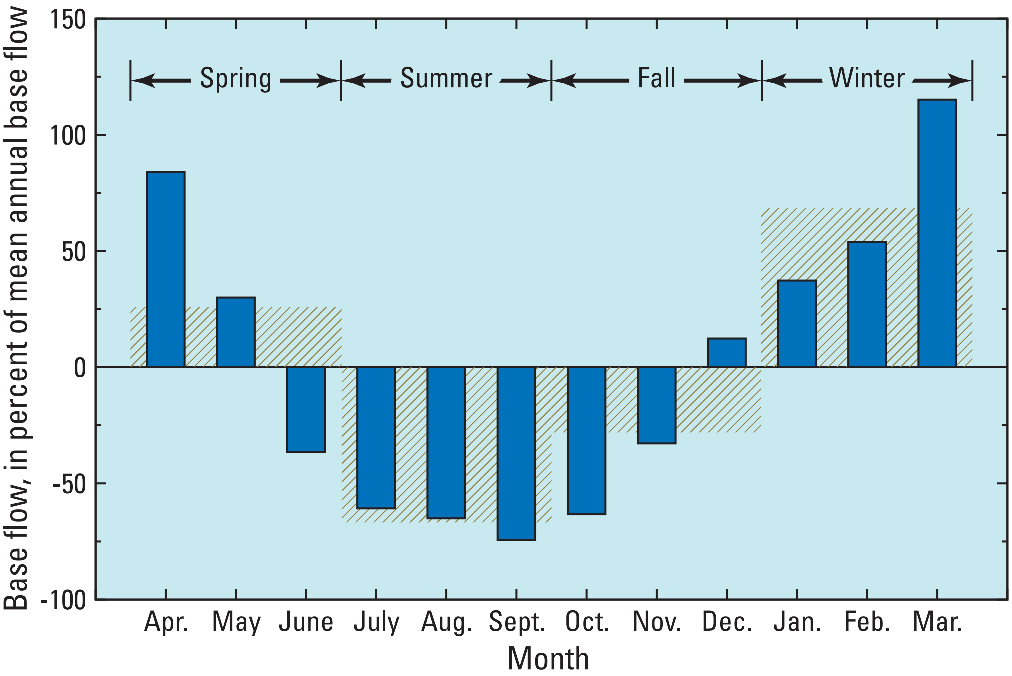
Prepared in cooperation with the West Virginia Department of Environmental Protection, Division of Water and Waste Management

Comparison of Base Flows to Selected Streamflow Statistics Representative of 1930–2002 in West Virginia



Scientific Investigations Report 2012–5121

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

Cover. Mean seasonal and mean monthly base flows as percentage of mean annual base flows for 15 streamflow-gaging stations in West Virginia, 1930–2002.

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Comparison of Base Flows to Selected Streamflow Statistics Representative of 1930–2002 in West Virginia

By Jeffrey B. Wiley

Abstract

Base flows were compared with published streamflow statistics to assess climate variability and to determine the published statistics that can be substituted for annual and seasonal base flows of unregulated streams in West Virginia. The comparison study was done by the U.S. Geological Survey, in cooperation with the West Virginia Department of Environmental Protection, Division of Water and Waste Management. The seasons were defined as winter (January 1–March 31), spring (April 1–June 30), summer (July 1–September 30), and fall (October 1–December 31).

Differences in mean annual base flows for five record sub-periods (1930–42, 1943–62, 1963–69, 1970–79, and 1980–2002) range from -14.9 to 14.6 percent when compared to the values for the period 1930–2002. Differences between mean seasonal base flows and values for the period 1930–2002 are less variable for winter and spring, -11.2 to 11.0 percent, than for summer and fall, -47.0 to 43.6 percent. Mean summer base flows (July–September) and mean monthly base flows for July, August, September, and October are approximately equal, within 7.4 percentage points of mean annual base flow. The mean of each of annual, spring, summer, fall, and winter base flows are approximately equal to the annual 50-percent (standard error of 10.3 percent), 45-percent (error of 14.6 percent), 75-percent (error of 11.8 percent), 55-percent (error of 11.2 percent), and 35-percent duration flows (error of 11.1 percent), respectively. The mean seasonal base flows for spring, summer, fall, and winter are approximately equal to the spring 50- to 55-percent (standard error of 6.8 percent), summer 45- to 50-percent (error of 6.7 percent), fall 45-percent (error of 15.2 percent), and winter 60-percent duration flows (error of 8.5 percent), respectively.

Annual and seasonal base flows representative of the period 1930–2002 at unregulated streamflow-gaging stations and ungaged locations in West Virginia can be estimated using previously published values of statistics and procedures.

Introduction

Streamflow can be separated into discharge from overland runoff and discharge from groundwater. Base flow is the portion of streamflow contributed by groundwater discharge. Generally, base flows are greater in wetter seasons than in dryer seasons because more water accumulates and is released from groundwater. Knowledge of climatic, seasonal, and monthly differences in base flows can assist scientists and water-resource managers in understanding the capacity of groundwater storage in watersheds and the ability of a stream to maintain flows during droughts.

Streamflow statistics have been computed for streamflow-gaging stations, and equations have been determined to estimate streamflows at ungaged locations in West Virginia for the period 1930 to 2002 (Wiley, 2006, 2008; Wiley and Atkins, 2010a). Equations for estimating base flows could be determined using similar methods, but a simpler and lower cost method for estimating base flows is already available if published streamflow statistics can be used as surrogates for base flows.

This study, conducted in cooperation with the West Virginia Department of Environmental Protection, Division of Waste and Water Management, investigated the climatic, seasonal, and monthly variability of base flows at 15 selected long-term streamflow-gaging stations, documented the development of relations between base flows and published streamflow statistics, and determined surrogate statistics (the published statistics that can be substituted for base flows) to be used to estimate annual and seasonal base flows at other streamflow-gaging stations and at ungaged locations. The results of this study are representative of the period 1930–2002 and are relevant only to West Virginia, but the procedures presented in this report can be used to determine substitute streamflow statistics that can be used to estimate base flows in other regions.

This report presents the procedures used to estimate base flows for 1930–2002. The climatic, seasonal, and monthly variability of base flows at 15 long-term streamflow-gaging stations is discussed. Relations between mean annual and mean seasonal base flows, and between mean annual and 50-percent duration flows, are shown in illustrations. Relations between mean seasonal base flows and seasonal duration flows are also shown in illustrations. Differences between mean annual base flows and annual streamflow statistics are listed in tables. Base flows for the 15 long-term streamflow-gaging stations are provided in an Appendix as supplementary information.

Description of Study Area

West Virginia can be differentiated into three physiographic provinces (fig. 1), the Appalachian Plateaus, Valley and Ridge, and Blue Ridge (Fenneman, 1938). The movement of air masses across the State allows identification of two climatic regions (fig. 1), separated by a line defined as the Climatic Divide (Wiley and others, 2000; Wiley and Atkins, 2010b).

Generally, the part of the State west of the Climatic Divide is in the Appalachian Plateaus Physiographic Province; altitudes in the Appalachian Plateaus range from about 2,500 to 4,861 ft (NAVD 88) at Spruce Knob along the Climatic Divide to about 550 to 650 ft along the Ohio River. The part of West Virginia east of the Climatic Divide is in the Valley and Ridge Physiographic Province, except for the extreme eastern tip of the State, which is in the Blue Ridge Physiographic Province. Altitudes decrease eastward from the Climatic Divide to 274 ft at Harpers Ferry in the Eastern Panhandle (U.S. Geological Survey, 1990, 2006; National Oceanic and Atmospheric Administration, 2006a).

The Appalachian Plateaus Physiographic Province consists of consolidated, mostly siliciclastic sedimentary rocks that have a gentle slope from southeast to northwest near the Climatic Divide and are nearly flat-lying along the Ohio River. One exception is in the northeastern area of the province (west of the Climatic Divide), where the rocks are gently folded and some carbonate rock crops out (Fenneman, 1938). The rocks in the Appalachian Plateaus Physiographic Province have been eroded to form steep hills and deeply incised valleys. Drainage patterns are dendritic.

The Valley and Ridge Physiographic Province in West Virginia consists of consolidated carbonate and siliciclastic sedimentary rocks that are folded sharply and extensively faulted (Fenneman, 1938). Northeast-trending valleys and ridges parallel the Climatic Divide. Drainage patterns are trellis.

The Blue Ridge Physiographic Province within West Virginia consists predominantly of metamorphosed sandstone and shale (Fenneman, 1938). The province has high relief between mountains and wide valleys that parallel the Climatic Divide. Drainage patterns are trellis.

The climate of West Virginia is primarily continental, with mild summers and cold winters. Major weather systems generally approach from the west and southwest, although polar continental air masses of cold, dry air that approach from the north and northwest are not unusual. Air masses from the Atlantic Ocean sometimes affect the area east of the Climatic Divide and less frequently affect the area west of the Climatic Divide. Generally, tropical continental masses of hot, dry air from the southwest affect the climate west of the Climatic Divide. Tropical maritime masses of warm, moist air from the Gulf of Mexico affect the climate east of the Climatic Divide more than west of the Climatic Divide. Evaporation from local and upwind land surfaces, lakes, and reservoirs also provides a source of moisture that affects the climate of the State (U.S. Geological Survey, 1991; National Oceanic and Atmospheric Administration, 2006a).

Annual precipitation averages about 42 to 45 in. statewide with about 60 percent received from March through August. July is the wettest month, and September through November are the driest months. Annual average precipitation in the State generally decreases northwestward from about 50 to 60 in. along the Climatic Divide to about 40 in. along the Ohio River; precipitation ranges from about 30 to 35 in. east of the Climatic Divide to about 40 in. in the extreme eastern tip of the State. Greater precipitation along and west of the Climatic Divide is a consequence of the higher elevations along the Divide and the orographic lifting of weather systems generally approaching from the west and southwest. Annual average snowfall follows the general pattern of annual average precipitation, decreasing northwestward from about 36 to 100 in. along the Climatic Divide to about 20 to 30 in. along the Ohio River. East of the Climatic Divide, annual average snowfall ranges from 24 to 36 in. (U.S. Geological Survey, 1991; Natural Resources Conservation Service, 2006; National Oceanic and Atmospheric Administration, 2006a, 2006b).

Previous Studies

Selected statistics for U.S. Geological Survey (USGS) streamflow-gaging stations representative of conditions during 1930–2002 were determined by Wiley (2006). In that study, a criterion-based sample of the record period was used to determine statistics representative of 1930–2002 rather than using the entire record period and (or) using record-extension techniques. The selected statistics included annual and seasonal hydrologically and biologically based low-flow frequency values, harmonic means, and flow-duration values (including variability index).

Wiley (2008) developed estimating procedures for the annual 1-, 3-, 7-, 14-, and 30-day 2-year; 1-, 3-, 7-, 14-, and 30-day 5-year; and 1-, 3-, 7-, 14-, and 30-day 10-year hydrologically based low-flow frequency values for unregulated streams in West Virginia. Equations and procedures for the annual 1-day 3-year and 4-day 3-year biologically based low-flow frequency values; the annual U.S. Environmental Protection Agency (USEPA) harmonic mean flows; and the annual 10-, 25-, 50-, 75-, and 90-percent flow-duration values

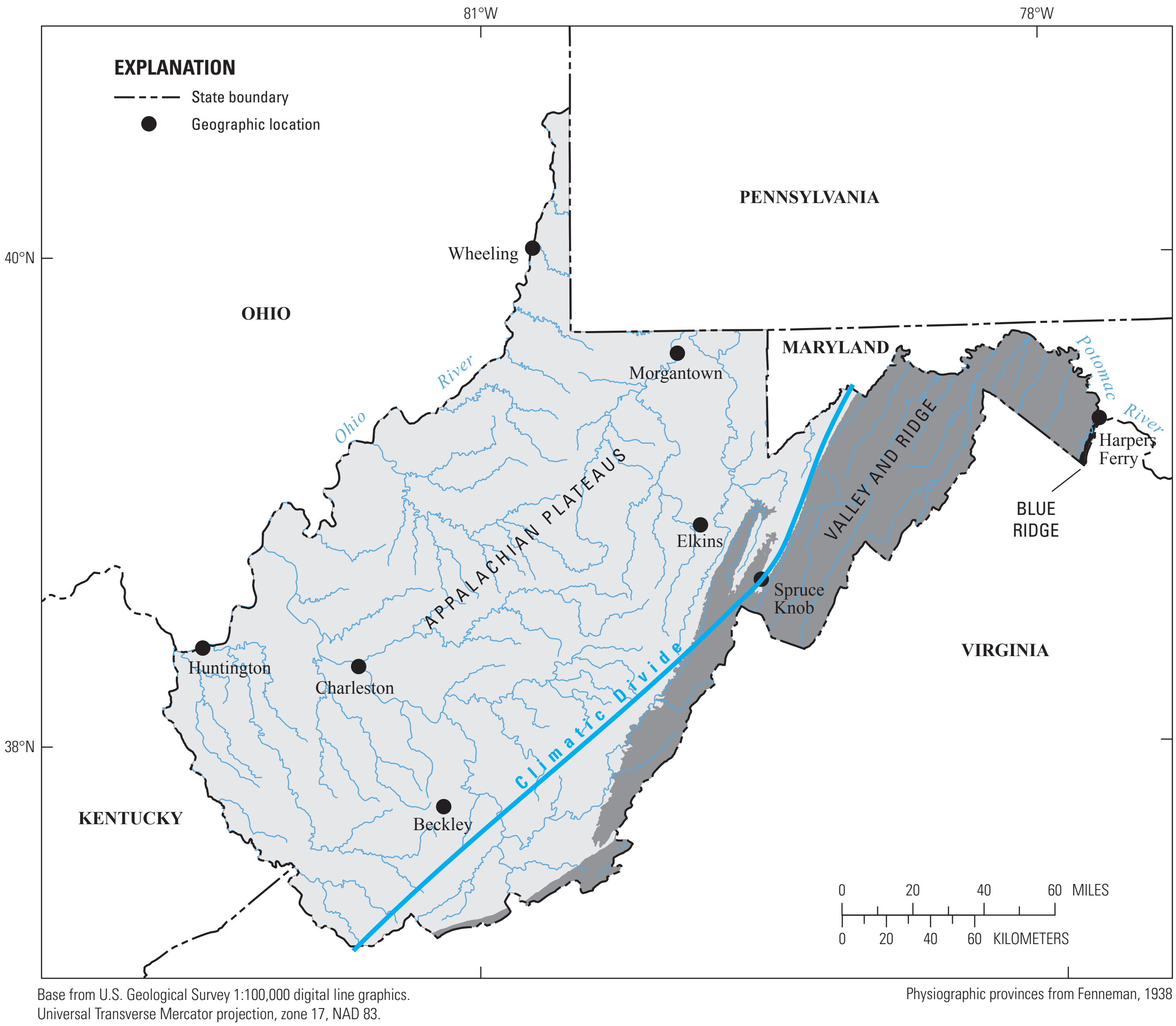


Figure 1. Appalachian Plateaus, Valley and Ridge, and Blue Ridge Physiographic Provinces, and Climatic Divide in West Virginia. (From Wiley and Atkins, 2010b, figure 2)

also were developed. Regional equations were developed using ordinary least squares regression with flow statistics from USGS streamflow-gaging stations as dependent variables and basin characteristics for these streamflow-gaging stations as independent variables.

Methods for estimating seasonal flow statistics at ungaged locations were developed by Wiley and Atkins (2010a) using data from Wiley (2006). The seasons were defined as winter (January 1–March 31), spring (April 1–June 30), summer (July 1–September 30), and fall (October 1–December 31). Regional equations for the seasonal 1-day 10-year, 7-day 10-year, and 30-day 5-year hydrologically based low-flow frequency values; the seasonal USEPA harmonic mean flows; and the seasonal 50-percent flow-duration values were developed using the same methods and regional boundaries used by Wiley (2006).

Computation of Base Flows

Base flow can be determined hydrographically using base-flow-recession methods (Olmsted and Hely, 1962; Riggs, 1964; Rorabaugh, 1964), curve-fitting methods (Pettyjohn and Henning, 1979; Linsley and others, 1982), and computer methods (Sloto and Crouse, 1996; Rutledge, 1998). A computer method is desired because computation time is substantially reduced, and a method that excludes individual biases of manipulation allows for reproducible results.

Daily mean discharge records for 14 USGS streamflow-gaging stations in West Virginia that have no more than 4 years of missing record during 1930–2002 were used to compute base flows. A combination of two nearby stations was used to supplement the 14 stations and provide information near the southern border of the State, but no stations were available along the western border that met the record-length criterion. Fifteen stations (counting the combination of the two Tug Fork stations as one) are identical to those used by Wiley (2006) to study the variability of selected annual and seasonal flow statistics (fig. 2, table 1).

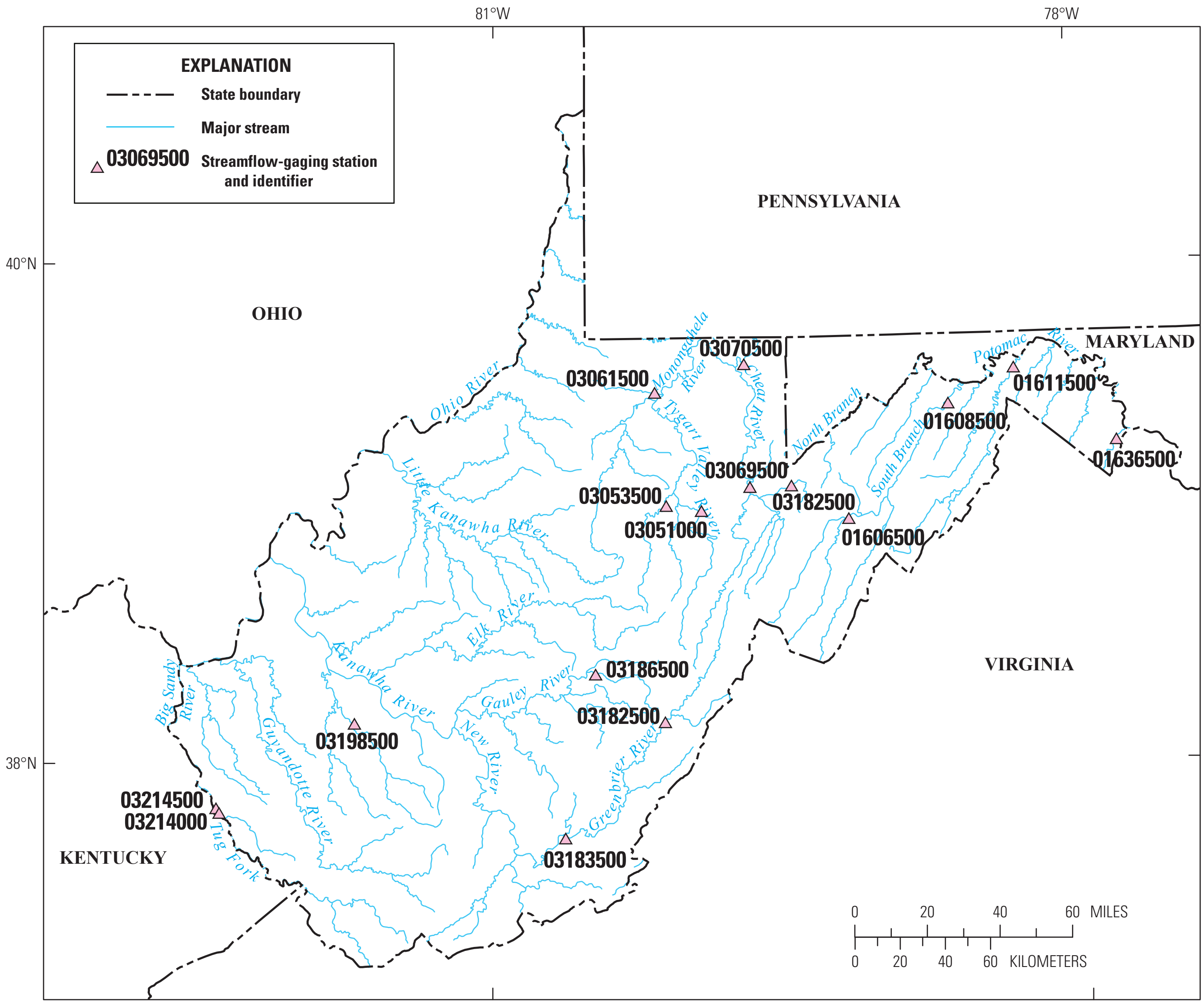
Base flows were computed for the 15 streamflow-gaging stations using the PART (streamflow PARTitioning) computer program developed by Rutledge (1998). Base flows for the 15 streamflow-gaging stations were computed annually, seasonally, and monthly for the period of record 1930 to 2002 and annually for five periods of record found by Wiley (2006) to have similar characteristics in annual minimum daily mean flows: 1930–42, 1943–62, 1963–69, 1970–79, and 1980–2002. The period 1930 to 2002 includes periods of droughts during the 1930s and 1960s and a wet period during the 1970s. Base flows were computed for climatic years (April 1 to March 31 of the indicated year) and for winter (January 1–March 31), spring (April 1–June 30), summer (July 1–September 30), and fall (October 1–December 31) for comparison with streamflow statistics computed by Wiley (2006).

The combined stations are Tug Fork near Kermit (station number, 03214000; drainage area, 1,188 mi^2) and Tug Fork at Kermit (03214500; 1,280 mi^2). Most annual, and all seasonal and monthly, base-flow calculations were computed using records for Tug Fork near Kermit from 1936 to 1985 (climatic years). The record period 1936–85 was representative of the period 1930–2002 (Wiley, 2006, table 13, page 190). The annual base flows for the period 1980–2002 were computed for Tug Fork at Kermit (1986–2002) and were estimated for Tug Fork near Kermit by multiplying the base flows by the ratio of drainage areas (1,188 mi^2/1,280 mi^2).

Comparison of Base Flows to Streamflow Statistics

Mean annual base flow was computed for each of the 15 streamflow-gaging stations for the five characteristically similar record periods and for the period 1930–2002. The percent differences between mean annual base flow for the five record periods and the mean annual base flow for the period 1930–2002 were computed and compared to percent differences in streamflow statistics previously selected and computed by Wiley (2006, tables 2 and 3) to assess climate variability (table 2). The streamflow statistics previously selected by Wiley (2006) are the annual 1-day 10-year (1Q10), 7-day 10-year (7Q10), and 30-day 5-year (30Q5) hydrologically based low-flow frequency values; the 1-day 3-year (1B3) and 4-day 3-year (4B3) biologically based low-flow frequency values; and the annual USEPA harmonic mean flow. Differences between mean annual base flows computed for the five record periods and the values computed for 1930–2002 vary from -14.9 to 14.6 percent. Generally, differences between mean annual base flows computed for the five periods and the values computed for the period 1930–2002 vary less than percent differences between the selected streamflow statistics computed for the five sub-periods and the values computed for the period 1930–2002, particularly for the wet period 1970–79 when differences for mean annual base flow were 14.6 percent greater, and the differences between selected statistics were approximately 100 to 200 percent greater. The difference between mean annual base flow computed for the period 1963–69 and the value computed for the period 1930–2002, -14.9 percent, is slightly greater than that for the period 1930–42, -12.6 percent.

Mean seasonal base flows computed for 1930–2002 and previously selected seasonal streamflow statistics (Wiley, 2006, table 4) were compared to base flows for the five record periods to assess seasonal variability (table 3). Differences between base flows for the five record periods and mean seasonal base flows were less variable in the winter and spring, from -11.2 to 11.0 percent, than in summer and fall, from -47.0 to 43.6 percent. The difference for base flows for the summer of 1963–69, -47.0 percent, was less than the difference for fall of 1930–42, -24.2 percent, and was the most negative seasonal percentage for all base flows, including those for all selected streamflow statistics for the five record periods.



Base from U.S. Geological Survey 1:100,000 digital line graphics.
Universal Transverse Mercator projection, zone 17, NAD 83.

Figure 2. Location of selected U.S. Geological Survey streamflow-gaging stations in West Virginia.

Table 1. The streamflow-gaging stations used to compare base flows and selected streamflow statistics in West Virginia.

[Records for stations 03214000 and 03214500 were combined and counted as one station]

Station number	Station name	Drainage area, in square miles
01606500	South Branch Potomac River near Petersburg	651
01608500	South Branch Potomac River near Springfield	1,461
01611500	Cacapon River near Great Cacapon	675
01636500	Shenandoah River at Millville	3,041
03051000	Tygart Valley River at Belington	406
03053500	Buckhannon River at Hall	277
03061500	Buffalo Creek at Barrackville	116
03066000	Blackwater River at Davis	85.9
03069500	Cheat River near Parsons	722
03070500	Big Sandy Creek at Rockville	200
03182500	Greenbrier River at Buckeye	540
03183500	Greenbrier River at Alderson	1,364
03186500	Williams River at Dyer	128
03198500	Big Coal River at Ashford	391
03214000	Tug Fork near Kermit	1,188
03214500	Tug Fork at Kermit	1,280

Table 2. Average, minimum, and maximum differences between mean annual base flows and selected annual statistics computed for 1930–2002, and those computed for the indicated record periods for 15 streamflow-gaging stations in West Virginia.

[Modified from Wiley, 2006, tables 2 and 3. Top number in each group is the average difference. Minimum difference followed by maximum difference in parentheses. Station numbers are 01606500, 01608500, 01611500, 01636500, 03051000, 03053500, 03061500, 03066000, 03069500, 03070500, 03182500, 03183500, 03186500, 03198500, and combined stations 03214000 and 03214500. A negative value means the average for the indicated record period is less than the average for 1930–2002; a positive value means the average for the indicated record period is greater than the average for 1930–2002. USEPA, U.S. Environmental Protection Agency]

Streamflow statistic	Difference for the indicated period, in percent				
	1930–42	1943–62	1963–69	1970–79	1980–2002
Base flow	-12.6 (-24.6, -4.3)	-1.1 (-5.8, 2.0)	-14.9 (-25.8, -4.3)	14.6 (8.7, 24.5)	5.5 (1.3, 10.3)
1-day 10-year hydrologically based low flow (1Q10)	-23.7 (-66.7, 4.6)	-11.2 (-56.3, 16.0)	5.4 (-31.4, 74.6)	187.0 (19.9, 524.4)	52.3 (-6.3, 250.0)
7-day 10-year hydrologically based low flow (7Q10)	-20.6 (-59.0, 12.0)	-13.6 (-56.2, 14.0)	2.4 (-29.4, 55.7)	182.8 (14.0, 582.5)	47.7 (-3.1, 217.5)
30-day 5-year hydrologically based low flow (30Q5)	-9.8 (-50.6, 11.1)	-12.7 (-35.4, 6.9)	-19.2 (-37.2, 3.2)	115.1 (13.9, 281.2)	24.1 (-2.1, 97.3)
1-day 3-year biologically based low flow (1B3)	-36.9 (-93.9, 21.2)	-10.7 (-42.6, 21.4)	9.2 (-30.0, 75.0)	200.7 (18.6, 541.9)	67.4 (-20.6, 367.6)
4-day 3-year biologically based low flow (4B3)	-32.1 (-91.3, 16.8)	-13.5 (-52.3, 17.2)	8.9 (-35.1, 66.6)	190.3 (13.4, 580.0)	58.9 (-20.0, 305.7)
USEPA harmonic mean flow	-21.0 (-62.3, 17.4)	-7.1 (-45.4, 16.4)	-15.2 (-30.1, 30.4)	90.7 (22.3, 244.3)	31.6 (3.5, 97.2)

Table 3. Average differences between base flows and selected seasonal statistics computed for 1930–2002, and those computed for the indicated record periods for 15 streamflow-gaging stations in West Virginia. (Modified from Wiley, 2006, table 4)

[Modified from Wiley, 2006, table 4. Winter, January 1–March 31; spring, April 1–June 30; summer, July 1–September 30; fall, October 1–December 31; station numbers are 01606500, 01608500, 01611500, 01636500, 03051000, 03053500, 03061500, 03066000, 03069500, 03070500, 03182500, 03183500, 03186500, 03198500, and combined stations 03214000 and 03214500. A negative value means the average for the indicated record period is less than the average for 1930–2002; a positive value means the average for the indicated record period is greater than the average for 1930–2002]

Season	Difference for the indicated period, in percent				
	1930–42	1943–62	1963–69	1970–79	1980–2002
Base flow					
Winter	-11.0	3.5	-11.2	11.0	1.2
Spring	-10.1	-0.9	-10.2	1.9	8.2
Summer	-8.9	-2.7	-47.0	21.0	12.5
Fall	-24.2	-11.7	-16.3	43.6	7.6
1-day 10-year hydrologically based low flow (1Q10)					
Winter	-9.7	6.0	-11.5	69.4	-2.6
Spring	-12.5	35.7	-29.5	32.4	9.2
Summer	-24.8	-6.5	-3.6	175.4	44.8
Fall	-26.2	-18.8	6.3	167.2	62.2
7-day 10-year hydrologically based low flow (7Q10)					
Winter	-12.2	-4.4	-17.3	58.5	0.1
Spring	-17.6	19.5	-29.2	27.1	3.4
Summer	-21.8	-8.3	-6.0	176.2	39.2
Fall	-25.6	-20.4	10.6	140.4	55.3
30-day 5-year hydrologically based low flow (30Q5)					
Winter	-19.2	2.3	-31.4	31.7	6.5
Spring	-18.7	13.1	-34.3	5.1	6.8
Summer	-12.5	-6.3	-29.2	85.4	20.0
Fall	-25.6	-17.5	-16.5	104.6	22.9
1-day 3-year biologically based low flow (1B3)					
Winter	-11.4	-4.2	1.7	73.8	5.8
Spring	-30.2	15.7	4.3	4.7	57.9
Summer	-35.0	-5.4	0.8	170.2	50.8
Fall	-35.7	-15.1	7.8	207.7	72.2
4-day 3-year biologically based low flow (4B3)					
Winter	-8.1	-4.4	-13.2	59.1	5.1
Spring	-24.3	18.6	3.0	0.6	53.7
Summer	-33.2	-5.8	-2.8	159.3	39.1
Fall	-40.0	-20.3	7.3	170.2	54.1
U.S. Environmental Protection Agency harmonic-mean flow					
Winter	-5.7	5.5	-19.5	37.9	-1.9
Spring	-25.3	4.0	-14.9	3.8	28.6
Summer	-21.9	1.0	-27.9	86.3	31.8
Fall	-18.3	-14.3	2.9	142.5	41.0

Mean seasonal and mean monthly base flows as percentages of mean annual base flows for 1930–2002 were compared (fig. 3). Summer base flows and the monthly base flows for July, August, and September are approximately equal, within 7.4 percentage points. Mean seasonal base flows for spring, fall, and winter show poor agreement with the mean monthly values, ranging from -35.4 percentage points between fall and the month of October to 58.3 percentage points between spring and the month of April. Base flows for the month of October are more similar to those of the summer season and summer months (within 7.4 percentage points) than to base flows for fall (35.4 percentage points less than fall base flows). Base flows for March were the highest at 84.0 percent of the mean annual base flow, and base flows for September were the lowest at -74.0 percent of the mean annual base flow.

Mean annual base flows (fig. 4) and mean seasonal base flows (fig. 5) were compared to various annual and seasonal duration flows (Searcy, 1959; Wiley, 2006) to determine whether annual and seasonal duration flows can be used as surrogate statistics for estimating base flows. (A duration flow is a flow that is equaled or exceeded some percentage of the time; for example, the 50-percent duration flow is equaled or exceeded 50 percent of the time.) All possible comparisons between annual and seasonal base flows and various annual and seasonal duration flows were evaluated to determine the minimum standard error. The mean annual base flow was approximated by the annual 50-percent duration flow with a standard error of 10.3 percent (fig. 4). The mean spring base flow was approximated by the spring 50- and 55-percent duration flows with a 6.8 percent standard error and the annual 45-percent duration flow with a 14.6 percent standard error (fig. 5). Summer 45- to 50-percent duration flow with a 6.7 percent standard error and annual 75-percent duration flow with a 11.8 percent standard error can be used as surrogates to estimate summer base flow. Fall 45-percent duration flow with 15.2 percent error and annual 55-percent duration flow with 11.2 percent error can be used to estimate fall base flow. Winter 60-percent duration flow with 8.5 percent error and annual 35-percent duration flow with 11.1 percent error can be used to estimate winter base flow (fig. 5).

Examples of Estimating Base Flows

Base flows at streamflow-gaging stations and ungaged locations can be estimated using the surrogate statistics, which can be determined using procedures described by Wiley (2008). Mean annual base flows at ungaged locations can be interpolated from duration flows determined from previously generated equations when equations for the desired duration flows are not available. Mean seasonal base flows can be determined only from flows at the streamflow-gaging stations because only equations for the seasonal 50-percent duration flows are available from Wiley and Atkins (2010a). Base-flow estimates determined using more than one surrogate statistic

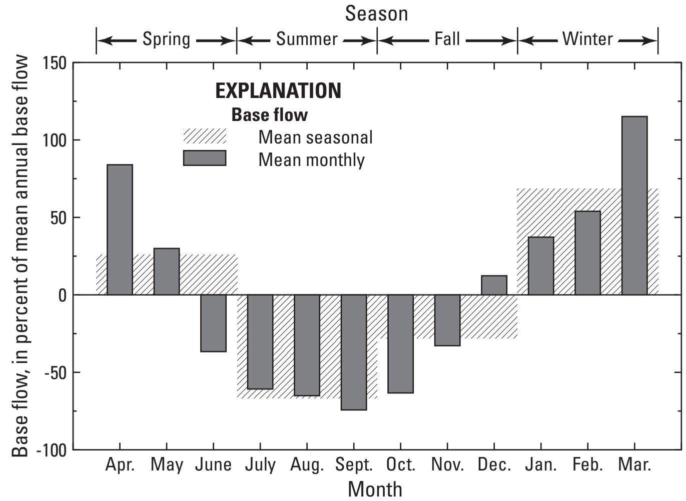


Figure 3. Mean seasonal and mean monthly base flows as percentage of mean annual base flows for 15 streamflow-gaging stations in West Virginia, 1930–2002.

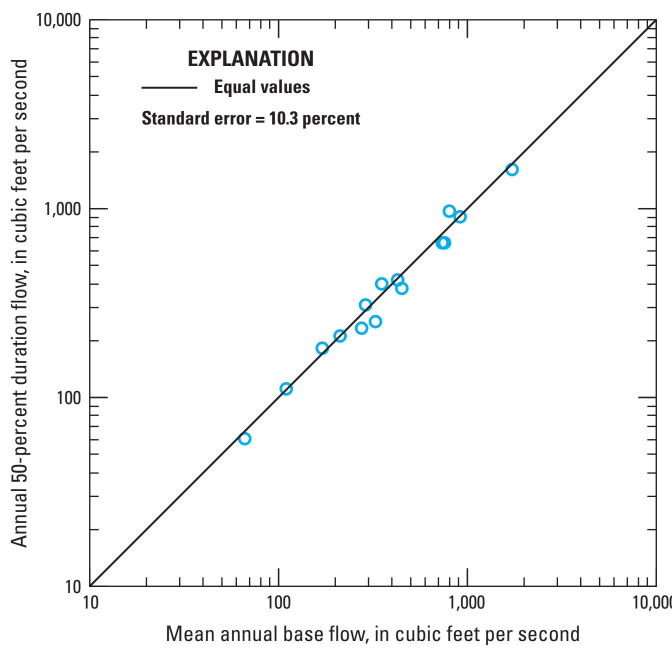


Figure 4. Mean annual base flows in relation to annual 50-percent duration flows for 15 streamflow-gaging stations in West Virginia, 1930–2002.

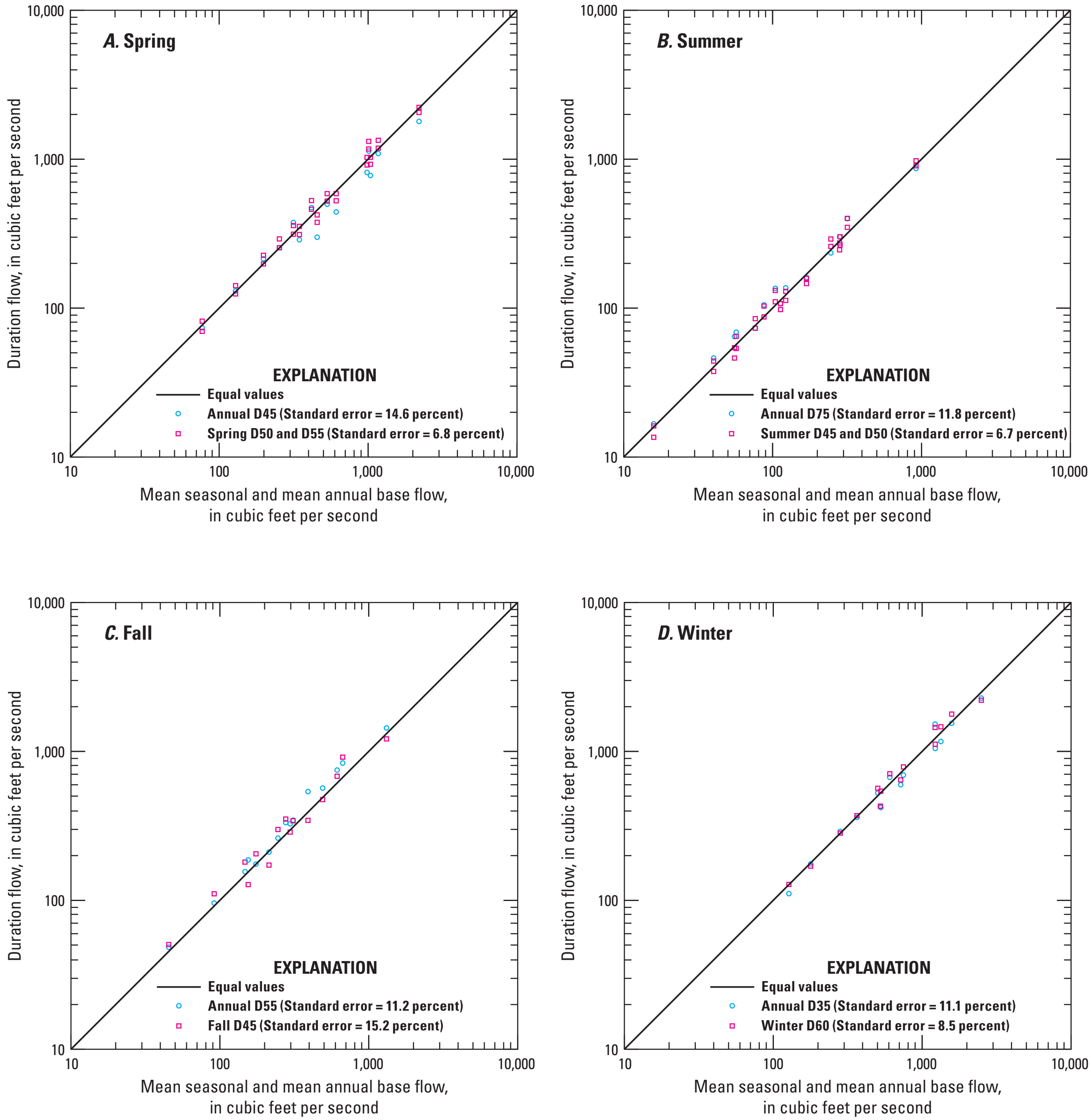


Figure 5. Mean seasonal and mean annual base flows in relation to selected duration flows for 15 streamflow-gaging stations during *A*, spring, *B*, summer, *C*, fall, and *D*, winter in West Virginia, 1930–2002. (Dn, n-percent duration flow)

can be averaged. Errors for estimated base flows are a summation of the standard error of the surrogate relation and the error of any regression equation used.

- **Example 1—**The mean annual base flow at the streamflow-gaging station Skin Creek at Brownsville (03057500) can be estimated by determining the annual 50-percent duration flow following procedures described by Wiley (2008, p. 12) in the section "At a Gaging Station." The procedure for "At a Gaging Station" is to read the value for the statistics from table 11 presented by Wiley (2006). The mean annual base flow is estimated from the surrogate statistic which is the 50-percent duration flow (fig. 4). The mean annual base flow is 13.4 ft^3/s (the 50-percent duration flow presented by Wiley, 2006, p.89).

- **Example 2—**The mean summer base flow at the streamflow-gaging station Skin Creek at Brownsville (03057500) can be estimated by averaging the surrogate statistics (fig. 5). The mean summer base flow is an average of (1) the annual 75-percent duration flow and (2) the average of the summer 45- and 50-percent duration flows. The annual and seasonal duration flows are determined using procedures described by Wiley (2008, p. 12) in "At a Gaging Station," which is to read values from table 11 presented by Wiley (2006). The mean summer base flow is 2.8 ft^3/s (3.2 ft^3/s + (2.8 ft^3/s + 2.2 ft^3/s /2)/2) based on values for surrogate statistics from Wiley (2006, p. 89).

- **Example 3—**The mean fall base flow at an ungaged location with a drainage area (AU) of 84.2 mi^2 upstream from the streamflow-gaging station South Fork South Branch Potomac River at Brandywine (01607500) can be estimated using equation 4 from Wiley (2008):

$$Q_U = Q_K \,(R_{U/K})^{EX} ,$$

where

Q_U is the value of the unknown streamflow statistic, in ft^3/s;
Q_K is the value of the known streamflow statistic, in ft^3/s;
$R_{U/K}$ is the ratio of the drainage area at the location of the unknown streamflow (A_U) to the drainage area at the location of the known streamflow (A_K), unitless; and
EX is the exponent for the particular statistic (Wiley, 2008, table 3), unitless.

This equation can be used because there are no additional streamflow-gaging stations upstream on the same stream and the size of the drainage area is within the limits for which the estimate can be made using drainage-area ratios. The surrogate statistic (fig. 5), annual 55-percent duration flow, for the streamflow-gaging station is 33.7 ft^3/s (Q_K) (Wiley, 2006, p. 73), and the drainage area at the streamflow-gaging stations is 103 mi^2 (A_K) (Paybins, 2008). The ratio of drainage areas ($R_{U/K}$) is A_U divided by A_K, or 84.2 mi^2 divided by 103 mi^2, which is 0.817. The exponent (EX) for the annual 55-percent duration flow is interpolated from the value for D50, 0.96 (Wiley, 2008, table 3), and the value for D75, 1.01 (Wiley, 2008, table 3), as 0.97 (0.96 + (55 – 50) (1.01 – 0.96) / (75 – 50)). Substituting into equation 4 from Wiley (2008), the mean fall base flow (annual 55-percent duration flow) at the ungaged location (Q_U) is 27.7 ft^3/s. The value of $R_{U/K}$ of 0.817 is greater than the upstream limit (R_{US}) of 0.21 (Wiley, 2008, table 3), indicating the establishment of a partial-record station (Wiley, 2008, p. 12) at the ungaged location is not required to estimate the flow statistic at this location.

- **Example 4—**The mean winter base flow at an ungaged location with a drainage area of 1,450 mi^2 (A_U) located downstream from the streamflow-gaging station Greenbrier River at Alderson (03183500), and upstream from the streamflow-gaging station Greenbrier River at Hilldale (03184000) can be estimated using equation 6 from Wiley (2008):

$$Q_U = [Q_{US}\,(A_{DS} - A_U) + Q_{DS}\,(A_U - A_{US})] \,/\, (A_{DS} - A_{US}),$$

when
$R_{U/K} < R_{DS}$ at upstream location and $R_{U/K} > R_{US}$ at downstream location,
or when
$R_{U/K} \geq R_{DS}$ at upstream location and $R_{U/K} \leq R_{US}$ at downstream location; and
Q_{KE} at the upstream location > Q_{US} and Q_{KE} at the downstream location > Q_{DS} or
Q_{KE} at the upstream location < Q_{US} and Q_{KE} at the downstream location < Q_{DS}; and
where
Q_U is the value of the unknown streamflow statistic, in ft^3/s;
Q_{US} is the value of the streamflow statistic at the upstream location, in ft^3/s;
Q_{DS} is the value of the streamflow statistic at the downstream location, in ft^3/s;
Q_{KE} is the regional equation evaluated at the location of the value of the known streamflow statistic, in ft^3/s;
A_U is the drainage area at the location of the unknown value of the streamflow statistic, in mi^2;
A_{US} is the drainage area at the upstream location, in mi^2;
A_{DS} is the drainage area at the downstream location, in mi^2;

R_{US} is the upstream limit of the ratio of drainage areas (Wiley, 2008, table 3), unitless; and

D_S is the downstream limit of the ratio of drainage areas (Wiley, 2008, table 3), unitless.

The drainage area is 1,364 mi^2 (A_{US}) for Greenbrier River at Alderson and 1,619 mi^2 (A_{DS}) for Greenbrier River at Hilldale (Paybins, 2008). This equation can be used because the ratio of drainage areas ($R_{U/K}$, or A_U divided by A_K) is equal to 1,450 mi^2 divided by 1,364 mi^2, or 1.06, which is less than the R_{DS} of 2 (Wiley, 2008, table 3) at the upstream location, and the $R_{U/K}$ (A_U divided by A_K, or 1,450 mi^2 divided by 1,619 mi^2) of 0.896 is greater than the R_{US} of 0.21 (Wiley, 2008, table 3) at the downstream location. The surrogate statistics (fig. 5), the annual 35-percent duration flow, at Alderson (Q_{US}) is 1,540 ft^3/s (Wiley, 2006, p. 116) and at Hilldale (Q_{DS}) is 1,840 ft^3/s (Wiley, 2006, p. 117). By substituting these values into equation 6, the mean winter base flow at the ungaged location (Q_U) is 1,641 ft^3/s.

- **Example 5—**The mean spring base flow for Lunice Creek just downstream from the confluence of North and South Forks of Lunice Creek in Grant County (Rig 7½-minute USGS topographic map) can be calculated from regional equations. (There are no streamflow-gaging stations on Lunice Creek or North Fork Lunice Creek.) The surrogate statistic (fig. 5), annual 45-percent duration flow, will be interpolated from available equations for the annual 25- and 50-percent duration flows. The streams are in the Eastern Panhandle Region (Wiley, 2008, fig. 3), and the drainage area is 52.78 mi^2 (Wiley and others, 2007, p. 26). The drainage area is within the limits of the regional equation from 8.83 to 3.41 mi^2 (Wiley, 2008, table 1), indicating that the procedure is valid. Installation of a partial-record station would not improve the estimate because the technique of transferring statistics from a streamflow-gaging station is limited to streamflows at and less than the 50-percent duration flow (Wiley, 2008, p.12). The annual 25- and 50-percent duration flows were calculated from the regression equations for the Eastern Panhandle Region (Wiley, 2008, table 1):

$$D25 = 1.70\ DA^{0.937}$$

and

$$D50 = 6.21 \times 10^{-1}\ DA^{0.969}\ ,$$

where

DA is the drainage area, in mi^2.

The annual 25- and 50-percent duration flows are calculated as 69.9 ft^3/s and 29.0 ft^3/s, respectively. The mean spring base flow is interpolated for the surrogate statistic, the annual 45-percent duration flow, as 37.2 ft^3/s (69.9 – (45 – 25) (69.9 – 29.0) / (50 – 25)).

Limitations of Base-Flow Estimates

Base-flow estimates are applicable only to unregulated streams in West Virginia because data used to develop methods were collected only from unregulated streams. All estimates are representative of the period 1930–2002. Estimates are best not made for streams regulated by large lakes, ponds, or navigation dams.

A partial-record station (Wiley, 2008, p. 12) can be established where there is some measurable streamflow, but estimates for ungaged locations are best not made without first determining that the streams involved are not losing or gaining water to or from underground mines or karst geology. A partial-record station will not help in determining the annual surrogate statistic for spring and winter base flows, the 45- and 35-percent duration flows, because the technique of transferring statistics from streamflow-gaging stations is limited to streamflows at and less than the 50-percent duration flow (Wiley, 2008, p.12).

Estimates for ungaged locations are best made only for perennial streams because data used to develop methods were collected only from perennial streams. The median drainage area upstream from the location where an intermittent stream becomes perennial was determined by Paybins (2003) to be 40.8 acres (0.064 mi^2). This value ranged from 10.2 to 150.1 acres (0.016 to 0.235 mi^2) in a limited study of 36 sites conducted in the southern coal fields of West Virginia and differed by region, with a median of 66.1 acres (0.103 mi^2) in the northeastern part of the southern coal fields and 34.8 acres (0.054 mi^2) in the southwestern part (Paybins, 2003). The procedures are not intended for use with drainage areas less than 0.05 mi^2 because the streams are likely not perennial; base flows for drainage areas less than 0.25 mi^2 can be estimated with some certainty only when there is some determination (such as a field observation at low streamflow) that the stream is perennial.

Estimates are not conservative at the confluence of streams. The value for base flow downstream from the confluence of two streams will not equal the summation of the values estimated upstream from the confluence.

Caution is called for when making estimates for areas with underground mining and karst terrain. Base flows may be reduced in streams that are "dewatered" by underlying underground mines or can be increased in streams that are downdip (where the elevation is lower and where the rock strata slope toward the stream) from flooded underground mines. Water also can be transferred between basins by drainage through coal mines and in karst terrain. Base flows at outflow points of large basins that are stratigraphically below mined coal beds likely would be increased from the pre-mining condition, except where large interbasin transfer of water occurs.

Summary and Conclusions

The U.S. Geological Survey, in cooperation with the West Virginia Department of Environmental Protection, Division of Water and Waste Management, compared base flows with published statistics at 15 streamflow-gaging stations to assess climate variability and determine surrogate statistics for estimating annual and seasonal base flows on unregulated streams in West Virginia. The seasons were defined as winter (January 1–March 31), spring (April 1–June 30), summer (July 1–September 30), and fall (October 1–December 31).

Mean annual and seasonal base flows representing the period 1930–2002 were compared to base flows and selected statistics computed for five sub-periods with similar characteristics in annual-minimum daily mean flows (1930–42, 1943–62, 1963–69, 1970–79, and 1980–2002) to assess climate variability. The differences in mean annual base flows range from -14.9 to 14.6 percent for the five sub-periods compared to the values for the period 1930–2002. The differences between mean seasonal base flows and base flows for the period 1930–2002 are less variable in the winter and spring, -11.2 to 11.0 percent, and more variable in the summer and fall, -47.0 to 43.6 percent.

Mean summer base flow (July–September) and mean monthly base flows for July, August, September, and October are approximately equal, within 7.4 percentage points of mean-annual base flow. The mean annual base flow is approximately equal, with a standard error of 10.3 percent, to the annual 50-percent duration flow. The mean spring base flow is approximately equal to the annual 45-percent duration flow with a standard error of 14.6 percent and the spring 50- to 55-percent duration flow with a standard error of 6.8 percent. The mean summer base flow is approximately equal to the annual 75-percent duration flow with a standard error of 11.8 percent and the summer 45- to 50-percent duration flow with a standard error of 6.7 percent. The mean fall base flow is approximately equal to the annual 55-percent duration flow with a standard error of 11.2 percent and the fall 45-percent duration flow with a standard error of 15.2 percent. The mean winter base flow is approximately equal to the annual 35-percent duration flow with a standard error of 11.1 percent and the winter 60-percent duration flow with a standard error of 8.5 percent.

Annual and seasonal base flows representative of the period 1930–2002 at unregulated streamflow-gaging stations and ungaged locations in West Virginia can be estimated using previously published values of surrogate statistics and procedures. Procedures that establish a partial-record station will not help to determine the spring and winter base flows because the technique of transferring statistics from a streamflow-gaging station is limited to streamflows at and less than the 50-percent duration flow. Estimates are best not made for streams regulated by large lakes, ponds, or navigation dams. Caution is called for when making estimates in areas of underground mining and karst terrain.

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Appendix 1

Annual and seasonal base flows at 15 streamflow-gaging stations in West Virginia for the period 1930–2002. Two stations are combined and counted as one. Period 1930–2002 consists of five sub-periods—1930–42, 1943–62, 1963–69, 1970–79, and 1980–2002.

Appendix 1. Annual and seasonal base flows at 15 streamflow-gaging stations in West Virginia, 1930–2002.

[Winter, January 1–March 31; spring, April 1–June 30; summer, July 1–September 30; fall, October 1–December 31]

Season	Base flow for the indicated period, in cubic feet per second					
	1930–2002	1930–42	1943–62	1963–69	1970–79	1980–2002
01606500 South Branch Potomac River near Petersburg						
Annual	452	411	451	361	510	480
Winter	724	647	735	610	815	753
Spring	619	587	636	518	600	661
Summer	170	173	170	92	182	185
Fall	297	235	262	224	442	321
01608500 South Branch Potomac River near Springfield						
Annual	763	696	757	612	864	807
Winter	1,230	1,080	1,270	1,080	1,380	1,260
Spring	1,050	1,020	1,060	860	1,020	1,110
Summer	283	285	270	141	317	321
Fall	492	393	426	370	741	534
01611500 Cacapon River near Great Cacapon						
Annual	329	286	325	275	401	343
Winter	528	442	542	484	626	536
Spring	462	431	468	386	479	490
Summer	113	102	112	73	162	112
Fall	214	168	179	155	339	236
01636500 Shenandoah River at Millville						
Annual	1,750	1,580	1,680	1,320	2,050	1,900
Winter	2,520	2,190	2,400	2,230	2,980	2,700
Spring	2,230	2,050	2,220	1,670	2,260	2,500
Summer	922	904	914	533	1,110	977
Fall	1,320	1,170	1,190	837	1,840	1,440
03051000 Tygart Valley River at Belington						
Annual	355	323	351	310	400	369
Winter	612	582	642	555	649	605
Spring	423	399	412	391	433	452
Summer	105	87	112	43	118	122
Fall	278	223	239	252	401	299
03053500 Buckhannon River at Hall						
Annual	290	256	292	250	319	308
Winter	506	463	542	436	528	510
Spring	319	302	303	298	314	352
Summer	88.2	69.1	95.3	40.9	104	100
Fall	248	188	230	224	330	270

Appendix 1. Annual and seasonal base flows at 15 streamflow-gaging stations in West Virginia, 1930–2002.—Continued

[Winter, January 1–March 31; spring, April 1–June 30; summer, July 1–September 30; fall, October 1–December 31]

Season	Base flow for the indicated period, in cubic feet per second					
	1930–2002	1930–42	1943–62	1963–69	1970–79	1980–2002
03061500 Buffalo Creek at Barrackville						
Annual	67	56	63	50	83	73
Winter	128	124	126	92	147	134
Spring	78	61	68	79	89	88
Summer	16	9.1	16	5.4	25	18
Fall	45	29	42	22	72	51
03066000 Blackwater River at Davis						
Annual	111	95	109	106	120	118
Winter	179	148	189	186	190	180
Spring	131	119	131	125	126	141
Summer	40	39	37	25	43	48
Fall	92	76	79	87	121	102
03069500 Cheat River near Parsons						
Annual	811	709	825	727	882	851
Winter	1,230	1,070	1,340	1,130	1,290	1,240
Spring	1,020	934	1,050	950	1,040	1,070
Summer	319	289	322	188	344	361
Fall	670	540	586	641	859	743
03070500 Big Sandy Creek at Rockville						
Annual	214	187	213	186	249	224
Winter	367	336	379	340	401	367
Spring	258	230	257	253	269	273
Summer	56	48	58	14	81	60
Fall	175	133	157	135	246	196
03182500 Greenbrier River at Buckeye						
Annual	432	402	440	374	479	437
Winter	754	733	788	672	823	732
Spring	537	484	561	511	523	558
Summer	123	127	127	53	136	132
Fall	312	264	284	260	433	326
03183500 Greenbrier River at Alderson						
Annual	919	818	922	781	1,017	974
Winter	1,590	1,400	1,650	1,370	1,710	1,660
Spring	1,190	1,080	1,200	1,080	1,150	1,280
Summer	284	320	277	138	330	295
Fall	616	471	560	530	880	660

Appendix 1. Annual and seasonal base flows at 15 streamflow-gaging stations in West Virginia, 1930–2002.—Continued

[Winter, January 1–March 31; spring, April 1–June 30; summer, July 1–September 30; fall, October 1–December 31]

Season	Base flow for the indicated period, in cubic feet per second					
	1930–2002	1930–42	1943–62	1963–69	1970–79	1980–2002
03186500 Williams River at Dyer						
Annual	173	165	171	153	190	176
Winter	284	295	293	255	297	272
Spring	201	173	207	184	204	214
Summer	57	56	55	29	66	65
Fall	149	136	130	144	192	155
03198500 Big Coal River at Ashford						
Annual	278	211	274	240	325	306
Winter	530	430	561	461	610	540
Spring	349	275	334	287	358	415
Summer	77	62	57	56	94	101
Fall	155	77	143	156	238	170
03214000 Tug Fork near Kermit and 03214500 Tug Fork at Kermit						
Annual	744	561	719	679	923	814
Winter	1,350	977	1,400	1,220	1,640	1,420
Spring	248	211	236	218	281	1,140
Summer	246	223	211	208	299	318
Fall	98	50	81	105	156	380

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