Methods for Estimating the Magnitude and Frequency of Peak Discharges of Rural, Unregulated Streams in Virginia

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4148

Prepared in cooperation with the

VIRGINIA DEPARTMENT OF TRANSPORTATION

USGS
science for a changing world

Methods for Estimating the Magnitude and Frequency of Peak Discharges of Rural, Unregulated Streams in Virginia

By James A. Bisese

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4148

Prepared in cooperation with the

VIRGINIA DEPARTMENT OF TRANSPORTATION

Richmond, Virginia

1995

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:
District Chief
U.S. Geological Survey
Room 606
3600 West Broad Street
Richmond, VA 23230

Copies of this report can be purchased from:
U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

CONTENTS

PLATE

FIGURE

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	2.04	meter per kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Sea level: 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.

Methods for Estimating the Magnitude and Frequency of Peak Discharges of Rural, Unregulated Streams in Virginia

By James A. Bisese

Abstract

Methods are presented for estimating the peak discharges of rural, unregulated streams in Virginia. A Pearson Type III distribution is fitted to the logarithms of the unregulated annual peak-discharge records from 363 stream-gaging stations in Virginia to estimate the peak discharge at these stations for recurrence intervals of 2 to 500 years. Peak-discharge characteristics for 284 unregulated stations are divided into eight regions based on physiographic province, and regressed on basin characteristics, including drainage area, main channel length, main channel slope, mean basin elevation, percentage of forest cover, mean annual precipitation, and maximum rainfall intensity. Regression equations for each region are computed by use of the generalized least-squares method, which accounts for spatial and temporal correlation between nearby gaging stations. This regression technique weights the significance of each station to the regional equation based on the length of records collected at each station, the correlation between annual peak discharges among the stations, and the standard deviation of the annual peak discharge for each station.

Drainage area proved to be the only significant explanatory variable in four regions, while other regions have as many as three significant variables. Standard errors of the regression equations range from 30 to 80 percent. Alternate equations using drainage area only are provided for the five regions with more than one significant explanatory variable.

Methods and sample computations are provided to estimate peak discharges at gaged and ungaged sites in Virginia for recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years, and to adjust the regression estimates for sites on gaged streams where nearby gaging-station records are available.

INTRODUCTION

Effective design and placement of structures near streams and on flood plains require understanding the peak-discharge characteristics of those streams. Knowledge of the magnitude and frequency of peak discharge is required to construct highway bridges and culverts; to locate highways, railroads, industries, farms, and residences on flood plains; and to design flood-control structures, such as reservoirs, levees, and floodwalls.

Since 1949, the U.S. Geological Survey (USGS), in cooperation with the Virginia Department of Transportation, has maintained a network of partial-record peak-discharge gaging stations, with as many as 211 gaging stations operating in a given year. Records from continuous-record and partial-record gaging stations provide annual peak-discharge data for more than 538 gaging stations throughout the State (Prugh and others, 1991b). Three hundred and sixty three gaging stations have 10 years or more of unregulated peak-discharge records and are shown on plate 1.

Purpose and Scope

This report summarizes a statistical analysis of peak-discharge data collected in Virginia from 1895 through 1991, and provides methods for estimating the peak discharge of gaged and ungaged streams in Virginia. Basin characteristics and station peak-discharge characteristics are presented for 363 stream-gaging stations located throughout the State. Generalized least-squares regression methods are used with gaging-station records to develop regional equations to estimate the peak discharges at ungaged sites for recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years. The State is divided into eight peak-discharge regions and equations are presented to estimate peak discharges at ungaged sites in each region.

Methods are given to incorporate peak-discharge data at gaging stations with the regional estimates to improve peak-discharge estimates at sites where nearby gaging-station records are available. This report updates previously published predictive equations and methods for computing peak-discharge (Miller 1978) by using the most current statistical procedures and peak-discharge data.

Previous Studies

Previous statistical analyses of peak-discharge data in Virginia have been reported by Tice (1950), Speer and Gamble (1964a; 1964b; 1965), and Miller (1969; 1978). This report expands on these earlier reports and incorporates 14 years of additional data collected since Miller's (1978) report. Because of the use of more rigorous statistical procedures, and the extended period of records, equations presented in this report should produce more reliable estimates of peak discharge than equations in previous reports.

DEVELOPMENT OF PEAK-DISCHARGE EQUATIONS

Peak-discharge characteristics can be determined for any site on a stream. At a gaging station, the station peak-discharge characteristics include the number of peaks recorded, the average and maximum peak discharges, and probability statistics, for instance the probability that a flood of a given magnitude will be exceeded during a given period of time. A relation of the station peak-discharge characteristics for each station to the topographic and physiographic characteristics of their basins can be derived. This relation can then be used to estimate the peak-discharge characteristics at ungaged sites. The following section describes the computational methods used to determine the peak-discharge characteristics at gaging stations, and also outlines the processes used to derive the relation of individual station peak-discharge characteristics to their basin characteristics.

Peak-Discharge Characteristics at Gaging Stations

The station peak-discharge characteristics can be estimated from the known station peak-discharge records using a frequency analysis. The frequency analysis technique used in this report is described in "Guidelines for Determining Flood Flow Frequency," Bulletin 17B of the Interagency Advisory Committee on Water Data (IACWD) (1982). This technique involves fitting a Pearson Type III frequency distribution to the logarithms of annual peak discharges and is used by all federal agencies for flood-frequency analysis.

Peak-Discharge Data

The peak-discharge data for active stations are published yearly in the annual water-data report for Virginia (Prugh and others, 1991a). All of the peak-discharge data used in this report are contained in "Annual Maximum Stages and Discharges of Selected Streams in Virginia through 1990" (Prugh and others, 1991b), with the exception of data from 1991. The entire peak-discharge data set is available in computer form in the Peak Flow File of the Water Data Storage and Retrieval System (WATSTORE) at the USGS National Center, Reston, Va. Information about the Peak Flow File and instructions on retrieving the peak-discharge data can be found in the "WATSTORE User's Guide, Volume 4" (Lepkin and others, 1981).

Methods for Estimating Peak Discharge at Gaging Stations

Reliably estimating peak-discharge characteristics at any gaging-station by using IACWD procedures requires a minimum of 10 years of gaging-station records. In Virginia, 363 stations of the 538 peak-discharge stations (Prugh, 1991b) have 10 or more years of unregulated peak-discharge records.

The IACWD (1982) procedures also assume that the recorded annual peak-discharge records are representative of both the recorded and the unrecorded annual peaks at the site. This assumption may not be valid where dams or other water diversions exist, or have been constructed upstream of a station during the period-of-data collection (Benson, 1962a; 1962b). Modifications can change the peak-discharge characteristics at a site by reducing or increasing the magnitude of peaks at that site. Examples of such modifications include flood control reservoirs that store water during peak-discharge events, canals that divert flow around gaging stations, or the installation of storm drains and impervious surfaces that may increase runoff rates and increase peak-discharge for a given amount of rainfall. To reduce the problem of using peak-discharge data that represent modified streamflow conditions, the gaging-station records for each station were screened, and all peaks recorded after the construction of reservoirs that impound more than 10 percent of the total drainage area at a station were removed from the peak-discharge data set. Peak-discharge analysis was performed using only unregulated peaks.

Channel or basin developments that have taken place during the period-of-data collection at other peak-discharge gaging stations can potentially affect the peak-discharge characteristics of the site. A Kendall's Tau trend analysis (Hirsch and others, 1982), which measures monotonic trends within data sets, was used to determine if any statistically significant trends were present in the station peak-discharge records at each station. Records for 14 unregulated stations were found to contain statistically significant trends (5 percent level of significance) (Hirsh and others, 1982). A comparison between the gaging-station records at these stations with the gaging-station records of nearby long-term stations, which do not have significant trends, indicate that at each station the trends can be attributed to the short periods of record. When a subset of concurrent records from the long-term stations was analyzed, the records from the long-term stations, during the same period, also contained a significant trend. Because the trends at the long-term stations are part of the normal variability of annual peak discharges, no adjustments were made to the period of record for these stations.

The IACWD (1982, p. 9) methods for estimating station peak-discharge characteristics fit a Pearson Type III distribution to the logarithms (base-10) of the annual peak-discharge records. The discharge for any selected recurrence interval is determined from this fitted curve. Application of the Pearson Type III distribution requires calculating the mean, variance, and skew of the logarithms of the annual peak-discharge records. These statistics are computed as follows:

$$\bar{\chi} = \frac{1}{N} \sum_{i=1}^{N} \chi_i, \qquad (1)$$

$$S^2 = \frac{1}{N-1} \sum_{i=1}^{N} (\chi_i - \bar{\chi})^2, \text{ and} \qquad (2)$$

$$G_s = \frac{N}{(N-1)(N-2)S^3} \sum_{i=1}^{N} (\chi_i - \bar{\chi})^3, \qquad (3)$$

where

$\bar{\chi}$ = the mean of the log-transformed annual peak discharges;

χ_i = the log-transformed annual peak discharge for year (i);

N = the number of annual peak discharges recorded at the station (i), (listed in appendix 2);

S^2 = the variance of the log-transformed annual peak discharges;

S = the standard deviation (square root of the variance) of the log-transformed annual peak discharges; and

G_s = the skew coefficient determined at the station.

Studies have shown that the station skew coefficient (G_s) is subject to a large variance because of high and (or) low outlier values (IACWD, 1982). To reduce this variance the station skew coefficient is weighted with a regional skew coefficient obtained from plate 1 in IACWD (1982).

The weighted skew coefficient is computed by weighting the station skew (G_s) and the regional skew (G_r) inversely to their mean square errors (MSE_s, MSE_r) by using the following equation:

$$G_w = \frac{MSE_r(G_s) + MSE_s(G_r)}{MSE_r + MSE_s}, \qquad (4)$$

where

G_w = the weighted skew coefficient;

G_s = the station skew coefficient;

G_r = the regional skew coefficient determined from IACWD (1982);

MSE_r = the mean square error of the regional skew coefficient, determined from IACWD (1982); and

MSE_s = the mean square error of the station skew coefficient, the function of the record length, and the absolute value of the station skew coefficient.

The Pearson Type III analysis assumes that the peak-discharge records collected at a site are statistically similar to peak-discharge events that occurred before and (or) after the period-of-data collection. Additional sources of information are often available that indicate that some peak-discharge events, occurring before, during, or after the period of gaging-station operation, are maximums for an extended period of time.

Historical information about peak-discharges can often be obtained from print media or from interviews with local residents. During peak-discharge events, USGS personnel have often compiled reports about historical peak-discharge events by interviewing local residents. At many gaging stations there is a systematic effort by the USGS to interview residents who have lived in the area long enough to offer details about historical peak-discharge events. This type of eye-witness account is most useful if the local resident can report about peak-discharge events witnessed before the gaging station was established.

The historical information is used to extend the systematic period of record to an extended historical period. In making the historical adjustment, the historic peaks represent the maximum peaks during the historical period, and the remaining peaks are assumed to be representative of the distribution of the unrecorded peaks in the intervening period between the systematic period of record and the extended historical period. Historical adjustments made to the systematic period of record for stations in this study are listed in appendix 2.

At some stations there are peak discharges that are much higher than any other peak in the record, yet there is only a short period of systematic record collection and no historical data that can be used to determine an extended historical period of record for the high-outlier. A study of these high outlier peaks showed that most occurred because of severe storms that affected multiple stations over wide areas across the State. These storms produced the largest peak-discharge records at stations with short periods of record, and at stations with much longer periods of record. For stations with high outlier peaks, comparisons were made between stations to extend a longer historical period of record to short-term stations, based on the longer systematic period of record at nearby stations. Adjustments were made only if a nearby station could be identified that had a longer period of record than the station of interest, if there were concurrent records between the two stations, and if the largest peaks at both stations occurred because of the same storm. The maximum historic period assigned to a high-outlier peak based on this correlation between stations is equal to the systematic period of record at the longer-term station. If no nearby station could be used to extend the historical period of record, the high-outlier peak was retained, and treated as part of the systematic record.

Annual peak discharges that are much lower than average also can have a strong effect on the station peak-discharge estimates. Adjustments to the peak-discharge analysis for stations with low outliers are made using IAWCD (1982) guidelines. These guidelines detail censoring zero flows and peaks below the minimum recordable gage value prior to carrying out any calculation. Tests are then made to identify and censor any peaks that are less than a computed low outlier threshold (IAWCD, 1982, pages 17–19). If any peaks are censored from the record during these tests, the frequency analysis is adjusted by a conditional probability adjustment as described in appendix 5 of Bulletin 17B (IAWCD, 1982).

The station peak-discharge estimates for recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years listed in appendix 2 are determined by using the equation:

$$\log_{10} Q_{(t)} = \bar{\chi} + K_{(t)} S, \tag{5}$$

where

$\log_{10} Q_{(t)}$ = the peak discharge estimated for recurrence interval (t), expressed in $\log_{10}$ units;

$K_{(t)}$ = a factor that is a function of the weighted skew for recurrence interval (t) (Interagency Advisory Committee on Water Data, 1982); and

$\bar{\chi}$ and S are determined as shown in equations 1 and 2, or are determined using historical adjustments as defined in IACWD, 1982, pages 17–19.

Computation of station peak-discharge estimates for various recurrence intervals are made by using the USGS computer program that implements the IACWD procedure (Lumb and others, 1990). Details of the computational procedure are found in Section C of "WATSTORE User's Guide, Volume 4" (Lepkin and others, 1981), and in Bulletin 17B (IACWD, 1982).

Accuracy and Limitations of Peak-Discharge Estimates at Gaging Stations

A number of factors contribute to the accuracy of station peak-discharge characteristics listed in appendix 2. Errors in the peak-discharge records can be introduced during field measurement or discharge computation. Because of the quality-assurance procedures used in field-data collection and in reviewing peak-discharge records, these errors are believed to be few and nonsystematic (Hardison, 1969).

Another potential source of error is estimating the peak discharge at a site by using a sample of peak-discharge data that is not representative of the long-term distribution. The station peak-discharge characteristics in appendix 2 are computed by using only unregulated records as defined in the previous section, "Methods for Estimating Peak Discharge at Gaging Stations," and using only data collected from 1895 through 1991. Caution must be exercised in using the station peak-discharge characteristics in appendix 2 directly, because sites that are currently (1994) unregulated may become regulated in the future. Additionally, some station peak-discharge characteristics are presented in this report for stations that are currently regulated. In these instances, only the peak-discharge records from the period before the regulation began was used in determining the station peak-discharge characteristics listed in appendix 2. Peak-discharge characteristics for these stations are used in the regression analysis, with the period-of-record collection truncated at the beginning of the regulated period.

Continued data collection at a site also may have a significant effect on the discharge estimates. A statistical measure of how well the known peak-discharge gaging-station records define the true long-term peak-discharge distribution is known as the time-sampling error, and this error is assumed to be large compared to other sources of error. The time-sampling error is a function of the number of peak-discharge events recorded at the site, the length of the systematic and (or) historic period of record, the slope and skew of the frequency curve, and the recurrence interval being estimated. The time-sampling error is quantified as the sum of the errors due to the estimation of the mean, standard deviation, and skew for the Pearson Type III analysis (eqs. 1, 2, and 3). The standard error is a measure of the accuracy of the station peak-discharge estimate, and is used in generalized least-squares regression, along with a measure of the correlation of the annual peak discharges among stations, to weight the relative importance of each station in the regional analysis.

Regional Peak-Discharge Analysis

Regional peak-discharge multiple-regression equations can be used to estimate the peak-discharge characteristics at an ungaged site. These equations are developed by regression analysis between the station peak-discharge characteristics and the physiographic characteristics of the drainage basin upstream of each gaging station. The equations also can be used to improve the peak-discharge estimate at a gaged site by reducing the importance of the time-sampling error to the final peak-discharge estimate. A weighted estimate of the regional and station peak-discharge characteristics is considered the best estimate at the gaging station.

Basin Characteristics Data

An earlier peak-discharge study in Virginia (Miller, 1978) determined the basin characteristics at 403 stream-gaging stations in the State, including all but 22 of the stations used in the current study. These basin characteristics include both physiographic and climatologic variables and were used in this study.

Values for the following basin characteristics tested in the regression analysis are listed in appendix 1:

Drainage area (in square miles).—The contributing drainage basin area, determined from either 1:24,000-scale or 1:62,500-scale topographic maps.

Main channel length (in miles).—The total distance from the gaging station to the basin divide, following the channel that drains the largest area, determined from either 1:24,000-scale or 1:62,500-scale topographic maps.

Main channel slope (in feet per mile).—The average slope between points 10 percent and 85 percent of the total channel length from the gaging station to the basin divide.

Mean basin elevation (in feet above sea level).—The average elevation measured from 1:250,000-scale topographic maps, using the transparent grid-sampling method.

Forested area (in percentage of drainage area plus one percent).—The percent of the total basin shown as forested area, measured from 1:250,000-scale topographic maps, using the transparent grid-sampling method.

Mean annual precipitation (in inches).—The mean annual precipitation determined from the "Climatic Data, Annual Summary," (U.S. Weather Bureau, 1968) for Virginia.

2-year, 24-hour rainfall intensity (in inches).—The annual maximum rainfall during a 24-hour period expected to be exceeded on the average once every 2 years, determined from U.S. Weather Bureau (1958).

For the 22 basins not included in Miller (1978), the drainage area, the main channel length, and the main channel slope were determined for the present study by using 1:24,000-scale topographic maps.

Delineation of Peak-Discharge Regions

Initially, peak-discharge characteristics for each peak-discharge gaging station in the entire State were regressed with basin characteristics data by using step-forward and step-backward ordinary least-squares regression analysis. Drainage area, main channel slope, main channel length, and average basin elevation were significant at the 5 percent level in the Statewide regression. Plots of the residuals from this regression showed significant geographic grouping. In particular, the Statewide equation overestimated the peak discharge in the eastern part of the State and underestimated the peak-discharge in the northern part of the State.

Different subgroupings of stations were defined and regressed independently, to improve the fit of the regression equations to the observed data, and to improve the predictive ability of the equations. Stations were split into groups based on hydrologic units, drainage basin size, and physiographic province.

Grouping stations by physiographic province significantly improved the predictive ability of equations generated by using ordinary least-squares regression. The physiographic provinces in Virginia were defined by Fenneman (1938) and include the Coastal Plain, the Piedmont, the Blue Ridge, the Valley and Ridge, and the Appalachian Plateaus. Plots of residuals for these groups showed some geographic trends and led to further testing for significant subgroups within each physiographic province. The final regionalization of the stations used in the remainder of this report is modified from the five physiographic provinces, with the Valley and Ridge split into a northern, central and southern section (split at major basin divides) and the Piedmont split into a northern and southern region (also split at a major basin divide). These peak-discharge regions are defined here to distinguish them from the physiographic provinces. The peak-discharge regions are shown in figure 1. The regions include the Coastal Plain (C), the Northern Piedmont (NP), the Southern Piedmont (SP), the Blue Ridge (B), the Northern (NV), Central (CV), and Southern Valley and Ridge (SV), and the Appalachian Plateaus (AP). The letter designation following the name of each peak-discharge region is used in the appendixes, and on plate 1 as the suffix for each site label.

Stations were assigned to a particular peak-discharge region by overlaying a map of station drainage basins onto a map of the peak-discharge regions shown on figure 1. Because the area of many drainage basins extend across several peak-discharge regions, regression tests were made to determine what percentage of each drainage basin could lie outside of a single region before the regression residuals for that region noticeably increased. Although there was no clear break point, a cutoff of 25 percent was chosen to allow the largest number of basins to be used in the regression, whereas not significantly affecting the regression analysis. Stations located in basins with less than 75 percent of their total area in a single peak-discharge region were not used in regional analysis. These stations are designated as being in a Mixed region (M) on plate 1 and in appendixes 1 and 2.

Peak-discharge data from 284 stations were used in the regional regression analysis. The number of stations in each peak-discharge region vary from 17 stations in the Appalachian Plateaus region to 67 stations in the Southern Piedmont region. Because of the small number of stations in the Appalachian Plateaus region, peak-discharge characteristics from eight stations in the Appalachian Plateaus region of Kentucky were included in the regressions. Published station peak-discharge characteristics for these eight stations were taken directly from Choquette (1988), who used data through 1985.

Dividing the State into peak-discharge regions based on physiographic province reduced the statistical significance of many of the basin characteristics in the regression analysis relative to the Statewide regression and the other regression groupings tested. A statistical summary of the basin characteristics tested in the regional regression analysis is presented in table 1. The variability of the basin characteristics within each peak-discharge region is generally less than the variability of the characteristics between regions. For example, the difference in average basin elevation for stations within each peak-discharge region is much smaller than the difference in average basin elevation between regions. This grouping of basins reduced the statistical significance of many of the characteristics, and minimized the number of parameters used in the final regression equations.

Generalized Least-Squares Regional Regression Analysis

After peak-discharge regions were delineated, regression analysis of the grouped data was made by using the generalized least-squares method (GLS) (Stedinger and Tasker, 1985; Tasker and Stedinger, 1989). This GLS method uses the latitude and longitude of each station to determine the distance between stations. Distance between gaging stations is used to smooth the correlation of peak discharges between the stations. The highly

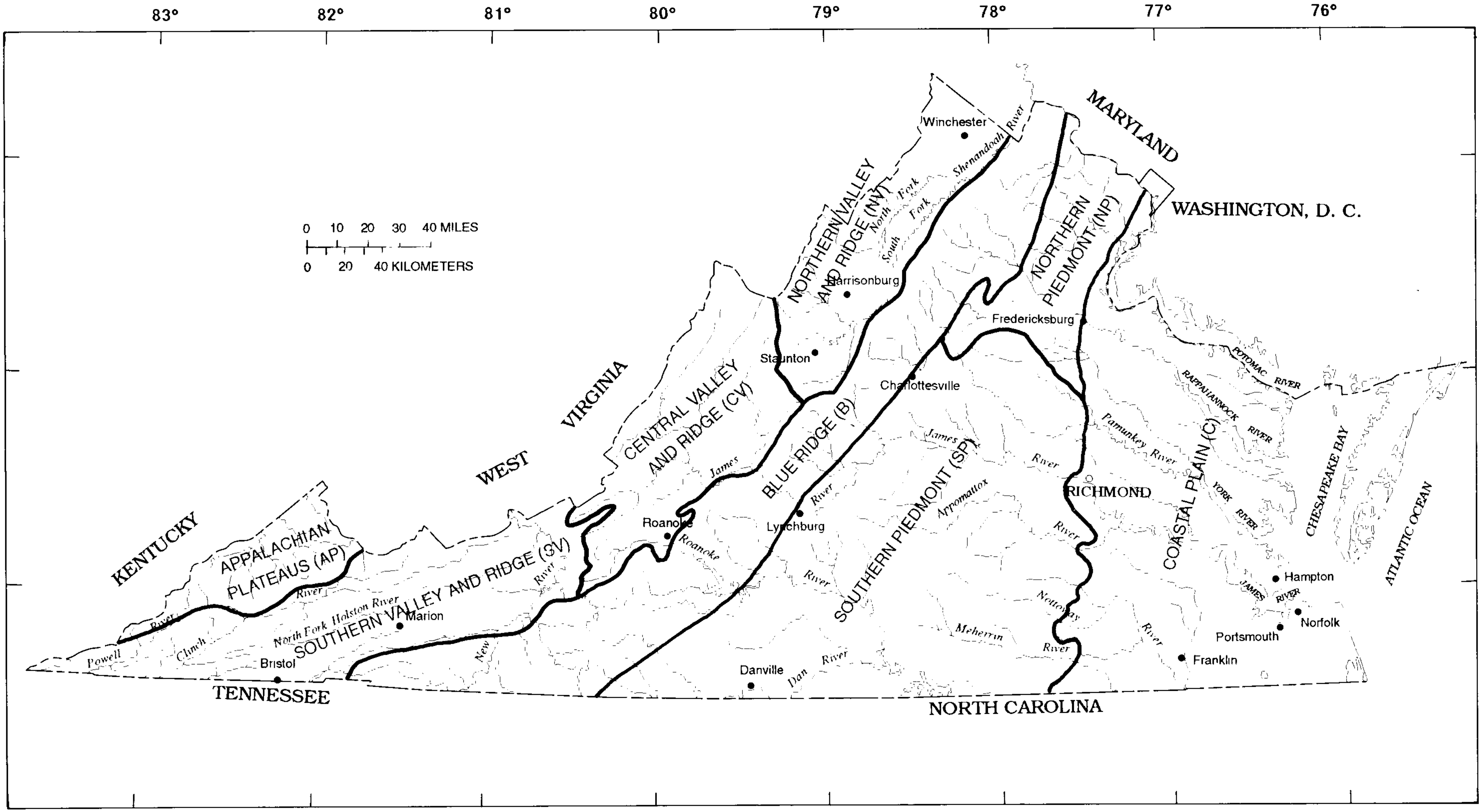

Figure 1. Peak-discharge regions in Virginia.

Table 1. Statistical summary of basin characteristics tested in regional regressions for streams in Virginia
[Location of peak-discharge regions are shown in figure 1. Average elevation is in feet above sea level; mi^2, square miles; ft/mi, feet per mile; in., inch]

Basin characteristic	Mean	Median	Minimum	Maximum
Coastal Plain (C)—29 Sites				
Drainage area (mi^2)	66.4	6.6	0.7	617
Main channel slope (ft/mi)	20.6	14.0	1.6	83
Main channel length (mi)	11.5	4.2	1.2	65
Average basin elevation (ft)	115	110	20	260
Percent forest plus one (percent)	70	72	1	95
Average annual precipitation (in.)	45.1	44.4	41.2	50.9
Two year, 24-hour rainfall (in.)	3.4	3.5	3.1	3.9
Northern Piedmont (NP)—19 Sites				
Drainage area (mi^2)	61.2	7.6	0.1	570
Main channel slope (ft/mi)	67.1	38.0	6.3	400
Main channel length (mi)	9.8	4.5	0.3	54
Average basin elevation (ft)	370	360	310	465
Percent forest plus one (percent)	66	65	40	97
Average annual precipitation (in.)	40.4	39.7	38.9	46.0
Two year, 24-hour rainfall (in.)	3.4	3.3	3.0	3.7
Southern Piedmont (SP)—67 Sites				
Drainage area (mi^2)	279.5	46.0	0.3	2,730
Main channel slope (ft/mi)	35.6	17.4	2.6	173
Main channel length (mi)	30.3	10.3	0.7	184
Average basin elevation (ft)	522	485	80	1,100
Percent forest plus one (percent)	71	73	17	99
Average annual precipitation (in.)	43.3	43.0	39.5	48.3
Two year, 24-hour rainfall (in.)	3.4	3.4	3.0	4.0
Blue Ridge (B)—54 Sites				
Drainage area (mi^2)	158.4	78.8	0.6	1,340
Main channel slope (ft/mi)	120.9	56.8	7.8	880
Main channel length (mi)	22.7	17.0	1.0	131
Average basin elevation (ft)	1,585	1,410	560	3,280
Percent forest plus one (percent)	59	57	17	100
Average annual precipitation (in.)	44.0	43.8	36.6	51.2
Two year, 24-hour rainfall (in.)	3.7	3.6	2.6	4.7
Northern Valley and Ridge (NV)—29 Sites				
Drainage area (mi^2)	247.2	70.1	0.3	1,642
Main channel slope (ft/mi)	139.5	37.9	7.7	973
Main channel length (mi)	28.2	19.4	1.0	145
Average basin elevation (ft)	1,638	1,550	760	3,330
Percent forest plus one (percent)	57	53	2	100
Average annual precipitation (in.)	37.9	38.0	34.0	42.1
Two year, 24-hour rainfall (in.)	3.0	3.0	2.5	3.6

Table 1. Statistical summary of basin characteristics tested in regional regressions for streams in Virginia—Continued
[Location of peak-discharge regions are shown in figure 1. Average elevation is in feet above sea level; mi^2, square miles; ft/mi, feet per mile; in., inch]

Basin characteristic	Mean	Median	Minimum	Maximum
Central Valley and Ridge (CV)—34 Sites				
Drainage area (mi^2)	358.3	111.0	0.7	3,259
Main channel slope (ft/mi)	91.6	28.6	9.3	592
Main channel length (mi)	36.7	31.4	1.7	169
Average basin elevation (ft)	2,077	2,150	1,280	2,890
Percent forest plus one (percent)	77	81	21	99
Average annual precipitation (in.)	40.6	40.5	37.8	43.1
Two year, 24-hour rainfall (in.)	3.0	2.9	2.5	3.5
Southern Valley and Ridge (SV)—35 Sites				
Drainage area (mi^2)	124.3	41.4	1.2	672
Main channel slope (ft/mi)	58.9	39.6	9.7	324
Main channel length (mi)	27.9	14.7	2.2	124
Average basin elevation (ft)	2,379	2,435	1,500	2,810
Percent forest plus one (percent)	52	62	5	96
Average annual precipitation (in.)	43.0	43.5	37.4	48.7
Two year, 24-hour rainfall (in.)	2.6	2.5	2.4	2.8
Appalachian Plateaus (AP)—17 Sites				
Drainage area (mi^2)	160.0	82.3	0.7	554
Main channel slope (ft/mi)	106.0	36.6	10.2	510
Main channel length (mi)	21.8	23.4	1.3	53
Average basin elevation (ft)	2,085	2,000	1,450	2,500
Percent forest plus one (percent)	85	90	1	97
Average annual precipitation (in.)	44.8	44.0	40.5	50.3
Two year, 24-hour rainfall (in.)	2.8	2.8	2.6	2.9

correlated stations, which are often nearby stations, are given less weight in the regional regression analysis. The weighting function used in the GLS method also includes the time-sampling error of the station peak-discharge characteristics. This time sampling error is a function of the length of record, the variability of the annual peak discharges, the skew coefficient, and the recurrence interval of peak-discharge characteristics. Those stations with higher time-sampling error are given less weight in the regional regression analysis

Multiple-parameter regression equations

GLS regressions were tested iteratively. Regressions were initially tested using all seven (variables) basin characteristics. Regression diagnostics were checked, and basin characteristics that were not significant at the 5-percent level were removed, and the regressions recomputed. This process was continued until all of the remaining basin characteristics were significant at the 5-percent level. To determine if the interaction between basin characteristics affected the results, regressions also were tested using sets of only two or three basin characteristics.

Final multiple-parameter regression equations for each of the eight peak-discharge regions are presented in table 2. The drainage area was determined to be the most significant explanatory variable in each peak-discharge region. The drainage area was the only variable significant at the 5-percent level in the Northern Piedmont region, the Blue Ridge region, and both the Central and Southern Valley and Ridge regions. The drainage area and the main channel slope were significant in the Coastal Plain and the Appalachian Plateaus regions. The drainage area, the average basin elevation, and the main channel length were significant in the Southern Piedmont region. In the Northern Valley and Ridge region, the drainage area, the main channel length, and the percentage of forest cover were significant.

The mean annual precipitation and the 2-year 24-hour maximum rainfall were not found to be statistically significant in predicting peak discharge in any region. The general lack of meteorologic effect can be attributed to the fact that within each peak-discharge region there is little climatic zonation with respect to the large storms that are typically responsible for annual peak discharges (Nuckels and others, 1991).

Drainage-area-only regression equations

Because drainage area proved to be the most significant explanatory variable in predicting peak discharge, an alternative to the multiple-parameter GLS regression equations is presented in table 3, using only drainage area. For the four regions with multiple-significant parameters in the regression analysis, these equations are intended to provide estimates of peak discharge that are easier to compute than the full equations. Statistical comparison of these drainage-area-only equations with the multiple-parameter equations indicates that although these equations have higher standard errors than the full equations, and lower equivalent years of record, these equations are not biased compared with the multiple-parameter regression equations. Equations for the four regions with only drainage area in table 2 are repeated in table 3.

Accuracy and Limitations of the Equations

Two estimates of the statistical accuracy of the regression equations are presented in tables 2 and 3. The two estimates are the average standard error of prediction and the average equivalent years of record. The average standard error of prediction is an estimate of how closely the regression equations predict the peak discharge at ungaged sites. The average standard error of prediction is computed as the square root of the sum of the average model error and the average sampling error at each ungaged site (Tasker and Stedinger, 1989). The standard error of prediction is expressed as a percentage. The estimate of peak discharge computed at an ungaged site using the regression equation in tables 2 and 3, will be within the one standard error of prediction about two-thirds of the time.

The equivalent years of record is a measure of how many years of peak-discharge data are needed at a site to have an equivalent statistical accuracy as a peak-discharge characteristics based on the regression estimate (Hardison, 1969, 1971). The equivalent years of record is used to weight the regional regression estimate and the station peak-discharge estimate at peak-discharge gaging stations, and at ungaged sites located near gaging stations.

The use of the equations in this report is limited to estimating peak discharges at sites where basin characteristics are within the range of the basin characteristics of the stations used to develop the regression equations, as listed in table 1. The accuracy and error associated with using these equations for sites outside of these ranges are unknown; therefore, application of the equations to such sites is discouraged.

The regression equations are based primarily on peak-discharge data of rural, unregulated streams in Virginia. The equations are not applicable to urbanized or channelized streams, or to streams where more than 10 percent of the drainage area is impounded. Anderson (1968) presents equations for predicting peak-discharge characteristics for urban streams in Virginia. Sauer and others (1983) provide procedures for estimating urban flood characteristics for watersheds throughout the entire country and include data from Anderson (1968). Because little additional urban stream data has been collected since Anderson's report, equations applicable to urban streams have not been updated and are not presented in this report.

These equations must be used with caution at sites where larger streams just downstream can impact the stage-discharge relation; for example, in areas where large streams downstream may create backwater into the site of interest. These equations also must not be used at sites affected by tides.

The basin characteristics used in computing the discharge from the regression equations are subject to measurement error when determined from maps or other sources of data. A sensitivity analysis for the multiple-parameter, 100-year discharge equation is presented in table 4 (results for the 100-year equation are similar to those for the remaining equations). The analysis indicates the sensitivity of the peak-discharge equations to possible errors in determining each basin characteristic. Table 4 lists the percentage of change in the computed discharge as the value of each variable is increased or decreased by 10, 20, and 30 percent, while the value of the other variables are held constant.

Methods for Regionally Weighting Peak-Discharge Estimates at Gaging Stations

The regional peak-discharge equations in tables 2 and 3 can be used to improve the peak-discharge estimates at gaging stations by using a regional weighting procedure.

Table 2. Multiple-parameter regional regression equations for estimating peak discharges of streams in Virginia

[A, drainage area, in square miles; Sl, main channel slope, in feet per mile; L, main channel length, in miles; El, average basin elevation, in feet above sea level; F, forest, in percent. Peak-discharge regions are shown in figure 1 and plate 1]

Regression equation	Standard error of prediction (percent)	Equivalent years of record
Coastal Plain (C)—29 Sites		
$Q_{(2)} = 2.4\,(A)^{1.005}\,(Sl)^{0.852}$	57.1	1.4
$Q_{(5)} = 4.0\,(A)^{0.999}\,(Sl)^{0.884}$	59.7	2.5
$Q_{(10)} = 4.9\,(A)^{1.005}\,(Sl)^{0.932}$	59.4	3.8
$Q_{(25)} = 6.0\,(A)^{1.016}\,(Sl)^{0.998}$	61.0	5.6
$Q_{(50)} = 6.8\,(A)^{1.024}\,(Sl)^{1.044}$	64.1	6.7
$Q_{(100)} = 7.6\,(A)^{1.033}\,(Sl)^{1.088}$	68.5	7.5
$Q_{(200)} = 8.3\,(A)^{1.042}\,(Sl)^{1.130}$	73.9	8.0
$Q_{(500)} = 9.2\,(A)^{1.055}\,(Sl)^{1.185}$	82.7	8.5
Northern Piedmont (NP)—19 Sites		
$Q_{(2)} = 179\,(A)^{0.655}$	51.1	1.6
$Q_{(5)} = 317\,(A)^{0.644}$	49.3	3.3
$Q_{(10)} = 438\,(A)^{0.641}$	50.2	4.9
$Q_{(25)} = 626\,(A)^{0.640}$	53.8	6.7
$Q_{(50)} = 793\,(A)^{0.640}$	58.0	7.7
$Q_{(100)} = 984\,(A)^{0.641}$	63.5	8.2
$Q_{(200)} = 1{,}200\,(A)^{0.643}$	70.1	8.5
$Q_{(500)} = 1{,}535\,(A)^{0.646}$	80.4	8.6
Southern Piedmont (SP)—67 Sites		
$Q_{(2)} = 21.6\,(A)^{0.881}\,(E)^{0.310}\,(L)^{-0.423}$	40.2	2.8
$Q_{(5)} = 31.9\,(A)^{0.854}\,(E)^{0.351}\,(L)^{-0.417}$	35.7	6.2
$Q_{(10)} = 38.8\,(A)^{0.848}\,(E)^{0.379}\,(L)^{-0.430}$	35.5	9.3
$Q_{(25)} = 54.8\,(A)^{0.852}\,(E)^{0.392}\,(L)^{-0.463}$	38.0	12.3
$Q_{(50)} = 74.3\,(A)^{0.860}\,(E)^{0.390}\,(L)^{-0.495}$	41.4	13.6
$Q_{(100)} = 101\,(A)^{0.869}\,(E)^{0.382}\,(L)^{-0.529}$	45.7	14.2
$Q_{(200)} = 136\,(A)^{0.879}\,(E)^{0.373}\,(L)^{-0.561}$	50.6	14.4
$Q_{(500)} = 197\,(A)^{0.893}\,(E)^{0.361}\,(L)^{-0.602}$	58.0	14.2
Blue Ridge (B)—54 Sites		
$Q_{(2)} = 95.4\,(A)^{0.760}$	33.4	4.0
$Q_{(5)} = 201\,(A)^{0.726}$	34.1	6.5
$Q_{(10)} = 298\,(A)^{0.710}$	35.5	8.8
$Q_{(25)} = 450\,(A)^{0.695}$	38.8	11.0
$Q_{(50)} = 584\,(A)^{0.687}$	42.2	12.0
$Q_{(100)} = 735\,(A)^{0.680}$	46.2	12.5
$Q_{(200)} = 907\,(A)^{0.674}$	50.7	12.6
$Q_{(500)} = 1{,}165\,(A)^{0.667}$	56.7	12.8
Northern Valley and Ridge (NV)—29 Sites		
$Q_{(2)} = 73.0\,(A)^{0.955}\,(L)^{-0.307}\,(F)^{0.041}$	37.8	3.6
$Q_{(5)} = 119\,(A)^{0.953}\,(L)^{-0.290}\,(F)^{0.063}$	33.5	7.4
$Q_{(10)} = 153\,(A)^{0.944}\,(L)^{-0.273}\,(F)^{0.081}$	31.4	12.2
$Q_{(25)} = 196\,(A)^{0.931}\,(L)^{-0.251}\,(F)^{0.107}$	30.9	18.5
$Q_{(50)} = 228\,(A)^{0.926}\,(L)^{-0.241}\,(F)^{0.124}$	31.9	22.2
$Q_{(100)} = 263\,(A)^{0.925}\,(L)^{-0.237}\,(F)^{0.138}$	33.8	24.4
$Q_{(200)} = 300\,(A)^{0.928}\,(L)^{-0.239}\,(F)^{0.149}$	36.3	25.3
$Q_{(500)} = 356\,(A)^{0.936}\,(L)^{-0.247}\,(F)^{0.161}$	40.8	25.1
Central Valley and Ridge (CV)—34 Sites		
$Q_{(2)} = 89.2\,(A)^{0.788}$	31.0	4.8
$Q_{(5)} = 222\,(A)^{0.712}$	29.3	8.7
$Q_{(10)} = 372\,(A)^{0.668}$	28.6	12.9
$Q_{(25)} = 647\,(A)^{0.620}$	29.5	17.5
$Q_{(50)} = 918\,(A)^{0.591}$	31.4	19.4
$Q_{(100)} = 1{,}254\,(A)^{0.565}$	34.1	20.2
$Q_{(200)} = 1{,}665\,(A)^{0.542}$	37.4	20.2
$Q_{(500)} = 2{,}354\,(A)^{0.514}$	42.6	19.5
Southern Valley and Ridge (SV)—35 Sites		
$Q_{(2)} = 45.7\,(A)^{0.880}$	45.0	1.7
$Q_{(5)} = 89.5\,(A)^{0.825}$	43.4	2.6
$Q_{(10)} = 127\,(A)^{0.800}$	44.2	3.3
$Q_{(25)} = 181\,(A)^{0.774}$	46.6	4.2
$Q_{(50)} = 228\,(A)^{0.759}$	49.1	4.7
$Q_{(100)} = 281\,(A)^{0.745}$	52.0	5.2
$Q_{(200)} = 339\,(A)^{0.733}$	55.3	5.5
$Q_{(500)} = 425\,(A)^{0.718}$	60.2	5.7
Appalachian Plateaus (AP)—17 Sites		
$Q_{(2)} = 262\,(A)^{0.749}\,(Sl)^{-0.175}$	33.6	3.5
$Q_{(5)} = 134\,(A)^{0.844}\,(Sl)^{0.032}$	21.3	12.2
$Q_{(10)} = 103\,(A)^{0.880}\,(Sl)^{0.136}$	18.1	23.5
$Q_{(25)} = 90.4\,(A)^{0.902}\,(Sl)^{0.227}$	19.3	31.5
$Q_{(50)} = 87.0\,(A)^{0.910}\,(Sl)^{0.280}$	21.9	33.0
$Q_{(100)} = 85.7\,(A)^{0.916}\,(Sl)^{0.324}$	24.7	33.4
$Q_{(200)} = 85.0\,(A)^{0.920}\,(Sl)^{0.365}$	27.9	33.5
$Q_{(500)} = 85.5\,(A)^{0.923}\,(Sl)^{0.411}$	31.9	33.5

Table 3. Drainage-area-only regional regression equations for estimating peak discharges of streams in Virginia
[*A*, drainage area, in square miles. Peak-discharge regions are shown in figure 1 and plate 1]

Regression equation	Standard error of prediction (percent)	Equivalent years of record	Regression equation	Standard error of prediction (percent)	Equivalent years of record
Coastal Plain (C)—29 Sites			**Northern Valley and Ridge (NV)—29 Sites**		
$Q_{(2)} = 57\,(A)^{0.589}$	55.8	1.4	$Q_{(2)} = 72\,(A)^{0.785}$	39.2	3.4
$Q_{(5)} = 106\,(A)^{0.569}$	58.3	2.5	$Q_{(5)} = 128\,(A)^{0.794}$	35.0	6.9
$Q_{(10)} = 153\,(A)^{0.555}$	62.1	3.5	$Q_{(10)} = 178\,(A)^{0.796}$	32.7	11.4
$Q_{(25)} = 230\,(A)^{0.539}$	68.6	4.5	$Q_{(25)} = 254\,(A)^{0.797}$	32.1	17.6
$Q_{(50)} = 302\,(A)^{0.528}$	74.1	5.2	$Q_{(50)} = 317\,(A)^{0.798}$	33.2	21.1
$Q_{(100)} = 388\,(A)^{0.518}$	80.2	5.7	$Q_{(100)} = 386\,(A)^{0.800}$	35.3	23.1
$Q_{(200)} = 489\,(A)^{0.509}$	86.7	6.2	$Q_{(200)} = 461\,(A)^{0.802}$	38.2	23.7
$Q_{(500)} = 652\,(A)^{0.497}$	96.1	6.7	$Q_{(500)} = 569\,(A)^{0.805}$	43.2	23.2
Northern Piedmont (NP)—19 Sites			**Central Valley and Ridge (CV)—34 Sites**		
$Q_{(2)} = 179\,(A)^{0.655}$	51.1	1.6	$Q_{(2)} = 89\,(A)^{0.788}$	31.0	4.8
$Q_{(5)} = 317\,(A)^{0.644}$	49.3	3.3	$Q_{(5)} = 222\,(A)^{0.712}$	29.3	8.7
$Q_{(10)} = 438\,(A)^{0.641}$	50.2	4.9	$Q_{(10)} = 372\,(A)^{0.668}$	28.6	12.9
$Q_{(25)} = 626\,(A)^{0.640}$	53.8	6.7	$Q_{(25)} = 647\,(A)^{0.620}$	29.5	17.5
$Q_{(50)} = 793\,(A)^{0.640}$	58.0	7.7	$Q_{(50)} = 918\,(A)^{0.591}$	31.4	19.4
$Q_{(100)} = 983\,(A)^{0.641}$	63.5	8.2	$Q_{(100)} = 1{,}254\,(A)^{0.565}$	34.1	20.2
$Q_{(200)} = 1{,}200\,(A)^{0.643}$	70.1	8.5	$Q_{(200)} = 1{,}665\,(A)^{0.542}$	37.4	20.2
$Q_{(500)} = 1{,}535\,(A)^{0.646}$	80.4	8.6	$Q_{(500)} = 2{,}354\,(A)^{0.514}$	42.6	19.5
Southern Piedmont (SP)—67 Sites			**Southern Valley and Ridge (SV)—35 Sites**		
$Q_{(2)} = 122\,(A)^{0.635}$	40.2	2.8	$Q_{(2)} = 46\,(A)^{0.880}$	45.0	1.7
$Q_{(5)} = 233\,(A)^{0.610}$	38.7	5.4	$Q_{(5)} = 90\,(A)^{0.825}$	43.4	2.6
$Q_{(10)} = 335\,(A)^{0.596}$	38.5	8.0	$Q_{(10)} = 127\,(A)^{0.800}$	44.2	3.3
$Q_{(25)} = 504\,(A)^{0.581}$	40.8	10.9	$Q_{(25)} = 181\,(A)^{0.774}$	46.6	4.2
$Q_{(50)} = 661\,(A)^{0.570}$	43.8	12.3	$Q_{(50)} = 228\,(A)^{0.759}$	49.1	4.7
$Q_{(100)} = 849\,(A)^{0.559}$	47.7	13.2	$Q_{(100)} = 281\,(A)^{0.745}$	52.0	5.2
$Q_{(200)} = 1{,}070\,(A)^{0.549}$	52.2	13.7	$Q_{(200)} = 339\,(A)^{0.733}$	55.3	5.5
$Q_{(500)} = 1{,}418\,(A)^{0.538}$	59.0	13.9	$Q_{(500)} = 425\,(A)^{0.718}$	60.2	5.7
Blue Ridge (B)—54 Sites			**Appalachian Plateaus (AP)—17 Sites**		
$Q_{(2)} = 95\,(A)^{0.760}$	33.4	4.0	$Q_{(2)} = 93\,(A)^{0.840}$	32.7	3.7
$Q_{(5)} = 201\,(A)^{0.726}$	34.1	6.5	$Q_{(5)} = 162\,(A)^{0.828}$	19.9	14.0
$Q_{(10)} = 298\,(A)^{0.710}$	35.5	8.8	$Q_{(10)} = 230\,(A)^{0.809}$	17.8	24.3
$Q_{(25)} = 450\,(A)^{0.695}$	38.8	11.0	$Q_{(25)} = 341\,(A)^{0.784}$	20.7	27.5
$Q_{(50)} = 584\,(A)^{0.687}$	42.2	12.0	$Q_{(50)} = 441\,(A)^{0.767}$	24.0	26.5
$Q_{(100)} = 735\,(A)^{0.680}$	46.2	12.5	$Q_{(100)} = 557\,(A)^{0.751}$	27.8	25.2
$Q_{(200)} = 907\,(A)^{0.674}$	50.7	12.6	$Q_{(200)} = 691\,(A)^{0.736}$	31.4	24.2
$Q_{(500)} = 1{,}165\,(A)^{0.667}$	56.7	12.8	$Q_{(500)} = 902\,(A)^{0.717}$	36.3	23.1

Table 4. Sensitivity analysis of multiple-parameter regional peak-discharge regression equations showing percent change in computed 100-year peak discharge within each of the peak-discharge regions of Virginia

[Percentage of change in basin characteristic from median values in table 1 for each peak-discharge region. Peak-discharge regions are shown in figure 1 and plate 1]

Peak-discharge region	Basin characteristic	Percentage of change in basin characteristic						
		-30	-20	-10	-0	+10	+20	+30
Coastal Plain	Drainage area	-31	-21	-10	0	10	21	31
	Channel slope	-32	-22	-11	0	11	22	33
Northern Piedmont	Drainage area	-20	-13	-7	0	6	12	18
Southern Piedmont	Drainage area	-27	-18	-9	0	9	17	26
	Basin elevation	-36	-24	-12	0	13	26	39
	Channel length	21	13	6	0	-5	-9	-13
Blue Ridge	Drainage area	-22	-14	-7	0	7	13	20
Northern Valley and Ridge	Drainage area	-28	-19	-9	-0	9	18	27
	Channel length	9	5	3	0	-2	-4	-6
	Percent forest	-5	-3	-1	0	1	3	4
Central Valley and Ridge	Drainage area	-18	-12	-6	0	6	11	16
Southern Valley and Ridge	Drainage area	-23	-15	-8	0	7	15	22
Appalachian Plateaus	Drainage area	-28	-19	-10	-1	8	17	26
	Channel slope	-11	-7	-3	0	3	6	9

This procedure reduces the time-sampling error, and may improve the final discharge estimate at the gaging station because stations with short periods of record may contain an unrepresentative period of high and (or) low peaks. The station discharge is weighted with the regional discharge as:

$$Q_{(t)w} = \frac{Q_{(t)s}(N) + Q_{(t)r}(E)}{N+E}, \qquad (6)$$

where

$Q_{(t)w}$ = the weighted discharge in ft^3/s for recurrence interval, (t);

$Q_{(t)s}$ = the station peak discharge in ft^3/s for recurrence interval, (t);

$Q_{(t)r}$ = the peak discharge in ft^3/s determined from the regression equation for recurrence interval, (t);

N = the number of years of peak-discharge records for the site; and

E = the equivalent years of record for the regional regression equation, listed in table 2;

The weighted discharges for all stations used in preparing the regression equations are given in appendix 2. Equation 6 also may be used to update estimates at gaging stations where additional data may be collected, and the station peak-discharge statistics recomputed.

METHODS FOR ESTIMATING PEAK DISCHARGES AT UNGAGED SITES

The appropriate method to calculate the peak-discharge estimates at an ungaged site depends on whether (1) the drainage basin lies within a single peak-discharge region, (2) the drainage area crosses peak-discharge region boundaries, or (3) the ungaged site is located on a gaged stream.

1. The peak-discharge estimates at sites on ungaged streams that lie entirely in a single peak-discharge region can be calculated by use of the multiple-parameter regression equations presented in table 2, or the drainage-area-only equations in table 3, for the appropriate region.

2. The peak-discharge estimates at sites with drainage areas that cross peak-discharge region boundaries are made by first determining the percentage of the basin in each region. Peak-discharge estimates are then computed for the entire basin area by using the appropriate equation for each region. The peak-discharge for the entire basin is computed by multiplying the peak discharge for each part of the basin by the percentage of the entire basin in that region, and summing the contributions from each region.

3. The peak-discharge estimates at an ungaged site located on a gaged stream, where the drainage area of the ungaged site is between 50 and 150 percent of the drainage area at the gaged site, can be adjusted using the following technique (Hannum, 1976; Glatfelter, 1984):

   (a) Estimate the peak discharge at the ungaged site using one of the methods previously described.

   (b) Compute a correction factor for the gaged site as follows:

$$C_g = \frac{Q_{(t)w(gaged)}}{Q_{(t)r(gaged)}}, \tag{7}$$

where

C_g = the correction factor for the gaged site;

$Q_{(t)w(gaged)}$ = the weighted peak-discharge estimate at the gaged site for recurrence interval, (t), from appendix 2; and

$Q_{(t)r(gaged)}$ = the regional regression peak-discharge estimate at the gaged site for recurrence interval, (t), from appendix 2.

   (c) Compute a correction factor for the ungaged site:

$$C_u = C_g - \left(\frac{2|A_g - A_u|}{A_g}\right)(C_g - 1), \tag{8}$$

where

C_u = the correction factor for the ungaged site;

C_g = the correction factor for the gaged site from equation 7;

A_g = the drainage area at the gaged site;

A_u = the drainage area at the ungaged site; and

$|A_g\text{-}A_u|$ = the absolute value of the difference between the drainage area of the gaged and the ungaged sites.

   (d) Estimate the adjusted peak discharge at the ungaged site as follows:

$$Q_{(t)a(ungaged)} = C_u Q_{(t)r(ungaged)}, \tag{9}$$

where

$Q_{(t)a(ungaged)}$ = adjusted peak-discharge estimate for the ungaged site for recurrence interval, (t);

C_u = correction factor ratio for the ungaged site, from equation 8; and

$Q_{(t)r(ungaged)}$ = regression peak-discharge estimate for the ungaged site for recurrence interval, (t).

As the difference in the drainage area between the gaged and the ungaged sites approaches either 50 or 150 percent of the drainage area of the gaged site, the correction factor for the ungaged site (C_u) approaches 1, and the adjusted value approaches the regression estimate for the ungaged site.

SAMPLE COMPUTATIONS

Example 1.—Estimate the 50-year peak discharge ($Q_{(50)}$) on Taylors Creek near Montpelier, Va., at an ungaged site that lies entirely within the Southern Piedmont region.

Given: (a) Drainage area (A) is 36.9 mi^2, measured from 1:24,000-scale topographic maps.

(b) Main channel length (L) is 16.1 mi, measured from 1:24,000-scale topographic maps.

(c) Average basin elevation (E) is 1,100 ft, measured by averaging the elevation of 50 points scattered evenly across the basin, measured from 1:24,000-scale topographic maps.

Solution: The regression estimate for the site is computed by the appropriate equation in table 2 for the 50-year discharge:

$$Q_{(50)} = 74.3(A)^{0.860}(E)^{0.390}(L)^{-0.495}.$$

Substituting the given basin characteristics:

$$Q_{(50)s} = 74.3(36.9)^{0.860}(1{,}100)^{0.390}(16.1)^{-0.495}, \text{ and}$$

$$Q_{(50)r} = 6{,}392 \text{ ft}^3/\text{s}.$$

Example 2.—Estimate the 100-year peak discharge at an ungaged site on the Smith River, which receives drainage from both the Blue Ridge and Southern Piedmont peak-discharge regions.

Given: (a) The drainage area at the site is 216 mi^2.

(b) The average basin elevation is 1,400 ft.

(c) The main channel length is 38.8 mi.

(d) 76 percent of the basin is located in the Southern Piedmont region, and the remaining 24 percent is in the Blue Ridge region (from fig. 1 and pl. 1).

Solution: Calculate the 100-year peak discharge for the basin by using each regional equation:

For Blue Ridge—

$$Q_{(100)r} \text{ Region B} = 735(A)^{0.680},$$

$$Q_{(100)r} \text{ Region B} = 735(216)^{0.680}, \text{ and}$$

$$Q_{(100)r} \text{ Region B} = 28{,}430 \text{ ft}^3\text{/s}.$$

For Southern Piedmont—

$$Q_{(100)r} \text{ Region SP} = 101(A)^{0.869}(E)^{0.382}(L)^{-0.529},$$

$$Q_{(100)r} \text{ Region SP} = 101(216)^{0.869}(1400)^{0.382}(38.8)^{-0.529},$$

and

$$Q_{(100)r} \text{ Region SP} = 24{,}790 \text{ ft}^3\text{/s}.$$

Use the percent drainage area in each region as the weighing factor to compute the final estimate for the basin:

$$Q_{(100)r} = (Q_{(100)r} \text{ Region B})(\text{percent in B}) + (Q_{(100)r} \text{ Region SP})(\text{percent in SP}),$$

$$Q_{(100)r} = (28{,}430)(.24) + (24{,}790)(.76), \text{ and}$$

$$Q_{(100)r} = 25{,}660 \text{ ft}^3\text{/s}.$$

Example 3.—Estimate the 50-year peak discharge at an ungaged site on the Blackwater River, 4-mi upstream from the gaged site Blackwater River near Dendron, Va. (USGS 02047500).

Given: (a) The drainage area of the ungaged site is 234 mi^2,

(b) The main channel slope at the ungaged site is 2.7 ft/mi, and

(c) The drainage area of the gaging station is 294 mi^2.

Solution: The drainage area at the site of interest is 78 percent of the drainage area at the gaged site. Using equation 7, the correction factor ratio (C_g) for the gaged station is:

$$C_g = \frac{Q_{(50)w}}{Q_{(50)r}},$$

$$C_g = \frac{7{,}400}{5{,}310} \text{ (from appendix 2), and}$$

$$C_g = 1.39.$$

The correction factor ratio (C_u) for the ungaged site is determined by using equation 8 as:

$$C_u = C_g - \left(\frac{2|A_g - A_u|}{A_g}\right)(C_g - 1),$$

$$C_u = 1.39 - \left(\frac{2|294 - 234|}{294}\right)(1.39 - 1), \text{ and}$$

$$C_u = 1.23.$$

Using the basin characteristics, the 50-year peak-discharge regional regression estimate for the ungaged site in the Coastal Plain peak-discharge region is:

$$Q_{(50)r} = 6.8(A)^{1.024}(SI)^{1.044},$$

$$Q_{(50)r} = 6.8(234)^{1.024}(2.7)^{1.044}, \text{ and}$$

$$Q_{(50)r} = 5{,}266 \text{ ft}^3\text{/s}.$$

And the adjusted discharge is estimated by multiplying the correction factor (C_u) and the regional estimate as:

$$Q_{(50)w} = C_u(Q_{(50)r}),$$

$$Q_{(50)w} = 1.23(5{,}266), \text{ and}$$

$$Q_{(50)w} = 6{,}480 \text{ ft}^3\text{/s}.$$

SUMMARY

This report provides methods for estimating the magnitude and frequency of peak discharges of rural, unregulated streams in Virginia. Peak-discharge characteristics and basin characteristics are presented for 363 stream-gaging stations in Virginia, and 8 stations in Kentucky. Station records were screened to remove data collected from urban, channelized, and regulated streams.

The State was divided into eight peak-discharge regions based on physiographic provinces, and peak-discharge characteristics for 284 stream-gaging stations were regressed on explanatory drainage-basin characteristics. Generalized least-squares regression methods were used to define regression equations for these regions.

The generalized least-squares regression indicates that the drainage area is the most significant basin characteristic to predict the magnitude of peak discharges in each region. The main channel slope is also significant in the Coastal Plain and the Appalachian Plateaus regions. The drainage area, the average basin elevation, and the main channel length are significant in the Southern Piedmont region; and in the Northern Valley and Ridge region, the drainage area, the main channel length, and the percent forest cover are significant. In the Northern Piedmont region, the Blue Ridge region, and the Central and Southern Valley and Ridge regions, the drainage area is the only basin characteristic significant at the 5-percent level. Additional equations using drainage-area only are presented for all the regions in Virginia.

Regression equations presented for the eight regions can be used to estimate the magnitude and frequency of peak discharges for unregulated streams in the State. For streams where peak-discharge data are available, peak-discharge estimates can be improved by weighting the regional regression equation with the gaged-site data.

REFERENCES CITED

Anderson, D.G., 1968, Effects of urban development on floods in Northern Virginia: U.S. Geological Survey Open-File Report, 26 p.

Benson, M.A., 1962a, Evolution of methods for evaluating the occurrence of floods: U.S. Geological Survey Water-Supply Paper 1580-A, 30 p.

__1962b, Factors influencing the occurrence of floods in a humid region of diverse terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Choquette, A.F., 1988, Regionalization of peak discharges for streams in Kentucky: U.S. Geological Survey Water-Resources Investigations Report 87-4209, 105 p.

Fenneman, N.M., 1938, Physiography of Eastern United States: New York, McGraw Hill, 534 p.

Glatfelter, D. R., 1984, Techniques for estimating magnitude and frequency of floods in Indiana: U.S. Geological Survey Water-Resources Investigations Report 84-4134, 110 p.

Hardison, C.H., 1969, Accuracy of streamflow characteristics: U.S. Geological Survey Professional Paper 650-D, p. D210-D214.

___1971, Predictive error of streamflow characteristics at ungaged sites: U.S. Geological Survey Professional Paper 750-C, p. 228-236.

Hannum, C.H., 1976, Techniques for estimating magnitude and frequency of floods in Kentucky; U.S. Geological Survey Water-Resources Investigations Report 76-62, 70 p.

Hirsch, R.M., Slack, J.R., and Smith, R.A., 1982, Techniques of trend analysis for monthly water quality data: Water Resources Research, v. 18, no. 4, p. 107-121.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Bulletin 17B of the Hydrology Subcommittee, U.S. Geological Survey, Office of Water Data Coordination, Reston, Va., 28 p.

Lepkin, W.D., DeLapp, M.M., Kirby, W.H., and Wilson, T.A., 1981, WATSTORE

User's Guide, Volume 4: U.S. Geological Survey Open-File Report 79-1336-I, p. C 1-C 57.

Lumb, A.M., Kittle, J.L., and Flynn, K.M., 1990, User's manual for ANNIE, a computer program for interactive hydrologic analysis and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080, 236 p.

Miller, E.M., 1969, Floods in Virginia, magnitude and frequency: U.S. Geological Survey Open-File Report, 54 p.

___1978, Technique for estimating magnitude and frequency of floods in Virginia: U.S. Geological Survey Water-Resources Investigations Report 78-5, 83 p.

Nuckels, E.H., Prugh, B.J., Michaels, P.J., and Jones, D.R., 1991: Virginia Floods and Droughts, in National Water Summary 1988-1989 -- Hydrologic Events and Floods and Droughts: U.S. Geological Survey Water-Supply Paper 2375, 591 p.

Prugh, B.J., Easton, F.J., and Belval, D.L., 1991a, Water resources data, Virginia, Water Year 1990--Volume 1. Surface water and surface-water-quality records: U.S. Geological Survey Water-Data Report VA-90-1, 407 p.

Prugh, B.J., Nuckels, E.H., and Humphrey, C.G., 1991b, Annual maximum stages and discharges of selected streams in Virginia through 1990: U.S. Geological Survey Open-File Report 90-587, 442 p.

Speer, P.R., and Gamble, C.R., 1964a, Magnitude and frequency of floods in the United States--Part 2A, South Atlantic Slope Basins, James River to Savannah River: U.S. Geological Survey Water-Supply Paper 1673, 329 p.

__1964b, Magnitude and frequency of floods in the United States--Part 3-B, Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1676, 340 p.

__1965, Magnitude and frequency of floods in the United States--Part 3-A, Ohio River Basin, except Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1675, 630 p.

Stedinger, J.R., and Tasker, G.D., 1985, Regional hydrologic analysis--1. Ordinary, weighted, and generalized least squares compared: Water Resources Research, v. 21, no. 9, p. 1421-1432.

Sauer, V.B., Thomas, W.O. Jr., Stricker, V.A., and Wilson, K.V., 1983, Flood characteristics of urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2207, 63 p.

Tasker, G.D., and Stedinger, J.R., 1989, An operational generalized least-squares model for hydrologic regression: Journal of Hydrology, v. 111, p. 361-375.

Tice, R.H., 1950, Magnitude and frequency of floods in the Shenandoah Valley of Virginia: U.S. Geological Survey Open-File Report, 33 p.

U.S. Weather Bureau, 1958, Rainfall intensity-frequency regime, Part 3-Middle Atlantic Region: U.S. Department of Commerce, Technical Paper 29, 38 p.

U.S. Weather Bureau, 1968, Climatological data, annual summary, 1968: U.S. Department of Commerce, v. 78, no. 13, 10 p.

APPENDIXES

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
01484800	Guy Creek near Nassawadox	C	37 30 00	75 52 12	1.72	14.8	3.1	20	20	44.0	3.43
01613900	Hogue Creek near Hayfield	NV	39 12 36	78 17 24	15	167	7.9	1,200	70	37.0	2.80
01615000	Opequon Creek near Berryville	NV	39 10 47	78 04 11	57.4	17.4	20.2	760	38	38.4	3.04
01616000	Abrams Creek near Winchester	NV	39 10 47	78 05 24	16.5	37.8	9.9	800	42	38.3	2.93
01620500	North River near Stokesville	NV	38 20 24	79 14 23	17.2	148	9.6	3,330	98	42.1	3.65
01621000	Dry River at Rawley Springs	NV	38 30 00	79 02 59	72.6	107	15	2,870	100	39.1	2.80
01621200	War Branch near Hinton	NV	38 28 11	78 59 23	9.45	88.2	4.6	1,830	74	35.5	2.80
01621400	Blacks Run at Harrisonburg	NV	38 25 47	78 52 47	5.52	37.9	4.4	1,350	2	38.5	3.00
01621450	Blacks Run Trib near Harrisonburg	NV	38 23 24	78 55 12	.72	176	1.4	1,290	8	37.4	2.83
01622000	North River near Burketown	NV	38 20 24	78 54 35	379	43.2	38.9	2,040	52	39.0	3.09
01622100	North River Trib at Mt Crawford	NV	38 19 47	78 56 23	1.55	100	2.9	1,250	25	39.0	3.24
01622300	Buffalo Branch Trib near Augusta Springs	NV	38 09 35	79 16 11	.55	973	1.5	2,000	95	39.5	2.95
01622400	Buffalo Branch Trib near Christian	NV	38 12 00	79 13 11	.49	950	1	1,800	63	37.8	2.88
01624300	Middle River near Verona	NV	38 14 24	79 02 24	178	17.1	30.1	2,000	65	37.2	2.84
01624800	Christians Creek near Fisherville	NV	38 07 48	78 59 23	70.1	26.7	19.4	1,550	40	38.9	3.19
01625000	Middle River near Grottoes	NV	38 15 35	78 51 35	375	10.2	64	1,600	30	39.3	3.04
01626000	South River near Waynesboro	M	38 03 36	78 54 35	127	15.3	23.4	1,820	67	45.9	3.95
01626850	South River near Dooms	M	38 05 24	78 52 47	149	12.9	--	--	--	--	--
01627500	South River at Harriston	M	38 13 11	78 50 24	212	10.6	41.8	1,740	61	43.9	3.85
01628500	SF Shenandoah River near Lynnwood	NV	38 19 12	78 45 36	1,084	27.4	55.6	1,750	45	40.2	3.25
01629500	SF Shenandoah River near Luray	NV	38 38 59	78 31 48	1,377	12.9	97.2	1,680	54	41.4	3.36
01629945	Chub Run near Stanley	B	38 34 47	78 27 35	3.16	272.2	2.4	1,470	57	49.0	4.35
01631000	SF Shenandoah River at Front Royal	NV	38 54 35	78 12 35	1,642	7.73	145	1,600	50	41.6	3.45
01632000	NF Shenandoah River at Cootes Store	NV	38 38 24	78 50 59	210	44.3	25.8	2,020	89	35.8	3.09
01632300	Long Meadow near Broadway	NV	38 34 47	78 45 36	8.15	48.8	5.4	1,260	15	37.4	2.90
01632900	Smith Creek near New Market	NV	38 41 23	78 38 24	93.2	20.5	25.1	1,400	50	38.0	3.58
01632950	Crooked Run Trib near Conicville	NV	38 47 59	78 43 11	.31	500	1	1,450	98	35.2	2.87
01632970	Crooked Run near Mt Jackson	NV	38 45 35	78 41 23	6.49	61.8	4.5	1,200	45	35.2	2.78
01633000	NF Shenandoah River at Mt Jackson	NV	38 45 00	78 38 24	506	24.3	45.9	1,670	53	37.0	3.14
01633500	Stony Creek at Columbia Furnace	NV	38 52 11	78 37 47	79.4	28.6	20.4	2,030	86	34.0	2.80

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
01633650	Pughs Run near Woodstock	NV	38 55 47	78 32 59	3.66	292.1	2.5	1,510	60	35.2	2.52
01634000	NF Shenandoah River near Strasburg	NV	38 58 47	78 20 24	768	9.86	103	1,430	50	36.5	3.03
01634500	Cedar Creek near Winchester	NV	39 04 47	78 19 47	103	33	23.4	1,350	86	34.6	2.87
01635500	Passage Creek near Buckton	NV	38 57 36	78 16 11	87.8	34.3	31.1	1,490	81	38.7	3.25
01636210	Happy Creek at Front Royal	B	38 54 35	78 11 23	14	212	5.4	1,330	58	36.6	3.50
01638480	Catoctin Creek at Taylorstown	B	39 15 00	77 34 47	89.6	14.1	27.5	600	30	41.3	3.19
01643700	Goose Creek near Middlebrug	B	38 59 24	77 47 59	123	16.8	22.9	700	40	39.8	3.18
01644000	Goose Creek near Leesburg	B	39 01 12	77 34 47	332	8.25	40.6	660	35	40.0	3.18
01644100	SF Sycolin Creek near Leesburg	B	39 04 12	77 36 35	2.05	71.7	3.1	560	17	39.9	3.00
01644291	Stave Run near Reston	NP	38 57 00	77 22 12	.08	166.6	.35	400	90	38.9	3.30
01644295	Smilax Branch at Reston	NP	38 57 00	77 22 12	.32	125	.8	410	85	38.9	3.30
01645700	Difficult Run near Fairfax	NP	38 52 11	77 20 24	4.29	50	2.4	410	73	39.5	3.55
01645784	Snakeden Branch at Reston	NP	38 55 47	77 20 59	.79	76.4	1.1	--	--	--	--
01646000	Difficult Run near Great Falls	NP	38 58 47	77 15 00	57.9	16	13.3	360	60	39.0	3.29
01646200	Scott Run near Mclean	NP	38 57 36	77 12 35	4.69	54	4.2	363	50	39.0	3.70
01646600	Pemmit Run near Falls Church	NP	38 54 35	77 10 48	2.87	59.4	--	--	--	--	--
01652400	Long Branch at Arlington	NP	38 51 35	77 07 47	.94	101.1	--	--	--	--	--
01652430	Doctors Run at Arlington	C	38 51 35	77 05 59	.9	81.2	--	--	--	--	--
01652500	Fourmile Run at Alexandria	M	38 50 24	77 04 47	14.4	45.4	7.2	220	14	39.0	3.70
01652600	Holmes Run at Merrifield	NP	38 51 35	77 12 35	2.7	36.8	--	--	--	--	--
01652610	Holmes Run near Annandale	NP	38 51 00	77 10 12	7.1	--	--	--	--	--	--
01652910	Back Lick Run at Alexandria	M	38 47 59	77 07 47	13.4	--	--	--	--	--	--
01653000	Cameron Run at Alexandria	M	38 48 36	77 06 35	33.7	32.9	10.9	270	46	39.3	3.66
01653900	Accotink Creek at Fairfax	NP	38 51 35	77 16 11	6.8	--	--	--	--	--	--
01654000	Accotink Creek near Annandale	NP	38 48 36	77 13 48	23.5	19.3	10	320	65	39.7	3.61
01654500	Long Branch at Annandale	NP	38 48 36	77 14 23	3.71	46.7	4	350	65	39.4	3.65
01655350	Pohick Creek near Springfield	NP	38 45 35	77 13 48	15	23.8	10	340	60	39.0	3.50
01655500	Cedar Run near Warrenton	B	38 44 24	77 47 24	12.3	77.1	4.8	640	33	39.9	3.25
01656000	Cedar Run near Catlett	M	38 38 24	77 37 47	93.4	18.3	20.3	430	36	40.4	3.29
01656100	Cedar Run near Aden	M	38 37 11	77 32 59	155	--	--	--	--	--	--

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elev-ation (feet)	Percent forest (percent plus one)	Mean annual precip-itation (inch)	24 hour, 2 year rain-fall (inch)
01656200	Broad Run near Warrenton	B	38 48 36	77 48 36	2.94	187	2	788	32	40.3	3.18
01656500	Broad Run at Buckland	B	38 46 48	77 40 12	50.5	23.6	16.3	610	38	40.1	3.16
01656600	Broad Run Trib at Buckland	NP	38 46 48	77 40 12	.79	80.8	1.8	380	61	40.4	3.15
01656650	Broad Run near Bristow	M	38 45 00	77 33 36	89.6	28.7	--	--	--	--	--
01656700	Occoquan River near Manassas	M	38 42 36	77 27 00	343	7.7	42.2	360	45	40.8	3.22
01656725	Bull Run near Catharpin	NP	38 53 24	77 34 11	25.8	28.2	7.3	440	40	39.6	3.04
01656960	Cub Run near Bull Run	NP	38 49 12	77 28 11	49.9	28.7	--	--	--	--	--
01657000	Bull Run near Manassas	NP	38 47 59	77 27 35	148	7.5	26.5	380	47	39.7	3.11
01657415	Bull Run near Clifton	NP	38 46 12	77 24 35	185	--	--	--	--	--	--
01657500	Occoquan River near Occoquan	NP	38 42 36	77 19 47	570	6.34	53.6	350	47	40.3	3.21
01658500	SF Quantico Creek near Independent Hill	NP	38 35 24	77 25 48	7.64	29.2	4.8	340	97	40.5	3.10
01660400	Aquia Creek near Garrisonville	NP	38 29 24	77 25 48	34.9	14.3	13.5	310	65	40.3	3.27
01661600	Great Wicomico River near Horse Head	C	37 53 24	76 27 00	6.98	19	3.5	80	66	41.6	3.08
01661800	Bush Mill Stream near Heathsville	C	37 52 48	76 29 23	6.82	20.3	4.2	80	85	41.7	3.08
01661900	Carter Run near Marshall	B	38 47 59	77 52 12	19.5	25.2	9.0	--	--	--	--
01662000	Rappahannock River near Warrenton	B	38 40 47	77 54 00	195	20.7	23.9	770	44	39.2	3.36
01662300	Thornton River Trib near Thornton Gap	B	38 40 12	78 17 24	1.38	880	2	2,210	100	46.1	4.21
01662500	Rush River at Washington	B	38 42 36	78 09 00	14.7	243	7.5	1,410	62	40.0	3.87
01662800	Battle Run near Laurel Mills	B	38 39 35	78 04 11	27.6	50	9.2	1,500	55	41.5	3.70
01663000	Thornton River near Laurel Mills	B	38 37 48	78 03 36	142	47.3	19.8	1,060	53	43.0	3.88
01663500	Hazel River at Rixeyville	B	38 35 24	77 58 11	287	29.5	31.7	980	41	39.8	3.93
01664000	Rappahannock River at Remington	B	38 31 48	77 48 36	620	9.43	39.7	790	43	40.2	3.65
01664500	Rappahannock River at KellySFord	B	38 28 47	77 46 48	641	7.83	44.2	770	43	40.7	3.64
01664800	Harpers Run near Morrisville	NP	38 31 12	77 43 11	2.28	59.4	2.1	350	75	46.0	3.26
01665000	Mountain Run near Culpeper	M	38 28 47	78 02 59	15.9	35.7	5.5	420	35	41.5	3.81
01665050	Pony Mountain Branch near Culpeper	NP	38 27 00	77 57 35	.3	400	.8	465	52	42.4	3.58
01665500	Rapidan River near Ruckersville	B	38 16 48	78 20 24	114	89.5	22.8	1,540	65	48.0	4.20
01666500	Robinson River near Locust Dale	M	38 19 12	78 05 59	179	35	30.2	940	65	42.5	3.90
01667000	Rapidan River at Rapidan	M	38 18 36	78 03 36	446	19.2	48	1,000	60	39.9	3.54
01667500	Rapidan River near Culpeper	M	38 21 00	77 58 48	472	14.9	54.6	860	53	43.2	3.67

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
01667600	Cedar Run Trib near Culpeper	NP	38 23 59	78 00 36	.58	71.4	0.9	360	70	41.7	3.60
01668000	Rappahannock River near Fredericksburg	M	38 19 12	77 31 11	1,596	6.64	70.2	660	54	42.5	3.49
01668300	Farmers Hall Creek near Champlain	C	38 00 00	76 58 48	2.18	46.7	2	120	68	41.5	3.45
01668500	Cat Point Creek near Montross	C	38 02 23	76 49 47	45.6	13.5	10.4	110	82	41.2	3.31
01668800	Hoskins Creek near Tappahannock	C	37 55 47	76 57 00	15.5	12.5	8	110	75	42.2	3.31
01669000	Piscataway Creek near Tappahannock	C	37 52 48	76 54 00	28	14	7.6	120	69	42.2	3.52
01669500	Dragon Swamp near Church View	C	37 40 47	76 43 48	84.9	4.08	19.7	120	71	43.2	3.35
01669800	My Ladys Swamp near Saluda	C	37 34 47	76 31 48	4.81	26.6	3.3	70	64	44.5	3.24
01670000	Beaverdam Swamp near Ark	C	37 28 11	76 33 36	6.63	10.9	4.2	90	90	45.7	3.29
01670300	Contrary Creek near Mineral	SP	38 02 23	77 52 47	5.53	43.2	--	--	--	--	--
01671000	North Anna River near Doswell	SP	37 53 24	77 29 23	441	3.64	58.6	320	73	41.7	3.47
01671100	Little River near Doswell	SP	37 52 11	77 30 36	107	5.02	31.9	290	72	41.8	3.68
01671500	Bunch Creek near Boswells Tavern	SP	38 01 48	78 11 23	4.37	32.8	4.2	420	75	42.5	3.43
01671615	Fosters Creek near Ferncliff	SP	37 57 36	78 11 23	.61	109.4	.85	570	46	40.9	3.41
01671650	Waldrop Creek near Louisa	SP	38 00 00	78 04 11	2.85	45.9	2.9	460	78	42.3	3.38
01671750	Harris Creek near Trevilians	SP	38 01 12	78 02 59	3.31	33.3	2.8	480	86	42.3	3.38
01672500	South Anna River near Ashland	SP	37 47 59	77 32 59	394	2.92	82.1	350	72	41.8	3.52
01673000	Pamunkey River near Hanover	SP	37 46 12	77 19 47	1,081	3.48	82.5	310	74	42.2	3.60
01673500	Totopotomoy Creek near Atlee	C	37 40 12	77 22 47	5.89	14.5	5.1	170	65	43.0	3.66
01673550	Totopotomoy Creek near Studley	C	37 39 35	77 15 36	26.2	28.7	--	--	--	--	--
01673800	Po River near Spotsylvania	NP	38 10 12	77 35 24	77.4	8.7	20	340	88	42.2	3.48
01674000	Mattaponi River near Bowling Green	M	38 03 36	77 23 24	257	6.89	37.7	280	81	42.0	3.51
01674100	Motto River Trib near Cedon	C	38 05 24	78 31 11	1.64	44.4	1.8	260	73	42.0	3.55
01674200	Reedy Creek near Dawn	C	37 52 48	77 21 35	16.8	8.96	9	180	85	42.0	3.68
01674500	Mattaponi River near Beulahville	M	37 53 24	77 09 35	601	3.42	74.1	210	76	42.1	3.59
01674700	Aylett Creek at Aylett	C	37 46 48	77 06 35	6.17	28.7	4	120	80	43.0	3.66
01677000	Ware Creek near Toano	C	37 26 23	76 47 24	6.29	25	2.8	--	--	--	--
02009500	Cattail Run near Bolar	CV	38 16 12	79 40 12	.74	800	2	2,380	70	40.8	2.80
02011400	Jackson River near Bacova	CV	38 02 23	79 52 47	158	--	--	--	--	--	--
02011460	Back Creek near Sunrise	CV	38 15 00	79 46 11	60.1	--	--	--	--	--	--

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
02011480	Back Creek at Rt 600 nr Mountain Grove	CV	38 07 48	79 51 35	85.8	27	5.3	--	--	--	--
02011500	Back Creek near Mountian Grove	CV	38 04 12	79 54 00	134	44.4	33.4	2,890	90	40.9	2.86
02012500	Jackson River at Falling Spring	CV	37 52 48	79 58 48	411	25.3	57.6	2,480	80	40.8	2.74
02012950	Sweet Spgs Cr Trib at Sweet Chalybeate	CV	37 39 35	80 14 23	.66	592	1.7	2,330	68	37.8	2.55
02013000	Dunlap Creek near Covington	CV	37 47 59	80 02 59	164	40.5	27.3	2,230	87	38.5	2.56
02014000	Potts Creek near Covington	CV	37 43 47	80 02 24	153	27.3	39.8	2,320	85	38.6	2.62
02014500	Smith Creek near Clifton Forge	CV	37 51 00	79 50 59	12.4	259	6.5	2,250	99	40.8	3.08
02015600	Cowpasture River near Head Waters	CV	38 19 12	79 26 23	11.3	63.3	6.4	2,450	81	40.5	3.30
02015700	Bullpasture River at Williamsville	CV	38 12 00	79 34 11	110	41.5	22.9	2,200	80	40.1	2.90
02016000	Cowpasture River near Clifton Forge	CV	37 47 23	79 45 36	461	12.4	74.3	2,030	81	40.1	2.84
02016500	James River at Lick Run	CV	37 46 12	79 46 48	1,373	15.3	93.4	2,210	82	40.0	2.75
02017000	Meadow Creek at New Castle	CV	37 29 24	80 06 35	13.8	161	7.9	2,220	37	39.2	3.05
02017300	Craig Creek at New Caslte	CV	37 30 00	80 05 59	112	26	30.3	2,000	80	40.5	3.00
02017400	Johns Creek Trib near New Castle	CV	37 33 36	80 00 00	1.57	480	3	2,160	98	38.3	2.75
02017500	Johns Creek at New Castle	CV	37 30 35	80 06 35	104	22.2	35.3	2,210	90	38.2	2.70
02017700	Craig Creek Trib near New Castle	CV	37 33 36	80 00 00	2.05	295	3	1,740	99	40.0	2.95
02018000	Craig Creek at Parr	CV	37 40 12	79 54 35	329	12.1	65.1	2,150	88	39.4	2.90
02018500	Catawba Creek near Catawba	CV	37 28 11	80 00 36	34.3	37.8	17	1,880	68	42.6	3.30
02018800	North Fork near Fincastle	CV	37 32 23	79 55 48	4.17	164	4.4	2,840	96	41.5	2.80
02019000	Catawba Creek near Fincastle	CV	37 32 59	79 49 47	104	29.8	32.8	1,500	60	42.2	3.27
02019400	Mill Creek near Buchanan	CV	37 30 00	79 45 36	29.6	41.6	10.2	1,280	21	42.0	3.40
02019500	James River at Buchanan	CV	37 31 48	79 40 48	2,075	11.5	131	2,080	81	40.4	2.88
02020100	Renick Run near Buchanan	CV	37 35 24	79 37 47	2.06	258	3.2	1,660	70	42.8	3.19
02020200	Calfpasture River near West Augusta	CV	38 16 12	79 17 59	12.8	156	6	2,420	98	41.5	3.55
02020500	Calfpasture River Ab Mill Cr at Goshen	CV	37 59 24	79 29 23	144	21.3	32.4	2,520	91	39.7	3.01
02021000	Calfpasture River at Goshen	CV	37 59 24	79 29 23	190	21.3	32.6	2,450	91	39.8	2.90
02021500	Maury River at Rockbridge Baths	CV	37 54 35	79 25 12	329	18.2	41.8	2,200	88	39.9	2.87
02021700	Cedar Grove Branch nr Rockbridge Baths	CV	37 52 48	79 23 24	12.3	112	4.9	1,510	29	42.0	2.96

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
02022500	Kerrs Creek near Lexington	CV	37 49 47	79 26 23	35	83.5	10.4	1,900	77	39.3	2.85
02023000	Maury River near Lexington	CV	37 48 36	79 26 23	487	21.1	54.7	1,810	75	40.6	2.92
02023300	South River near Steeles Tavern	B	37 55 47	79 10 12	15.7	162	7	2,750	100	49.0	3.60
02023500	South River near Riverside	M	37 46 48	79 21 35	111	64.2	23	1,820	64	46.5	3.25
02024000	Maury River near Buena Vista	CV	37 45 35	79 23 24	646	19.4	61.9	1,950	70	43.1	3.01
02024500	Maury River at Glasgow	CV	37 37 48	79 26 23	831	16.6	75.7	1,880	68	42.7	3.09
02025000	Pedlar River near Pedlar Mills	B	37 32 23	79 15 00	91	56.8	24.7	2,220	82	44.5	4.25
02025500	James River at Holcombs Rock	CV	37 30 00	79 15 36	3,259	9.3	169	1,990	77	41.0	3.11
02026000	James River at Bent Creek	M	37 32 23	78 49 11	3,683	8.12	209	1,900	77	41.2	3.14
02026500	Tye River at Roseland	B	37 45 00	78 59 23	68	133	17.6	1,740	79	51.2	4.65
02027000	Tye River near Lovingston	B	37 43 11	78 58 48	92.8	99.4	21.3	1,530	72	50.7	4.40
02027500	Piney River at Piney River	B	37 42 00	79 01 48	47.6	151	16.5	2,080	81	49.6	4.48
02027700	Buffalo River Trib near Amherst	SP	37 33 36	78 57 35	.46	173	1	730	90	46.0	3.40
02027800	Buffalo River near Tye River	B	37 36 35	78 55 12	147	27.9	33.4	2,000	70	47.4	3.46
02028000	Tye River near Norwood	B	37 37 48	78 52 47	360	43.2	34.2	1,600	65	49.0	4.17
02028500	Rockfish River near Greenfield	B	37 52 11	78 49 11	94.6	102	13.1	1,400	70	47.2	4.18
02028700	Cove Creek near Covesville	B	37 52 11	78 43 48	4	233	3.2	890	50	45.0	3.85
02028800	Ballinger Creek at Esmont	SP	37 49 47	78 36 35	5.42	45.7	3.1	570	67	45.0	3.45
02028900	Miller Creek near Scottsville	SP	37 48 36	78 30 36	6.6	27.1	4.6	430	40	43.3	3.43
02029000	James River at Scottsville	M	37 47 59	78 29 23	4,584	7.16	248	1,790	76	42.5	3.31
02029200	NF Hardware River at Red Hill	B	37 58 11	78 37 12	11	66.1	3.4	739	45	44.3	3.70
02029400	S B Of NF Hardware River nr N Garden	B	37 57 36	78 39 35	6.59	312	3.7	979	65	44.0	3.85
02029500	Hardware River near Scottsville	M	37 50 24	78 28 11	104	20.8	17.6	800	72	44.8	3.53
02030000	Hardware R Bl Briery Rn nr Scottsville	M	37 48 36	78 27 35	116	18.9	19.8	800	72	44.1	3.48
02030500	Slate River near Arvonia	SP	37 42 00	78 22 47	226	8.36	36.8	550	84	42.2	3.51
02030800	Stockton Creek near Afton	B	38 01 48	78 48 36	2.8	597	2.6	2,000	81	42.3	4.10
02031000	Mechum River near Ivy	B	38 06 00	78 35 24	97	18	18.6	870	60	43.6	3.98
02031500	NF Moormans River near Whitehall	B	38 08 24	78 45 00	11.4	238	6.2	2,170	93	42.0	3.85
02032250	Moormans River near Free Union	B	38 08 24	78 33 36	74.6	78.7	15.8	--	--	--	--
02032400	Buck Mountain Creek near Free Union	B	38 08 59	78 32 24	37	45.2	10.0	--	--	--	--

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
02032500	SF Rivanna River near Earlysville	B	38 07 11	78 31 11	216	13	27.2	1,350	56	44.5	4.04
02032530	Parker Branch near Stanardsville	B	38 17 23	78 37 12	3.24	240	2	960	55	48.3	4.16
02032540	Haneytown Creek near Stanardsville	B	38 16 48	78 30 36	4.45	468	4.9	1,800	78	48.5	4.15
02032550	Lynch River at Nortonsville	B	38 14 24	78 32 24	13.6	219	9.2	1,680	83	47.7	4.20
02032680	NF Rivanna River near Profitt	M	38 05 24	78 24 35	176	65.3	14.8	1,400	60	46.3	3.43
02032700	Schenks Branch at Charlottesville	SP	38 02 23	78 28 11	1.34	109	1.4	400	80	45.9	3.49
02033300	Moores Creek near Charlottesville	B	38 00 35	78 34 11	3.52	147	2.1	800	65	44.8	3.55
02033500	Rivanna River near Charlottesville	M	38 01 12	78 27 00	507	8.44	41.1	1,000	60	45.3	3.37
02034000	Rivanna River at Palmyra	M	37 51 35	78 16 11	664	6.39	60.6	800	58	45.4	3.66
02034050	Hunters Branch near Palmyra	SP	37 57 00	78 14 23	1.63	50	2.3	480	71	42.7	3.41
02034250	Whispering Creek at Sprouses Corner	SP	37 31 48	78 28 48	.43	80.4	.7	610	84	39.5	3.44
02034300	Little Willis River at Curdsville	SP	37 24 35	78 27 35	7.07	27.3	5.9	500	73	41.5	3.43
02034500	Willis River at Flanagan Mills	SP	37 40 12	78 10 12	262	6.79	43.2	480	76	40.6	3.42
02035000	James River at Cartersville	M	37 40 12	78 05 24	6,257	6.16	280	1,560	74	42.7	3.35
02035400	Big Lickinghole Creek Trib nr Ferncliff	SP	37 49 47	77 58 11	.55	99	1.3	1,340	93	41.5	3.42
02036500	Fine Creek at Fine Creek Mills	SP	37 36 00	77 49 11	22.1	14.8	9.4	300	86	41.7	3.60
02037500	James River near Richmond	M	37 33 36	77 32 59	6,758	5.51	320.6	1,500	70	43.1	3.64
02037800	Falling Creek near Midlothian	M	37 27 00	77 35 24	18.1	17.5	8	370	98	43.4	3.56
02038000	Falling Creek near Chesterfield	M	37 26 23	77 31 11	32.8	13.2	12.1	270	95	43.5	3.60
02038500	Falling Creek near Drewrys Bluff	M	37 27 36	77 28 11	54	13.2	16.5	240	90	43.6	3.59
02038800	Appomattox River near Appomattox	SP	37 22 48	78 47 24	5.79	55.3	2.6	780	47	42.8	3.32
02038840	Holiday Creek near Toga	SP	37 25 47	78 41 23	1.68	108	2.4	750	99	42.0	3.40
02038845	North Holiday Creek near Toga	SP	37 26 23	78 40 12	1.31	56	2.5	650	99	42.0	3.40
02038850	Holiday Creek near Andersonville	SP	37 25 12	78 38 24	8.53	58.8	5.2	700	99	41.5	3.42
02039000	Buffalo Creek near Hampden Sydney	SP	37 15 35	78 29 23	69.7	12.5	10.7	490	74	42.2	3.25
02039500	Appomattox River at Farmville	SP	37 18 36	78 23 24	303	9.22	37.4	490	75	42.1	3.00
02040000	Appomattox River at Mattoax	SP	37 25 12	77 51 35	726	3.87	84.3	460	75	42.7	3.24
02040500	Flat Creek near Amelia	SP	37 23 24	78 03 36	73	7.7	24.1	390	50	42.5	3.60
02040600	Nibbs Creek Trib near Amelia	SP	37 23 59	77 58 11	.35	142	.8	280	19	42.0	3.42

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
02041000	Deep Creek near Mannboro	SP	37 16 48	77 52 12	158	7.5	21.5	320	75	43.2	3.63
02041500	Appomattox River near Petersburg	SP	37 13 47	77 32 24	1,335	2.66	120	400	77	42.8	3.37
02041650	Appomattox River at Matoaca	SP	37 13 11	77 28 48	1,344	2.6	123.8	170	64	46.3	3.44
02042200	Glebe Creek Trib near Charles City	C	37 22 11	77 04 11	.7	66.6	1.2	120	43	45.7	3.50
02042250	Bailey Branch Trib at Spring Grove	C	37 10 12	76 59 23	.71	36.4	1.4	100	70	43.0	3.85
02042300	Horsepen Branch at Richmond	C	37 36 00	77 30 36	1.35	83.3	1.6	260	1	43.5	3.54
02042500	Chickahominy River nr Providence Forge	C	37 26 23	77 03 36	248	4.24	45.5	170	63	44.4	3.63
02042700	Collins Run near Providence Forge	C	37 23 59	77 02 59	2.84	22.9	3	100	86	45.6	3.49
02042780	WB Long Hill Swamp near Lightfoot	C	37 18 36	77 46 11	2.47	22.2	1.8	80	92	46.5	3.43
02043500	Cypress Swamp at Cypress Chapel	C	36 37 11	76 35 59	23	6.25	6.5	60	73	50.9	3.85
02044000	Nottoway River near Burkeville	SP	37 04 47	78 12 00	38.7	20.3	9.2	500	86	43.2	3.85
02044200	Falls Creek Trib near Victoria	SP	37 01 48	78 10 12	.34	103	.9	240	85	44.0	3.70
02044500	Nottoway River near Rawlings	SP	36 58 47	77 47 59	309	7.32	37.3	420	69	43.9	3.74
02045500	Nottoway River near Stony Creek	SP	36 53 59	77 24 00	579	5.3	70.4	370	75	44.8	3.59
02046000	Stony Creek near Dinwiddie	SP	37 04 12	77 35 59	112	7.69	22.4	250	82	45.7	3.51
02046400	Jones Hole Swamp Trib near Carson	C	37 04 12	77 20 24	3.02	13.2	3.3	140	82	48.4	3.27
02046500	Anderson Branch at Sussex	C	36 55 12	77 15 36	5.35	10.7	3.8	100	72	49.5	3.15
02046900	Musgrave Branch near Drewryville	C	36 42 00	77 16 11	1.99	24.3	2.4	100	62	47.7	3.20
02047000	Nottoway River near Sebrell	M	36 46 12	77 10 12	1,421	2.92	105	220	79	46.4	3.42
02047500	Blackwater River near Dendron	C	37 01 12	76 52 12	294	2.23	41.9	130	78	46.6	3.19
02048000	Blackwater River at Zuni	C	36 52 11	76 50 24	456	1.9	56	110	81	46.6	3.25
02048400	Seacock Creek near Ivor	C	36 55 12	76 55 48	27.4	5	8.1	96	95	49.0	3.27
02049500	Blackwater River near Franklin	C	36 45 35	76 54 00	617	1.62	64.7	100	80	49.8	3.62
02049700	Cypress Swamp near Burdette	C	36 44 24	76 56 23	8.55	12.5	4.9	50	70	50.0	3.50
02050050	Blackwater River Trib near Holland	C	36 38 59	76 51 35	2.76	26.5	2.2	60	70	50.5	3.65
02050400	North Meherrin River near Briery	SP	37 04 12	78 27 35	1.19	59.1	1.4	590	61	42.7	3.43
02050500	North Meherrin River near Keysville	SP	37 02 59	78 25 12	9.2	33.9	4.1	550	53	42.9	3.45
02051000	North Meherrin River near Lunenburg	SP	37 00 00	78 20 59	55.6	21.2	10.7	470	80	43.4	3.49
02051400	Saddletree Creek near Lawrenceville	SP	36 43 47	77 54 35	.87	50	1.6	280	55	44.4	3.27
02051500	Meherrin River near Lawrenceville	SP	36 43 11	77 49 47	552	4.17	62.4	420	72	44.7	3.35

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
02051600	Great Creek near Cochran	SP	36 48 36	77 55 12	30.7	15.8	10	350	75	44.4	3.40
02051650	Rocky Run near Dolphin	SP	36 47 23	77 49 47	1.41	54.2	1.6	320	81	44.3	3.32
02052000	Meherrin River at Emporia	SP	36 41 23	77 32 24	747	3.46	82.9	400	76	44.7	3.40
02052500	Fountains Creek near Brink	SP	36 37 11	77 42 00	65.2	8.8	18.9	300	66	44.8	3.40
02053800	SF Roanoke River near Shawsville	M	37 08 24	80 16 11	110	82.1	12.2	2,300	25	42.8	2.97
02054500	Roanoke River at Lafayette	M	37 14 24	80 12 35	257	43	22.8	1,840	76	42.2	3.00
02055000	Roanoke River at Roanoke	M	37 15 35	79 56 23	395	17.4	45.3	1,680	74	42.2	3.13
02055100	Tinker Creek near Daleville	CV	37 25 12	79 56 23	11.7	92.9	4.2	1,470	26	42.0	3.36
02056000	Roanoke River at Niagara	CV	37 15 00	79 52 12	512	15.4	50.6	1,550	70	42.3	3.23
02056650	Back Creek near Dundee	M	37 13 47	79 52 12	56.8	28.2	18.2	--	--	--	--
02056900	Blackwater River near Rocky Mount	B	37 02 23	79 50 24	115	--	--	--	--	--	--
02057000	Blackwater River near Union Hall	B	37 02 23	79 41 23	208	10.9	57.5	1,360	66	43.4	3.51
02057500	Roanoke River near Toshes	M	37 01 48	79 31 11	1,020	10.1	92.8	1,330	69	42.9	3.45
02057700	Powder Mill Creek at Rocky Mount	B	37 00 35	79 52 12	.64	207	2	1,230	54	43.2	3.46
02058000	Snow Creek at Sago	SP	36 53 59	79 39 00	60	17.4	19.2	1,100	70	43.3	3.77
02058400	Pigg River near Sandy Level	M	36 57 00	79 31 11	350	9.47	66.2	1,100	55	42.6	3.96
02058500	Pigg River near Toshes	M	36 58 47	79 30 36	394	9.47	70.4	1,050	55	43.4	3.67
02059500	Goose Creek near Huddleston	B	37 10 12	79 31 11	188	19	30.5	1,140	63	44.0	4.02
02060500	Roanoke River at Altavista	M	37 06 00	79 17 59	1,789	8.31	119	1,170	66	43.0	3.65
02061000	Big Otter River near Bedford	B	37 21 35	79 25 12	116	25.2	17	870	69	43.8	4.15
02061150	Chestnut Branch near Forest	B	37 22 11	79 23 24	1.65	27.3	2.5	950	36	40.7	3.55
02061300	Nininger Creek near Bedford	B	37 16 12	79 29 23	4.77	66.1	4	975	50	44.0	4.35
02061500	Big Otter River near Evington	B	37 12 36	79 17 59	320	14.2	32	1,010	60	43.0	4.09
02062500	Roanoke River at Brookneal	M	37 02 23	78 57 00	2,415	6.4	150	1,080	57	42.7	3.67
02064000	Falling River near Naruna	SP	37 07 48	78 57 35	173	12.6	22.2	700	67	40.9	3.24
02065100	Snake Creek near Brookneal	SP	37 00 35	78 57 35	1.68	86.7	2	520	70	41.5	3.28
02065300	Right Hand Fork near Appomattox	SP	37 16 12	78 49 11	2.08	119	1.7	700	83	41.5	3.27
02065500	Cub Creek at Phenix	SP	37 04 47	78 45 36	98	11.4	20.4	600	75	41.4	3.28
02066000	Roanoke Creek at Saxe	M	36 54 35	78 44 23	2,977	5.82	179	990	60	42.5	3.59
02066500	Roanoke Creek at Saxe	SP	36 55 47	78 40 12	135	6.82	17.6	490	76	42.3	3.33

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
02067000	Roanoke River near Clover	M	36 50 24	78 40 12	3,230	5.56	186	940	59	42.5	3.57
02067810	Maple Swamp B Trib nr Meadows of Dan	B	36 44 24	80 26 23	.49	464	.9	520	70	48.0	4.30
02069700	South Mayo River near Nettleridge	M	36 34 12	80 07 47	84.6	38.8	21.4	1,440	40	50.5	3.42
02070000	North Mayo River near Spencer	SP	36 34 12	79 59 23	108	19.3	25.5	1,100	82	48.3	3.52
02072500	Smith River at Bassett	B	36 46 12	80 00 00	259	20.3	44.8	1,450	85	46.3	3.60
02073000	Smith River at Martinsville	M	36 39 35	79 52 47	380	14.9	58.4	1,290	79	46.0	3.58
02074500	Sandy River near Danville	SP	36 37 11	79 30 00	112	17.4	22.2	820	52	44.2	3.57
02075000	Dan River at Danville	SP	36 35 24	79 22 47	2,050	10.4	144	1,030	66	46.6	3.65
02075350	Powells Creek near Turbeville	SP	36 34 47	79 11 23	.28	109.4	.85	460	17	43.7	3.12
02075450	Little Winns Creek near Turbeville	SP	36 35 24	79 05 24	2.3	64.7	2.3	465	58	43.8	3.20
02075500	Dan River at Paces	SP	36 38 24	79 05 24	2,550	7.83	171	1,000	65	43.7	3.20
02075900	Lawsons Creek at Turbeville	SP	36 36 35	79 01 11	8.7	27.3	4.3	500	60	44.0	3.10
02076000	Dan River at South Boston	SP	36 41 23	78 54 00	2,730	6.98	184	900	64	46.0	3.58
02076200	Bearskin Creek near Chatham	SP	36 50 24	79 28 48	4.06	51.9	3.6	850	65	45.0	3.45
02076400	Whitehorn Creek Tributary at Gretna	SP	36 55 47	79 22 12	1.93	68.5	2.6	--	--	--	--
02076500	Georges Creek near Gretna	SP	36 56 23	79 18 36	9.24	11.5	6.9	860	55	42.2	3.99
02076700	Blacks Creek near Mt Airy	SP	36 56 23	79 10 12	3.44	84.1	3	600	93	42.0	3.96
02077000	Banister River at Halifax	SP	36 46 48	78 55 12	547	5.59	62	620	62	43.3	3.82
02077500	Hyco River near Denniston	SP	36 35 24	78 54 00	289	3.05	58.9	550	68	44.5	3.32
02078000	Hyco River near Omega	SP	36 38 24	78 48 36	413	3.05	67.8	530	69	44.7	3.36
02079000	Roanoke River at Clarksville	M	36 37 48	78 32 59	7,320	4.86	207	850	62	44.1	3.57
02079640	Allen Creek near Boydton	SP	36 40 47	78 19 47	53.4	12.5	15.4	400	70	45.4	3.15
03164000	New River near Galax	B	36 38 59	80 58 48	1,131	9.52	111	3,280	55	46.9	3.33
03165000	Chestnut Creek at Galax	B	36 38 59	80 55 12	39	25.3	11	2,560	40	45.0	3.08
03165500	New River at Ivanhoe	B	36 49 47	80 57 00	1,340	8.91	131	3,170	55	46.2	3.16
03166800	Glade Creek at Grahams Forge	SV	36 55 47	80 54 00	7.15	65.8	2.5	--	--	--	--
03167000	Reed Creek at Grahams Forge	SV	36 56 23	80 53 24	247	11.4	41	2,500	43	38.6	2.68
03167300	Mira Fork Tributary near Dugspur	B	36 50 24	80 35 59	.62	534	1	2,860	45	43.5	3.05

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
03167500	Big Reed Island Creek near Allisonia	B	36 53 24	80 43 48	278	15.2	46.3	2,570	69	44.6	3.34
03167700	Beaverdam Creek at Hillsville	B	36 46 12	80 43 48	4.13	93.9	2.8	2,600	30	43.0	3.05
03168000	New River at Allisonia	M	36 56 23	80 45 00	2,202	9.56	149	2,910	54	44.3	3.05
03168500	Peak Creek at Pulaski	SV	37 02 59	80 46 48	60.9	47.7	14.2	2,350	72	37.6	2.54
03168600	Peak Creek Tributary near Pulaski	SV	37 04 12	80 46 11	.61	83.3	1.6	2,110	75	38.0	2.48
03168750	Thorne Springs Branch near Dublin	SV	37 05 24	80 44 23	4.77	54.3	3.1	2,110	5	37.8	2.47
03169350	Brush Creek at Terrys Fork	B	37 02 59	80 16 48	1.4	140.9	1.5	2,640	29	43.1	3.25
03169500	Little River near Copper Valley	B	37 00 00	80 31 11	239	9.26	57.7	2,500	50	41.3	2.77
03170000	Little River at Graysonton	B	37 02 23	80 33 36	300	9.73	65.1	2,470	46	43.6	3.45
03171000	New River at Radford	M	37 08 24	80 34 11	2,748	3.43	175.4	2,800	53	39.4	2.50
03171150	Crab Creek Trib near Christiansburg	SV	37 07 48	80 27 35	1.23	109.4	2.2	2,130	13	40.8	2.62
03171500	New River at Eggleston	M	37 17 23	80 37 12	2,941	8.0	199	2,740	51	43.5	2.88
03173000	Walker Creek at Bane	SV	37 16 12	80 42 35	305	20.1	53.7	2,590	64	37.4	2.56
03175500	Wolf Creek near Narrows	SV	37 18 36	80 50 59	223	35.9	45	2,810	71	40.6	2.57
03176500	New River at Glen Lyn	M	37 22 11	80 51 35	3,768	6.72	225	2,700	53	42.3	2.80
03177700	Bluestone River at Bluefield	SV	37 15 35	81 16 48	39.8	31.6	15.2	2,800	90	43.2	2.50
03207400	Prater Creek at Vasant	AP	37 13 11	82 05 59	19.8	119	6.3	1,700	95	40.5	2.78
03207500	Levisa Fork near Grundy	AP	37 17 59	82 07 47	235	36.6	23.5	2,040	92	41.6	2.71
03207800	Levisa Fork at Big Rock	AP	37 21 00	82 12 00	297	26.5	31.8	2,000	90	43.5	2.60
03207962	Dicks Fork at Phyllis, Kentucky	AP	37 26 56	82 20 16	.82	509.9	1.46	2,500	.82	44.0	2.80
03208000	Levisa Fork Below Fishtrap Dam, Kentucky	AP	37 24 57	82 25 15	392	16.9	52.7	1,900	85	44.0	2.80
03208500	Russell Fork at Haysi	AP	37 12 36	82 17 59	286	19.3	23.5	2,120	97	42.6	2.82
03208950	Cranes Nest River near Clintwood	AP	37 07 11	82 26 23	66.5	42.5	17	2,090	95	46.0	2.84
03209000	Pound River Bl Flannagan Dam nr Haysi	AP	37 13 47	82 20 24	221	10.2	41.3	2,000	92	46.9	2.82
03209300	Russell Fork at Elkhorn City, Kentucky	AP	37 17 59	82 17 59	554	21.2	40.27	2,000	86	44.0	2.80
03277290	Bottom Fork near Mayking, Kentucky	AP	37 08 24	82 45 32	3.03	276.1	3.69	2,000	86	41.9	2.80
03277437	Breeding Creek near Isom, Kentucky	AP	37 12 32	82 55 40	.69	366.0	1.34	2,000	86	41.9	2.80

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elevation (feet)	Percent forest (percent plus one)	Mean annual precipitation (inch)	24 hour, 2 year rainfall (inch)
03277450	Carr Fork near Sassafras, Kentucky	AP	37 13 51	83 02 09	60.6	17.1	19.81	1,450	95	48.0	2.80
03400500	Poor Fork at Cumberland, Kentucky	AP	36 58 26	82 59 34	82.3	28.1	25.8	2,500	90	48.0	2.90
03471100	Dickey Creek at Sugar Grove	B	36 46 12	81 25 12	7.28	140	5.2	3,150	84	41.5	2.60
03471200	SF Holston River at Teas	M	36 46 12	81 27 00	31.1	61.2	5.3	3,090	70	41.5	2.70
03471500	SF Holston R at Riverside nr Chilhowie	M	36 45 35	81 37 47	76.1	32	18.4	2,870	83	42.0	2.83
03472500	Beaverdam Creek at Damascus	B	36 37 48	81 47 24	56	56.9	17.3	2,950	89	45.7	2.77
03473000	SF Holston Creek near Damascus	M	36 38 59	81 50 24	301	23.2	37.3	2,930	76	43.2	2.03
03473500	MF Holston River at Groseclose	SV	36 53 24	81 20 59	7.39	46.2	3.6	2,710	49	39.0	2.69
03473800	Staley Creek near Marion	SV	36 49 12	81 28 11	8.33	154	5.4	2,500	95	40.5	2.48
03474000	MF Holston River at Sevenmile Ford	SV	36 48 36	81 37 12	132	24.3	25	2,480	64	40.0	2.50
03474500	MF Holston River at Chilhowie	SV	36 47 59	81 40 48	155	21.5	29.4	2,470	60	40.5	2.49
03474700	Hutton Creek near Chilhowie	SV	36 46 48	81 43 48	8.32	82.1	3.7	2,230	22	43.0	2.50
03474800	Hall Creek near Glade Spring	SV	36 45 35	81 47 59	7.9	68.2	4.4	2,110	25	43.5	2.55
03475000	MF Holston River near Meadowview	SV	36 42 36	81 49 11	211	14.6	42.8	2,390	51	41.4	2.52
03475600	Cedar Creek near Meadowview	SV	36 45 00	81 51 35	3.38	65.9	2.2	2,610	6	44.4	2.72
03475700	Spring Creek near Abingdon	SV	36 40 47	82 02 24	2.99	54.8	2.8	2,120	14	46.0	2.62
03477500	Beaver Creek near Wallace	SV	36 38 24	82 06 35	13.7	40.4	7.7	2,180	11	45.6	2.58
03478400	Beaver Creek near Bristol	SV	36 37 48	82 07 47	27.7	40	9.3	2,140	14	45.6	2.58
03487800	Lick Creek near Chatham Hill	SV	36 57 36	81 28 11	25.5	39.1	14.7	2,770	96	42.6	2.65
03487850	Possum Jaw Creek near Chatham Hill	SV	36 57 36	81 27 35	4.36	114	4.7	2,510	63	43.0	2.65
03487900	Sprouts Creek near Chatham Hill	SV	36 58 11	81 30 36	7.64	324	2.8	2,760	76	42.6	2.65
03488000	NF Holston River near Saltville	SV	36 53 59	81 45 00	222	21.7	47.6	2,730	63	43.4	2.58
03488500	NF Holston River at Holston	SV	36 46 12	82 04 11	402	17.7	72.8	2,500	65	44.8	2.41
03489500	NF Holston River at Mendota	SV	36 42 00	82 18 36	493	13.9	93.2	2,480	66	44.1	2.51
03489800	Cove Creek near Shelleys	SV	36 38 59	82 20 59	17.3	68.3	8.4	1,500	70	45.9	2.52
03489850	Cove Creek near Hilton	SV	36 38 59	82 21 35	17.6	62.7	8.9	1,500	70	45.9	2.52
03489870	Big Moccasin Creek near Hansonville	SV	36 44 24	82 19 11	41.9	24.4	22.1	2,110	30	45.0	2.50
03489900	Big Moccasin Creek near Gate City	SV	36 38 59	82 32 59	79.6	16.7	51.9	2,290	25	46.0	2.50
03490000	NF Holston River near Gate City	SV	36 36 35	82 34 11	672	9.69	124	2,370	64	44.4	2.50
03521500	Clinch River at Richlands	SV	37 05 24	81 46 48	139	23	37.5	2,580	34	44.8	2.65

Appendix 1. Basin characteristics at peak-discharge gaging stations in Virginia—Continued

[Modified from Miller, 1978, p. 34–51; Kentucky stations are from Choquette (1987, p. 98–105); Peak-discharge regions are shown in figure 1 and plate 1; M, is mixed regions; --, no data is available; latitude and longitude are reported in degrees, minutes, and seconds; R., river; nr, near; Cr., creek; Trib., tributary; SF, south fork; NF, north fork; MF, middle fork; WB, west branch; SB, south branch]

Station number	Station name	Peak-discharge region	Latitude	Longitude	Drainage area (square miles)	Main channel slope (feet per mile)	Main channel length (mile)	Mean basin elev-ation (feet)	Percent forest (percent plus one)	Mean annual precip-itation (inch)	24 hour, 2 year rain-fall (inch)
03523000	Cedar Creek near Lebanon	SV	36 54 35	82 02 24	51.5	39.6	15.6	2,400	40	43.5	2.48
03524000	Clinch River at Cleveland	SV	36 56 23	82 09 00	528	14.9	86.9	2,490	42	43.9	2.65
03524500	Guest River at Coeburn	M	36 55 47	82 27 35	87.3	13.1	25.9	2,520	81	47.6	2.92
03525000	Stony Creek at Fort Blackmore	SV	36 46 12	82 34 47	41.4	178	13.8	2,800	93	47.7	2.82
03526000	Copper Creek near Gate City	SV	36 40 12	82 34 11	106	16.1	44.7	2,100	35	45.5	2.52
03527000	Clinch River at Speers Ferry	M	36 38 59	82 45 00	1,126	9.36	148	2,300	50	45.3	2.67
03529500	Powell River at Big Stone Gap	AP	36 52 11	82 46 48	112	41.2	23.4	2,480	84	48.6	2.66
03530000	SF Powell River at Big Stone Gap	SV	36 51 35	82 46 11	40	156	14.6	2,370	63	48.7	2.65
03530500	NF Powell River at Pennington Gap	AP	36 46 12	83 01 48	70	59.4	14.8	2,500	95	50.3	2.70
03531000	Powell River near Pennington Gap	M	36 43 47	83 00 00	290	21.5	45.9	2,270	67	49.1	2.77
03531500	Powell River near Jonesville	M	36 39 35	83 05 24	319	16.8	58.9	2,290	64	49.4	2.73