavista	371105	791645	1930–36	372	193	181	57.9	45.2	51.0	21.0	.50	7.04
02062500	Roanoke (Staunton) River at Brookneal	370228	785702	1925–62	2,415	1,574	1,715	734	568	648	344	.37	8.85
02063000	Caldwells Creek near Appomattox	371940	785120	1954–60	5.10	2.54	2.30	1.30	.86	.84	.40	.25	6.77
02063500	Falling River at Spring Mills	371440	785500	1955–60	52.2	27.7	26.4	13.1	9.66	9.50	3.70	.30	7.21
02064000	Falling River near Naruna	370736	785736	1931–84	173	93.1	92.9	36.2	27.5	32.0	15.0	.41	7.30
02064500	Little Falling River at Hat Creek	370750	785450	1930–34	43.0	16.0	18.6	4.97	1.80	4.60	1.50	.57	5.06
02065000	Falling River near Brookneal	370454	785607	1935–41	228	154	153	82.8	71.2	63.0	33.0	.27	9.15
02065500	Cub Creek at Phenix	370445	784550	1948–84	98.0	63.3	63.7	24.9	18.3	22.0	8.20	.41	8.77
02066000	Roanoke (Staunton) River at Randolph	365454	784428	1902–62	2,977	1,950	2,209	1,018	773	847	426	.34	8.89
02066500	Roanoke Creek at Saxe	365549	783956	1948–72	135	56.0	55.5	15.5	8.18	8.70	.80	.55	5.63
02067000	Roanoke (Staunton) River near Clover	365017	784002	1931–52	3,230	2,038	2,279	1,011	799	914	433	.35	8.56
02069700	South Mayo River near Nettleridge	363415	800747	1964–84	84.6	99.2	96.9	50.7	41.6	44.0	27.0	.28	15.92
02070000	North Mayo River near Spencer	363405	795915	1930–84	108	93.7	95.4	49.1	40.2	44.0	25.0	.29	11.78
02072500	Smith River at Bassett	364612	800004	1940–50	259	268	271	149	128	125	95.0	.26	14.04
02073500	Leatherwood Creek near Old Liberty	363810	794730	1925–34	68.0	28.1	32.3	11.1	6.96	15.0	7.50	.46	5.61
02074500	Sandy River near Danville	363710	793016	1930–84	112	70.0	72.6	34.0	27.4	29.0	15.0	.33	8.48
02075000	Dan River at Danville	363515	792255	1936–50	2,050	1,400	1,709	866	748	739	515	.29	9.27
02076500	Georges Creek near Gretna	365611	791842	1950–84	9.24	7.44	7.10	3.70	2.60	3.20	1.60	.28	10.93

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
02078000	Hyco River near Omega	363809	784820	1935–50	413	148	150	27.7	16.6	14.0	2.70	0.73	4.87
02079000	Roanoke (Staunton) River at Clarksville	363740	783304	1936–52	7,320	4,558	5,558	2,610	2,158	2,195	1,423	.33	8.45
02079640	Allen Creek near Boydton	364046	781937	1963–84	53.4	17.5	15.2	1.40	.64	.94	.03	1.04	4.45
03164000	New River near Galax	363850	805845	1931–84	1131	1,367	1,472	674	569	611	400	.34	16.41
03165000	Chestnut Creek at Galax	363845	805510	1946–84	39.4	52.6	53.6	29.1	24.6	27.0	17.0	.27	18.13
03165500	New River at Ivanhoe	365005	805710	1931–78	1,340	1,403	1,696	748	619	663	427.0	.36	14.21
03166000	Cripple Creek near Ivanhoe	365135	805850	1930–34	148	74.8	64.0	32.5	28.5	38.0	27.0	.29	6.86
03166800	Glade Creek at Grahams Forge	365551	805402	1978–84	7.15	.46	.33	.10	.08	.14	.10	.52	.87
03167000	Reed Creek at Grahams Forge	365622	805313	1910–84	247	186	160	73.3	65.2	70.0	52.0	.34	10.22
03167500	Big Reed Island Creek near Allisonia	365320	804340	1910–84	278	293	315	165	141	146	101	.28	14.32
03168000	New River at Allisonia	365615	804445	1931–84	2,202	2,156	2,476	1,138	954	1,040	725	.34	13.29
03168500	Peak Creek at Pulaski	370250	804635	1952–56	60.9	21.4	12.5	2.50	2.00	3.80	2.50	.70	4.78
03170000	Little River at Graysontown	370215	803325	1930–84	300	255	268	123	104	109	69.0	.34	11.53
03171500	New River at Eggleston	371722	803701	1916–35	2,941	2,515	2,971	1263	1,070	1,280	770	.37	11.61
03172500	Walker Creek at Staffordsville	371430	804240	1909–16	277	220	190	49.7	42.1	36.0	24.0	.58	10.80
03173000	Walker Creek at Bane	371605	804235	1939–84	305	207	166	49.8	42.9	44.0	33.0	.52	9.22
03175500	Wolf Creek near Narrows	371820	805100	1910–84	223	196	153	39.7	32.6	35.0	23.0	.59	11.93
03176500	New River at Glen Lyn	372222	805139	1929–38	3,768	3,207	3,645	1487	1,234	1,700	800	.39	11.56
03471500	SF Holston River at Riverside near Chilhowie	364537	813753	1922–84	76.1	84.0	71.5	28.1	24.6	25.0	20.0	.41	14.98
03472500	Beaverdam Creek at Damascus	363740	814728	1949–59	56.0	65.4	52.7	12.9	8.26	9.50	4.70	.61	15.86
03473000	SF Holston River near Damascus	363906	815039	1933–84	301	333	305	113	95.3	99.0	73.0	.43	15.03
03473500	MF Holston River at Groseclose	365319	812051	1949–57	7.39	7.46	5.70	3.50	3.1	3.30	2.70	.21	13.70
03474000	MF Holston River at Seven Mile Ford	364826	813720	1944–81	132	109	94.3	37.9	33.4	34.0	27.0	.40	11.24
03474500	MF Holston River at Chilhowie	364745	814050	1922–31	155	131	120	42.4	36.3	40.0	25.0	.45	11.48
03475000	MF Holston River near Meadowview	364247	814908	1978–84	211	191	187	79.6	69.6	65.0	50.0	.37	12.30
03477500	Beaver Creek near Wallace	363825	820642	1947–56	13.7	12.9	10.3	4.40	3.80	4.50	3.20	.37	12.77
03478400	Beaver Creek at Bristol	363754	820802	1959–84	27.7	30.9	28.2	12.2	10.4	11.0	8.50	.36	15.15
03487800	Lick Creek near Chatham Hill	365744	812821	1966–68	25.5	18.5	18.4	1.70	.86	.75	.39	1.03	9.82
03488000	NF Holston River near Saltville	365348	814447	1922–84	222	178	156	39.9	32.3	34.0	24.0	.59	10.89
03488100	NF Holston River near Plasterco	365152	815017	1963–66	259	133	116	30.2	25.5	39.0	28.0	.59	6.95
03488445	Brumley Creek near Hansonville	365121	820243	1980–81	4.29	5.73	5.20	.35	.19	.14	.05	1.17	18.12
03488450	Brumley Creek at Brumley Gap	364730	820110	1980–81	21.1	22.7	17.9	1.70	.88	.43	.15	1.02	14.60
03488500	NF Holston River at Holston	364629	820422	1953–59	402	313	231	59.0	51.9	66.0	48.0	.59	10.58
03489500	NF Holston River at Mendota	364205	821826	1922–31	493	385	376	90.3	70.6	81.0	46.0	.62	10.60
03489850	Cove Creek near Hilton	363908	822153	1966–68	17.6	11.9	12.0	2.60	1.90	2.10	1.40	.66	9.17

Appendix 1. Base-flow characteristics at continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Period of record	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
03489870	Big Moccasin Cr. at Collinwood near Hansonville	364416	821925	1966–68	41.9	36.0	38.2	9.54	8.27	5.30	3.50	0.60	11.66
03489900	Big Moccasin Creek near Gate City	363847	823312	1966–68	79.6	66.8	68.8	19.9	17.0	10.0	6.70	.54	11.40
03490000	NF Holston River near Gate City	363631	823405	1958–81	672	553	532	127	102	97.0	56.0	.62	11.16
03521500	Clinch River at Richlands	370510	814652	1972–84	137	131	124	34.1	27.2	29.0	19.0	.56	12.99
03522000	Little River at Wardell	370216	814752	1950–52	103	118	98.5	35.2	30.0	25.0	18.0	.45	15.52
03523000	Big Cedar Creek near Lebanon	365429	820220	1953–59	51.5	42.9	28.6	7.52	6.67	5.10	3.20	.58	11.32
03524000	Clinch River at Cleveland	365641	820918	1922–84	528	415	378	98.0	78.4	81.0	54.0	.59	10.68
03525000	Stony Creek at Fort Blackmore	364630	823450	1950–52	41.4	49.1	41.8	3.10	2.00	1.80	.52	1.13	16.10
03526000	Copper Creek near Gate City	364026	823357	1949–72	106	93.1	74.4	27.5	24.1	24.0	18.0	.43	11.93
03527000	Clinch River at Speers Ferry	363855	824502	1951–81	1,126	911	864	190	151	148	100	.66	10.98
03527500	NF Clinch River at Duffield	364240	824745	1953–59	23.1	22.6	9.78	1.60	1.30	1.90	.95	.79	13.26
03531500	Powell River near Jonesville	363943	830542	1933–84	319	288	248	52.1	38.1	42.0	24.0	.68	12.26

Appendix 2. Base-flow characteristics at partial-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia

[Latitude and longitude are reported in degrees, minutes, and seconds; mi^2, square mile; ft^3/s, cubic foot per second; in/yr, inch per year; Q_{50}, Q_{90}, and Q_{95}, indicate the 50-, 90-, and 95-percent discharge on the streamflow-duration curve, respectively; 7Q2 and 7Q10, indicate the annual minimum average 7-consecutive-day low-flow discharge having 2-year and 10-year recurrence intervals, respectively; leaders (- - -) indicate value could not be determined; NF, North Fork; SF, South Fork]

Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
01613570	Back Creek at Gainesboro	391709	781551	34.4	8.15	7.15	3.00	2.62	2.80	2.00	0.38	3.22
01613590	Issac Creek near Gainesboro	391805	781650	15.8	2.75	4.20	.50	.37	.36	.18	.92	2.36
01616100	Dry Marsh near Berryville	391132	780410	11.4	13.0	11.3	5.20	4.50	4.70	2.90	.34	15.48
01620690	North River at Route 727 near Bridgewater	382342	790155	102	50.5	41.0	5.95	4.25	4.90	2.30	.84	6.72
01621300	Dry River at Route 257 at Bridgewater	382427	785833	120	45.0	33.0	6.50	5.10	6.40	3.40	.71	5.09
01622230	Middle River below Trimbles Mill near Swoope	380810	791306	20.6	9.75	9.38	3.80	3.30	3.60	2.70	.39	6.42
01628080	Madison Run near Grottoes	381524	784606	5.78	4.80	3.20	.30	.20	.33	.12	1.03	11.27
01630700	Gooney Run near Glen Echo	385006	781356	20.6	25.0	18.0	4.10	2.90	3.20	1.80	.64	16.47
01632080	Linville Creek at Broadway	383622	784813	42.3	16.5	14.0	6.25	5.00	6.00	4.00	.35	5.29
01632840	Smith Creek at Route 717 near Lacey Spring	383218	784503	21.3	10.5	8.75	3.10	2.55	3.10	1.80	.45	6.69
01632890	Smith Creek at Route 794 near Lacey Spring	383651	784021	72.7	51.0	42.0	15.5	12.5	15.0	9.20	.43	9.52
01633475	Riles Run at Route 703 near Conicville	385039	784229	5.65	1.50	1.25	.50	.41	.61	.47	.40	3.60
01633485	Stony Creek near Liberty Furnace	385341	783957	57.0	24.0	17.0	4.30	2.90	6.90	4.40	.60	5.71
01633510	Swover Creek near Conicville	385029	784039	3.26	---	---	.14	.09	.10	.05	---	---
01633540	Stony Creek at US HWY 11 at Edinburg	384921	783408	104	51.0	44.0	18.5	16.3	18.0	11.0	.38	6.65
01633730	Toms Brook at Toms Brook	385642	782632	9.35	2.35	1.90	.65	.53	.54	.34	.47	3.41
01633745	Toms Brook near Toms Brook	385535	782530	16.2	3.10	2.62	1.30	1.08	1.10	.85	.30	2.60
01634340	Cedar Creek near Lebanon Church	390453	782530	50.1	35.0	26.0	7.00	4.50	4.30	3.20	.57	9.48
01635045	Buffalo Marsh Run near Middletown	390334	781817	5.27	3.58	2.88	1.19	.96	1.00	.54	.38	9.22
01635100	Cedar Creek near Strasburg	385927	781942	157	67.5	53.0	20.5	15.8	16.0	11.0	.41	5.83
01635250	Passage Creek at Route 776 near Detrick	384749	782742	31.7	14.0	9.50	2.30	1.50	1.70	.91	.62	5.99
01635300	Peters Mill Run near Detrick	385148	782625	4.22	3.10	2.20	.56	.42	.42	1.20	.59	9.97
01636270	Borden Marsh Run at Route 624 near Boyce	390009	780551	8.71	8.20	6.20	2.38	2.00	2.10	1.20	.42	12.78
01636300	Westbrook Run near Boyce	390422	780530	1.40	1.30	1.10	.43	.35	.40	.20	.41	12.60
01636690	Piney Run near Lovettsville	391839	774306	13.7	8.75	7.50	.88	.44	.53	.11	.93	8.67
01643585	Potomac River Tributary No 1 near Lucketts	391232	772839	2.00	---	.58	.13	.09	.10	.04	.65	---
01643600	Limestone Branch Tributary No 1 near Leesburg	391027	773148	6.82	---	3.70	1.50	1.10	1.20	.60	.39	---
01643643	Goose Creek at Delaplane	385451	775520	45.6	26.5	23.5	2.77	1.45	1.60	.20	.93	7.89
01643800	NF Goose Creek at Route 722 near Lincoln	390438	774152	24.0	---	---	1.73	1.10	1.10	.34	---	---
01643950	Goose Creek at Oatlands	390138	773717	276	138	118	18.0	10.2	12.0	2.90	.82	6.79

Appendix 2. Base-flow characteristics at partial-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
01643988	Little River near Oatlands	390025	773653	47.7	26.0	22.0	3.40	1.80	2.10	0.50	0.81	7.40
01644255	SF Broad Run at Arcola	385710	773209	5.31	.80	.58	.01	.00	.01	.00	1.76	2.04
01644280	Broad Run near Leesburg	390335	772622	76.1	---	---	.60	.22	.28	.02	---	---
01644300	Sugarland Run at Herndon	385800	772217	3.36	.44	.48	.08	.05	.00	.00	.78	1.78
01646200	Scott Run near Mclean	385732	771221	4.69	2.90	2.70	.82	.54	.73	.12	.52	8.39
01656200	Broad Run near Warrenton	384825	774847	2.94	1.57	1.32	.18	.09	.11	.03	.87	7.25
01656655	Kettle Run near Nokesville	384328	773632	11.9	---	---	.00	.00	.00	.00	---	---
01656659	Kettle Run at Brentsville	384158	773042	25.0	---	---	.00	.00	.00	.00	---	---
01656670	Broad Run at Brentsville	384132	772942	137	---	---	4.20	2.40	3.30	1.20	---	---
01656705	Black Branch near Haymarket	385446	773743	3.05	---	2.50	.02	.01	.02	.00	2.10	---
01656715	Chestnut Lick near Catharpin	385317	773537	11.1	---	---	.01	.00	.01	.00	---	---
01656743	Lick Branch at Catharpin	385058	773424	3.06	---	.90	.00	.00	.00	.00	---	---
01656750	Little Bull Run near Bull Run	385032	773222	27.2	---	---	.42	.17	.20	.00	---	---
01656768	Flat Branch near Manassas	384622	772957	1.10	.08	.07	.00	.00	.00	.00	---	.99
01657245	Russia Branch at Manassas	384542	772637	1.47	.26	.21	.03	.01	.02	.00	.85	2.40
01661840	Rappahannock River near Flint Hill	384532	780142	65.9	34.0	30.1	5.52	2.82	3.00	.46	.74	7.00
01662110	Hazel River at Route 631 near Woodville	383627	781415	5.54	13.5	12.5	2.80	1.60	1.70	.36	.65	33.07
01662150	Hughes River near Nethers	383427	781749	9.92	16.3	16.0	2.70	1.50	1.80	.30	.77	22.30
01665100	Jonas Run near Brandy Station	382920	775408	11.4	---	4.60	.00	.00	.00	.00	---	---
01665150	Mountain Run near Kellys Ford	382737	774850	118	---	23.0	4.40	2.60	4.10	.80	.72	---
01665220	Deep Run at Route 615 near Goldvein	382707	773746	15.4	6.30	5.65	.50	.21	.53	.10	1.05	5.55
01665400	Conway River near Stanardsville	381958	782353	25.8	26.0	24.0	2.70	1.40	1.70	.30	.95	13.68
01665850	Robinson River at Route 231 near Criglersville	382654	781644	47.8	85.0	75.0	6.10	2.65	3.00	.45	1.09	24.13
01667600	Cedar Run Tributary near Culpeper	382350	780025	.58	.23	.20	.03	.02	.01	.00	.82	5.38
01667650	Cedar Run near Culpeper	382148	775832	33.2	---	2.50	.05	.00	.03	.00	1.70	---
01667700	Sumerduck Run near Culpeper	382219	775627	11.0	---	1.00	.00	.00	.00	.00	---	---
01667848	Black Walnut Run at Burr Hill	382036	775134	12.1	6.55	5.41	.83	.30	.35	.05	.81	7.35
01667850	Mine Run at Burr Hill	382036	775133	31.8	---	---	1.84	.70	.78	.10	---	---
01670120	Mountain Run at Route 643 near Gordonsville	380939	780606	14.1	4.80	4.80	1.60	.95	.95	.20	.48	4.62
01670200	Pamunkey Creek at Route 651 near Lahore	380916	775702	51.7	30.3	29.8	5.58	3.29	4.00	1.00	.73	7.94
01671040	Long Creek at Route 655 near Buckner	375538	774744	8.01	2.29	2.24	.54	.30	.35	.10	.62	3.88
01671680	South Anna River at Route 208 near Louisa	375850	780254	113	34.4	31.8	9.45	5.20	6.00	2.00	.53	4.13
01671950	Deep Creek at Route 640 near Apple Grove	375157	775453	10.1	3.43	3.34	.62	.31	.42	.10	.73	4.61
01672200	Taylors Creek at Route 715 near Montpelier	374749	774327	22.0	9.02	8.95	2.08	1.10	1.50	.50	.63	5.56
01672400	South Anna River Tributary No 6 near Ashland	374840	773420	.33	.17	.17	.04	.02	.02	.00	.63	6.99

Appendix 2. Base-flow characteristics at partial-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
01672800	Newfound River at Route 685 near Ashland	375035	773230	36.3	9.18	8.58	2.17	1.09	1.40	.40	0.60	3.43
01673960	Mat River near Marye	380623	773607	14.5	3.60	3.40	.16	.04	.05	.00	1.33	3.37
01674172	Polecat Creek near Ladysmith	375813	772913	10.8	4.35	4.20	.38	.14	.17	.00	1.04	5.47
02002000	Jackson River at US HWY 220 at Vanderpool	382205	793735	13.0	7.50	6.50	1.80	1.40	1.40	.90	.56	7.83
02015600	Cowpasture River near Head Waters	381930	792614	11.3	8.10	6.90	2.00	1.60	1.60	1.00	.54	9.73
02015800	Thompson Creek at Route 39 near Bath Alum	380238	794105	15.7	8.10	6.40	1.90	1.60	2.20	1.80	.53	7.00
02016600	Craig Creek above Muddy Branch near McDonalds Mill	372116	801723	23.0	10.0	5.60	.42	.31	.31	.17	1.12	5.90
02017300	Craig Creek at New Castle	373006	800618	112	.58	.48	.22	.18	.20	.15	.34	.07
02017400	Johns Creek Tributary near New Castle	373030	801130	1.57	.70	.50	.11	.08	.09	.06	.66	6.05
02019100	Spreading Spring Branch at Springwood	373257	794442	6.76	3.20	2.80	1.10	.88	1.00	.55	.41	6.42
02020170	East Fork Elk Creek at Belfast Trail near Natural Bridge	373417	792931	4.15	1.93	1.50	.39	.31	.32	.22	.59	6.31
02020200	Calfpasture River near West Augusta	381624	791802	12.8	---	5.60	.03	.01	.01	.00	2.27	---
02021700	Cedar Grove Branch near Rockbridge Baths	375300	792308	12.3	4.60	3.90	1.85	1.65	1.80	1.40	.32	5.07
02024240	South Buffalo Creek at Route 611 near Lexington	374414	793418	21.1	9.95	8.95	4.55	4.10	4.20	3.40	.29	6.40
02024760	Reed Creek at Route 637 near Big Island	373010	792407	7.46	10.8	9.44	3.45	2.74	3.00	1.80	.44	19.66
02024900	Pedlar River below Davis Mill Creek near Buena Vista	374448	791609	18.2	13.5	11.5	4.50	3.90	4.20	3.00	.41	10.07
02025650	Harris Creek at Route 675 near Monroe	372935	790910	34.5	28.0	27.0	7.20	4.90	4.20	1.10	.57	11.01
02025800	Burton Creek Tributary at Lynchburg	372110	791105	2.36	1.19	1.11	.33	.23	.30	.10	.53	6.84
02025900	Beaver Creek at Route 660 near Bocock	372116	790427	24.0	13.6	13.1	5.20	3.90	4.60	2.10	.40	7.69
02026400	SF Tye River at Nash	375124	790247	14.2	15.5	13.0	5.30	4.00	4.40	2.10	.39	14.81
02027600	Buffalo River below Forks of Buffalo	374047	791320	15.9	16.0	12.3	2.40	1.50	2.00	.69	.71	13.66
02027670	Buffalo River near Amherst	373618	790135	93.1	58.8	52.2	17.2	12.4	14.0	6.60	.48	8.57
02027700	Buffalo River Tributary near Amherst	373345	785735	.46	.40	.33	.04	.02	.03	.00	.92	11.80
02028450	Sycamore Creek at Route 601 near Howardsville	374043	783955	9.94	5.40	5.20	1.80	1.40	1.60	.55	.46	7.37
02028700	Cove Creek near Covesville	375206	784332	4.00	3.70	3.30	1.03	.73	.90	.30	.51	12.55
02029200	NF Hardware River at Red Hill	375803	783704	11.0	11.8	11.0	3.10	2.15	3.00	.85	.55	14.56
02029400	South Branch NF Hardware River near North Garden	375721	783935	6.59	5.40	5.20	1.70	1.20	1.60	.50	.49	11.12
02030150	Slate River at Buckingham	373308	783353	63.0	39.8	38.3	12.8	9.50	11.0	3.50	.48	8.57
02030300	Slate River near Dillwyn	373708	782910	154	80.0	85.0	27.0	18.2	22.0	5.80	.50	7.05
02030850	Stockton Creek near Crozet	380237	784154	20.4	11.5	10.5	3.20	2.20	2.00	.22	.52	7.65
02033750	Buck Island Creek below Houchins Creek near Simeon	375713	782415	31.0	11.0	10.0	1.40	.75	1.30	.18	.85	4.82
02034150	Little Byrd Creek at Route 667 near Fife	374550	780524	29.9	---	6.60	.78	.42	.66	.10	.93	---
02034300	Little Willis River at Curdsville	372438	782735	7.07	2.80	2.70	1.10	.83	.95	.40	.39	5.37
02035075	Maxey Mill Creek at Ballsville	373107	780731	12.0	4.75	4.95	1.40	.92	1.10	.34	.55	5.37
02035460	Big Lickinghole Creek at Route 613 near Goland	374352	775721	28.7	8.20	8.20	3.00	2.00	2.30	.96	.44	3.88

Appendix 2. Base-flow characteristics at partial-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow varia-bility index	Effective recharge (in/yr)
02036700	Bernards Creek near Manakin	373325	774033	15.4	6.20	5.90	1.00	.00	.00	0.00	0.77	5.46
02038900	Dry Creek near Farmville	372045	782445	3.64	.41	.38	.06	.04	.05	.00	.80	1.53
02039600	Briery Creek at US HWY 460 (Bus) near Rice	371649	782148	41.5	12.0	11.9	4.40	3.25	3.70	1.40	.43	3.92
02039700	Sandy River at US HWY 460 near Rice	371631	781917	39.7	13.8	13.5	4.50	3.20	3.60	1.30	.48	4.72
02039800	Angola Creek near Angola	372216	781744	6.74	1.95	1.90	1.00	.80	.86	.46	.28	3.93
02040500	Flat Creek near Amelia	372327	780345	73.0	38.3	36.0	5.45	2.80	2.60	.30	.82	7.11
02040600	Nibbs Creek Tributary near Amelia	372345	775820	.35	.15	.15	.02	.01	.01	.00	.88	5.82
02040900	Little Creek near Denaro	371332	780110	3.93	1.85	1.80	.66	.46	.46	.14	.44	6.39
02041400	Whipponock Creek at Route 627 near Church Road	371145	773923	3.27	1.03	.98	.18	.09	.12	.01	.74	4.27
02042050	Franks Branch at Route 626 near Colonial Heights	371642	772835	16.8	8.50	7.70	.58	.20	.25	.01	1.12	6.87
02044200	Falls Creek Tributary near Victoria	370204	781026	.34	.12	.11	.02	.01	.01	.00	.74	4.79
02044300	Little Nottoway River at Route 40 near Blackstone	370225	780207	72.6	44.5	42.0	7.80	3.90	3.40	.48	.73	8.32
02044400	Hurricane Branch at Blackstone	370447	775855	1.61	.17	.17	.04	.02	.02	.00	.63	1.43
02045800	White Oak Creek at Route 620 near Hebron	370740	774854	5.94	---	---	.46	.16	.12	.01	---	---
02046300	Hatcher Run at Route 613 near Reems	370723	772845	35.7	8.00	7.00	1.20	.60	.86	.08	.77	3.04
02046750	Three Creek at Route 616 near Emporia	364325	773113	67.2	10.7	10.3	1.80	.96	1.20	.29	.76	2.16
02050400	North Meherrin River near Briery	370420	782745	1.19	.58	.56	.18	.14	.14	.05	.49	6.61
02051100	South Meherrin River near Chase City	365134	782522	27.6	6.51	6.00	1.02	.61	.70	.16	.77	3.20
02051175	Meherrin River at Route 636 near North View	364803	781004	305	85.0	80.0	21.0	14.0	13.0	8.70	.58	3.78
02051200	Flat Rock Creek near Kenbridge	365358	780722	21.5	14.0	13.1	2.70	1.80	1.80	.36	.69	8.84
02051300	Evans Creek near Brodnax	364407	775734	14.6	5.60	5.60	2.30	1.60	1.80	.65	.39	5.20
02051650	Rocky Run near Dolphin	364735	774935	1.41	.49	.42	.03	.01	.01	.00	1.15	4.72
02052100	Rattlesnake Creek near Ankum	363648	775225	6.55	1.40	1.40	.10	.03	.04	.00	1.15	2.90
02054120	NF Roanoke River near Lusters Gate	371318	802156	44.6	19.5	17.0	6.10	5.00	4.80	2.60	.45	5.93
02056700	Beaverdam Creek at Route 757 near Hardy	371328	794523	24.8	---	---	4.00	2.80	3.20	.88	---	---
02056950	Maggodee Creek near Boones Mill	370757	795820	11.0	8.75	8.25	2.15	1.30	1.20	.34	.58	10.79
02057050	Gills Creek at Route 122 near Burnt Chimney	370731	794658	21.8	13.0	14.0	5.00	3.60	6.00	.24	.45	8.09
02057600	Pigg River at Route 40 near Rocky Mount	365834	795532	40.5	40.5	40.0	18.0	13.5	17.0	8.50	.35	13.57
02057700	Powder Mill Creek at Rocky Mount	370026	795225	.64	.36	.36	.12	.09	.11	.05	.48	7.63
02057750	Little Chestnut Creek near Syndorsville	365407	795055	15.5	9.50	10.0	3.40	2.50	2.90	1.10	.47	8.32
02058100	Turkeycock Creek at Route 969 at Sago	365253	793752	29.5	12.2	12.4	10.0	8.00	8.90	4.20	.09	5.61
02059420	NF Goose Creek near Montvale	372214	794155	31.5	10.4	10.3	8.80	7.90	8.40	6.50	.07	4.48
02059460	Shockoe Creek at Route 755 near Irving	371846	794034	4.02	2.25	2.05	.37	.26	.30	.10	.74	7.60
02060400	Sycamore Creek at Sycamore	370125	792124	5.30	1.60	1.60	1.05	.09	1.00	.70	.18	4.10
02061200	Little Otter River at Route 122 near Bedford	372141	793003	18.3	12.0	11.0	4.20	3.10	3.60	1.50	.42	8.90

Appendix 2. Base-flow characteristics at partial-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
02062300	Seneca Creek at Route 633 near Long Island	370623	790722	52.0	26.5	26.5	9.00	7.00	8.00	3.30	0.47	6.92
02063400	Reedy Creek near Spring Mills	371654	785414	12.6	7.83	7.67	2.70	2.03	2.40	.90	.45	8.43
02063600	Button Creek near Rustburg	371525	790410	.59	.39	.39	.10	.06	.08	.03	.59	8.97
02065100	Snake Creek near Brookneal	370042	785752	1.68	.78	.77	.45	.36	.40	.25	.23	6.30
02065220	Catawba Creek at Route 626 at Clarkton	365830	785345	40.3	11.3	11.2	8.75	6.75	8.00	4.40	.11	3.80
02065300	Right Hand Fork near Appomattox	371612	784914	2.08	1.27	1.27	.62	.48	.57	.30	.31	8.29
02065400	Big Cub Creek at Route 701 near Madisonville	371213	784405	37.2	12.5	12.5	10.2	7.50	9.00	4.00	.09	4.54
02066450	Roanoke Creek near Charlotte Court House	370327	783503	42.7	11.3	11.2	5.65	4.00	4.80	1.60	.30	3.58
02067100	Difficult Creek at US HWY 360 near Scottsburg	364746	784710	40.3	15.7	15.0	6.12	5.05	6.20	2.40	.39	5.29
02067810	Maple Swamp Branch near Meadows of Dan	364410	802628	.49	.57	.64	.35	.36	.30	.21	.26	15.79
02069600	Anglin Branch near Stuart	363815	801255	3.10	3.50	3.50	1.45	1.10	1.20	.58	.38	15.32
02069800	Grassy Branch at Route 721 near Sanville	364203	800548	3.29	3.20	3.20	1.60	1.25	1.40	.82	.30	13.20
02071600	Smith River near Charity	364818	801204	79.7	80.0	80.0	4.10	3.45	38.0	22.0	1.29	13.62
02071800	Nicholas Creek near Ferrum	365211	800310	12.2	11.1	11.1	4.65	3.20	3.60	1.30	.38	12.35
02072600	Reed Creek near Collinsville	364517	795448	12.4	7.25	7.25	3.30	2.60	2.80	1.40	.34	7.93
02074450	Sandy River near Swansonville	364423	793654	24.1	11.2	11.3	7.38	6.00	6.00	3.20	.18	6.28
02075020	Fall Creek at Route 719 near Danville	364042	792413	5.39	2.10	2.15	.59	.39	.44	.15	.56	5.29
02075275	Sandy Creek (River) at US HWY 58 near Ringgold	363450	791331	18.2	7.63	7.75	4.03	3.50	3.50	1.90	.28	5.69
02075600	Birch Creek near Birch	364212	791303	19.8	10.5	10.5	3.70	1.90	3.20	1.30	.45	7.21
02075900	Lawsons Creek at Turbeville	363639	790128	8.70	2.70	2.70	1.10	.75	.98	.42	.39	4.21
02076300	Banister River at US HWY 29 near Chatham	364641	792333	84.8	46.0	48.0	19.0	13.5	16.0	6.70	.40	7.36
02076650	Banister River at Route 640 near Mount Airy	365439	791100	269	160	162	79.8	34.8	63.0	31.0	.31	8.07
02076700	Blacks Creek near Mount Airy	365640	790956	3.44	1.35	1.35	.18	.06	.12	.02	.88	5.33
02076770	Sandy Creek at Route 832 at Meadville	364932	790139	99.0	43.4	42.1	21.5	16.4	19.0	9.10	.29	5.95
02078400	Bluestone Creek at Route 699 near Laconi	364348	783658	47.8	18.0	16.5	1.20	.62	.60	.05	1.14	5.11
02079660	Jolly Hollow Branch at Boydton	364038	782313	3.60	1.10	1.05	.37	.28	.32	.18	.45	4.15
02079665	Cox Creek at Baskerville	364058	781615	11.5	5.10	5.00	1.67	1.15	1.30	.40	.48	6.02
03162415	Helton Creek at US HWY 58 near Whitetop	363633	813352	5.28	7.75	5.50	.85	.65	2.60	1.60	.81	19.92
03162650	Wilson Creek at Volney	363720	812336	17.7	8.25	5.50	.70	.53	2.20	1.30	.90	6.33
03163500	Elk Creek at Mount Carmel Church near Galax	364153	810326	63.5	50.0	52.5	14.5	10.3	12.0	5.10	.56	10.69
03165350	Brush Creek at Route 94 near Ivanhoe	364559	805905	15.1	.32	.12	---	---	1.00	.25	---	.29
03165750	Blue Springs Creek near Cedar Springs	364814	811822	12.9	6.80	5.80	2.50	2.20	2.40	1.70	.37	7.15
03166400	Stony Fork near Favonia	370030	811127	7.77	4.40	3.40	.63	.50	.52	.34	.73	7.68
03167200	Laurel Fork at Route 638 near Laurel Fork	364434	803149	28.3	33.0	34.5	21.5	19.3	20.0	14.0	.21	15.82
03167695	Beaverdam Creek at Hillsville	365545	804342	4.19	4.15	4.20	2.73	2.38	2.30	1.60	.19	13.44

Appendix 2. Base-flow characteristics at partial-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean base flow (ft^3/s)	Q_{50} (ft^3/s)	Q_{90} (ft^3/s)	Q_{95} (ft^3/s)	7Q2 (ft^3/s)	7Q10 (ft^3/s)	Base-flow variability index	Effective recharge (in/yr)
03168750	Thorne Springs Branch near Dublin	370530	804434	4.77	0.93	0.62	0.14	0.10	0.10	0.04	0.65	2.65
03169150	Pine Creek at Route 682 near Floyd	365703	801703	10.7	9.00	8.75	6.00	5.10	5.60	4.40	.16	11.41
03169370	Brush Creek at Route 616 near Riner	370157	802349	19.1	6.60	5.80	2.30	1.85	1.90	1.10	.40	4.69
03171400	Neck Creek at Route 617 near Belspring	371103	803724	7.92	6.30	5.30	2.15	1.90	2.00	1.60	.39	10.79
03171550	Sinking Creek at Route 700 near Newport	371840	803055	65.4	63.2	51.5	12.8	9.90	10.00	6.00	.60	13.11
03171900	Kimberling Creek near Holly Brook	371038	805854	27.3	5.60	3.50	.24	.17	.18	.08	1.16	2.78
03177600	Bluestone River above Bluefield	371357	811800	16.7	16.2	15.1	8.20	7.40	7.10	6.00	.27	13.16
03475700	Spring Creek near Abingdon	364403	820229	2.99	3.60	3.40	1.20	1.00	1.00	.70	.45	16.34
03489800	Cove Creek near Shelleys	363913	822116	17.3	23.0	14.0	1.60	1.20	1.20	.65	.94	18.04
03521950	Maiden Spring Creek near Thompson Valley	370328	813126	17.8	11.0	10.5	7.00	6.50	7.00	6.00	.18	8.39
03523650	Thompson Creek at Artrip	365801	820642	19.5	8.50	7.60	1.30	.98	1.00	.55	.77	5.92
03523700	Weaver Creek at Artrip	365733	820748	18.1	5.50	4.80	.50	.34	.37	.18	.98	4.12
03525100	Cove Creek near Stanleytown	364500	823725	23.5	15.2	14.5	3.50	2.80	2.80	1.90	.62	8.78
03525490	Stock Creek at Clinchport	364032	824444	31.2	24.0	22.0	4.30	3.40	3.20	2.10	.71	10.44
03527480	NF Clinch River near Duffield	364402	824751	16.1	13.0	12.0	2.10	1.60	1.60	1.00	.76	10.96
03527490	Dry Branch near Duffield	364354	824749	4.24	.20	.14	---	---	.00	.00	---	.64
03529800	SF Powell River at East Stone Gap	365205	824448	27.2	20.0	17.0	3.80	2.60	3.00	1.60	.65	9.98
03529900	Butcher Fork at East Stone Gap	365224	824414	8.15	6.60	5.60	1.45	1.08	1.20	.69	.59	10.99
03531505	Batie Creek near Jonesville	363934	830908	17.4	10.0	9.50	3.30	2.60	2.80	1.90	.46	7.80
03531520	Wallen Creek near Jonesville	363758	831019	47.4	40.0	36.0	12.4	10.0	11.0	7.30	.46	11.45
03531530	Hardy Creek near Smiley	363901	831450	17.3	16.0	14.0	4.00	3.10	3.40	2.10	.54	12.55
03531535	Dry Creek near Smiley	363908	831448	23.6	10.5	9.00	1.90	1.40	1.50	.88	.68	6.04

Appendix 3. Basin characteristics and aquifer properties for selected continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia

[mi/mi^2, mile per square mile; in/yr, inch per year; ft^2/d, feet squared per day; BR, Blue Ridge region; PN, Piedmont northern region; PS, Piedmont southern region; VR, Valley and Ridge region. Effective recharge rates are presented in appendix 1]

Station number	Potential surface-water yield	Region	Percentage of basin underlain by hydrogeologic unit: Valley and Ridge, Small	Valley and Ridge, Medium	Valley and Ridge, Large	Blue Ridge and Piedmont, Small	Blue Ridge and Piedmont, Medium	Blue Ridge and Piedmont, Large	Drainage density (mi/mi^2)	Aquifer half-width (ft)	Recession index (days/log cycle)	Riparian evapo-transpiration (in/yr)	Average ground-water gradient (ft/mi)	Total stream length (mi)	Areal diffu-sivity (ft^2/d)	Areal trans-missiv-ity (ft^2/d)	Stor-age coeffi-cient
01626850	High	BR	35.3	0.0	22.8	35.9	6.1	0.0	1.34	1,977	81.0	1.59	110	199	45,000	330	0.007
01627500	High	VR	39.5	.0	20.0	39.7	.8	.0	1.27	2,077	84.7	1.53	104	270	47,500	320	.007
01632000	Low	VR	97.8	2.1	.1	.0	.0	.0	1.32	2,001	52.5	1.57	301	165	71,200	99	.001
01632900	Moderate	VR	63.0	.0	37	.0	.0	.0	1.33	1,987	81.6	.82	110	68.8	45,200	350	.008
01634500	Moderate	VR	91.3	8.7	.0	.0	.0	.0	1.39	1,901	52.4	1.28	200	143	64,300	100	.002
01638480	Moderate	BR	.0	.0	.0	27.9	72.1	.0	1.42	1,859	61.9	.99	57.0	127	52,100	400	.008
01643700	Moderate	BR	.0	.0	.0	76.9	23.1	.0	1.48	1,783	43.2	1.87	96.0	182	68,700	280	.004
01646000	Moderate	PN	.0	.0	.0	98.3	1.3	.4	1.49	1,777	106	.60	45.0	86.0	27,800	450	.016
01654000	Moderate	PN	.0	.0	.0	87.3	12.7	.0	1.47	1,801	65.7	.82	45.0	34.5	46,000	390	.008
01658500	Low	PN	.0	.0	.0	100	.0	.0	1.41	1,872	37.0	1.20	34.0	8.9	88,400	540	.006
01660400	Low	PN	.0	.0	.0	100	.0	.0	1.29	2,039	47.6	.90	34.0	45.1	81,500	600	.007
01662800	Moderate	BR	.0	.0	.0	.0	100	.0	1.57	1,682	59.6	1.20	74.0	15.9	44,300	810	.018
01663500	Moderate	BR	.0	.0	.0	13.5	86.5	.0	1.59	1,662	59.5	1.36	115	188	43,300	520	.012
01666500	Moderate	PN	.0	.0	.0	47.6	52.4	.0	1.41	1,872	63.3	1.67	74.0	177	51,600	590	.011
01673800	Low	PS	.0	.0	.0	78.6	21.4	.0	1.34	1,963	45.5	.96	28.0	104	79,100	650	.008
02011400	Moderate	VR	90.8	6.7	2.5	.0	.0	.0	1.76	1,499	59.1	1.74	337	77.1	35,500	220	.006
02011460	Moderate	VR	94.5	2.9	2.6	.0	.0	.0	1.76	1,501	68.7	1.70	431	35.0	30,600	170	.006
02014000	Moderate	VR	95.8	4.0	.2	.0	.0	.0	1.73	1,530	58.5	1.88	354	264	37,300	63	.002
02015700	High	VR	85.0	15.0	.0	.0	.0	.0	1.78	1,486	67.9	1.57	253	54.1	30,400	350	.012
02017500	Moderate	VR	97.5	2.5	.0	.0	.0	.0	1.83	1,440	50.5	2.08	303	191	38,300	74	.002
02018000	Moderate	VR	91.8	4.5	3.7	.0	.0	.0	1.72	1,531	57.0	1.33	297	567	38,400	70	.002
02022500	Moderate	VR	85.9	.0	14.1	.0	.0	.0	1.80	1,467	62.0	1.12	258	63.0	32,400	68	.002
02027000	Moderate	BR	.0	.0	.0	3.2	96.8	.0	1.62	1,634	60.6	2.33	340	150	41,100	110	.003
02027800	Moderate	BR	.0	.0	.0	21.2	78.8	.0	1.64	1,608	87.7	1.50	110	241	27,500	230	.008
02028500	Moderate	BR	.0	.0	.0	20.4	79.6	.0	1.73	1,527	67.4	2.03	240	164	32,300	130	.004
02031000	Moderate	BR	.0	.0	.0	28.5	71.5	.0	1.32	2,004	68.3	1.34	109	126	54,800	270	.005
02032400	Moderate	BR	.0	.0	.0	35.8	64.2	.0	1.58	1,666	49.3	1.49	137	33.7	52,600	290	.006
02038850	Moderate	PS	.0	.0	.0	98.5	1.5	.0	1.44	1,830	79.0	.67	31.0	12.3	39,500	690	.017
02039000	High	PS	.0	.0	.0	98.8	1.2	.0	1.51	1,753	108.7	.98	41.0	105	26,400	500	.019
02044500	Moderate	PS	.0	.0	.0	62.8	37.2	.0	1.48	1,782	69.2	.64	22.0	458	42,800	830	.019

Appendix 3. Basin characteristics and aquifer properties for selected continuous-record streamflow-gaging stations in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces of Virginia—Continued

Station number	Potential surface-water yield	Region	Percentage of basin underlain by hydrogeologic unit: Valley and Ridge			Blue Ridge and Piedmont			Drainage density (mi/mi²)	Aquifer half-width (ft)	Recession index (days/log cycle)	Riparian evapo-transpiration (in/yr)	Average ground-water gradient (ft/mi)	Total stream length (mi)	Areal diffusivity (ft²/d)	Areal transmissivity (ft²/d)	Storage coefficient
			Small	Medium	Large	Small	Medium	Large									
02052500	Low	PS	0.0	0.0	0.0	68.5	20.3	11.2	1.34	1,969	47.5	0.97	22.0	87.0	76,100	830	0.011
02053800	Moderate	BR	36.7	.0	1.4	17.0	45.0	.0	1.45	1,818	99.3	.96	223	160	31,100	100	.003
02055000	Moderate	VR	86.9	.0	12.3	.1	.7	.0	1.44	1,832	80.3	.87	203	569	39,000	95	.002
02055100	Moderate	VR	65.9	.0	34.1	.0	.0	.0	2.10	1,259	68.4	1.17	56.0	23.1	21,600	330	.015
02056650	Moderate	BR	17.0	.0	7.2	.0	75.8	.0	1.51	1,744	61.9	1.21	208	86.0	45,900	110	.002
02056900	High	PB	.0	.0	.0	57.5	42.5	.0	1.78	1,487	104.3	1.01	133	204	19,800	170	.008
02058400	High	PB	.0	.0	.0	98.6	1.4	.0	1.66	1,586	113.9	.82	87.0	582	20,600	230	.011
02059500	High	BR	15.5	.0	.0	7.0	77.4	.0	1.79	1,473	93.1	1.04	110	337	21,700	150	.007
02061500	Moderate	BR	.0	.0	.0	17.3	82.7	.0	1.73	1,525	78.4	1.18	83.0	554	27,700	230	.008
02065500	Moderate	PS	.0	.0	.0	76.6	23.4	.0	1.59	1,657	92.7	.72	41.0	156	27,600	460	.017
02069700	High	PB	.0	.0	.0	28.8	71.2	.0	1.36	1,941	113	1.58	112	115	31,100	370	.012
02070000	High	PB	.0	.0	.0	100	.0	.0	1.41	1,872	138.7	1.03	74.0	152	23,600	390	.017
02079640	Low	PS	.0	.0	.0	100	.0	.0	1.60	1,649	58.9	.76	44.0	85.5	43,100	240	.006
03165000	High	PB	.0	.0	.0	79.5	20.5	.0	1.28	2,059	128	1.36	109	50.5	30,900	440	.014
03167000	High	BR	80.5	.0	19.5	.0	.0	.0	1.49	1,771	78.7	.93	131	368	37,200	180	.005
03167500	High	PB	.0	.0	.0	98.8	1.2	.0	1.28	2,059	113.3	1.39	139	356	34,900	280	.008
03170000	High	BR	5.0	.0	.0	77.4	17.6	.0	1.47	1,792	91.7	1.41	121	442	32,700	230	.007
03173000	Moderate	VR	77.4	.0	22.6	.0	.0	.0	1.44	1,829	69.0	.92	234	440	45,300	96	.002
03471500	High	BR	63.6	.0	36.4	.0	.0	.0	1.49	1,768	88.9	1.33	280	114	32,800	130	.004
03475000	High	VR	54.0	.7	45.3	.0	.0	.0	2.18	1,212	80.1	1.53	153	460	17,100	130	.008
03488000	Moderate	VR	74.2	.3	25.5	.0	.0	.0	1.28	2,055	53.9	2.17	325	285	73,100	100	.001