Prepared in cooperation with West Virginia Department of Transportation, Division of Highways; U.S. Department of Agriculture, Natural Resources Conservation Service; and Canaan Valley Institute

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Scientific Investigations Report 2005-5076

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

Cover photograph of Big Cedar Creek near Lebanon, Virginia; view looking upstream,
by Jefferson N. Keaton, U.S. Geological Survey

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Velocity	
foot per second (ft/s)	0.3048	meter per second (m/s)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Development and Analysis of Regional Curves for Streams in the Non-Urban Valley and Ridge Physiographic Province, Maryland, Virginia, and West Virginia

By Jefferson N. Keaton, Terence Messinger, and Edward J. Doheny

Abstract

Regression relations for bankfull stream characteristics based on drainage area (often called "regional curves") are used in natural stream channel design to verify field determinations of bankfull discharge and stream channel characteristics. Bankfull stream characteristics were assessed for stream reaches at 41 streamflow-gaging stations in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia. Data collected included bankfull cross-sectional geometry, flood plain geometry, and longitudinal profile data. In addition, particle-size distributions of streambed material were determined and data on basin characteristics were compiled for each reach. Regional curves were developed for bankfull cross-sectional area, width, and discharge with R^2 values of 0.95, 0.89, 0.87, and 0.91, respectively. Examination of the regional curves residuals indicates that there is more variability in bankfull cross-sectional area, width, and discharge for smaller streams than for larger streams. In contrast, there is more variability for bankfull mean depth for larger streams than for smaller streams.

Geographic analysis of regional curve residuals indicated that there were no further subdivisions within the Valley and Ridge Physiographic Province in the three-state study area for which individual sets of regional curves should be developed. In addition, two separate sets of regional curves were developed with data from the 41 sites to examine potential differences in the relations between the southern (n = 9) and central (n = 32) sections of the province. There were differences in slope and intercept between the two bankfull discharge test relations and a difference in intercept for the width test relations at the 95-percent confidence level. However, the results of this analysis were inconclusive and therefore one set of regional curves for the study area is presented in this report.

The regional curves were compared to regression models developed from similar data collected in the Pennsylvania and Maryland portions of the province. No statistical difference in the slope or intercept of regression lines of the three data sets was detected for any of the four bankfull parameters at the 95-percent confidence level.

Basin characteristics such as percentage of basin forested (percent forested) and percentage of basin underlain by carbonate bedrock (percent carbonate) were analyzed to evaluate variability among regression points. Multivariate regression relations including explanatory terms for percent carbonate and drainage area produced higher R^2 values than the regional curves for bankfull cross-sectional area ($R^2 = 0.95$), bankfull width ($R^2 = 0.92$), and bankfull discharge ($R^2 = 0.93$). There was no improvement for the bankfull mean depth relation from adding the additional term. Inclusion of the other basin characteristics in multivariate relations did not improve the regression models.

Regression models developed for the 1.5-year discharge for all streamflow-gaging stations with peak discharge data throughout Virginia (n = 486) and throughout the Valley and Ridge Physiographic Province in Virginia (n = 147) were compared to the regional curve relating bankfull discharge to drainage area. A similar trend in decreasing variability with increasing drainage area was observed for the 1.5-year discharge for all stations in Virginia. This indicates that the change in variability observed in the discharge regional curve likely would exist with a larger data set. There was no statistical difference at the 95-percent confidence level between regression relations for the southern section of the province (n = 40) and the central section (n = 107). This finding supports maintaining only one set of regional curves for the study area.

Not all of the variability in the regional curves is explained by drainage area alone. Causes of the remaining variability likely vary among study sites. Users of the regional curves developed in this study are cautioned that, because of inherent variability in hydrologic data, a thorough analysis of the fluvial system and the drainage basin is necessary when evaluating the bankfull characteristics of a stream.

Introduction

Rebuilding of physically degraded stream channels is becoming a key element in the management of surface-water resources throughout the Nation. Driven largely by Section 404 of the Federal Clean Water Act, many states are required to mitigate impacts to streams caused by construction, mining, and other activities. Loss of physical habitat and sedimentation in streams are among the most widespread causes of stream impairment. In 2000, states reported that 39 percent of all streams assessed for Section 305(b) of the Water Pollution Control Act (699,946 miles of streams or approximately 19 percent of all stream miles) were impaired. Sedimentation was reported as the cause of degradation in 31 percent of impaired streams and habitat loss was reported as the cause for an additional 22 percent (U.S. Environmental Protection Agency, 2002). A report by the U.S. Environmental Protection Agency (2000) indicates that only 17 percent of the streams in the Mid-Atlantic Highlands region supported "good" fish populations and only 25 percent were rated "good" for aquatic insects. The major cause of these impairments was destruction of riverine and riparian habitat (U.S. Environmental Protection Agency, 2000).

Natural channel design, or "stream restoration," involves rebuilding a channel with the dimensions, slope, and plan-view pattern that will convey the water and sediment loads from the drainage basin without aggrading or degrading. Stream channels designed to approximate natural, stable conditions are more likely to remain in equilibrium over time and therefore reduce erosion and sedimentation and provide suitable aquatic habitat.

The current practice of natural channel design is based largely on the science of fluvial geomorphology, which focuses on how land forms are shaped by flowing water (Brookes and Shields, 1996). The importance of this discipline in designing functional channels has been documented in the engineering literature at least since the 1950's (Lane, 1955). Application of this science in natural channel design has grown tremendously in recent years, however, due in part to the availability of relatively simple methods outlined by Rosgen (1996). Rosgen has developed a descriptive stream classification system and associated techniques of natural channel design founded largely upon scientific principles outlined by earlier geomorphologists such as Leopold, Wolman, and Miller (Leopold and others, 1964). The Rosgen methodology, in which stream restoration designs are based on the dimensions of a similar stable stream, or "reference reach," has become widely used in the United States (Watson and others, 1995).

Natural channel designs are often sized to convey the "bankfull" discharge. Bankfull discharge, which many researchers have related to a peak flow return frequency of approximately 1 to 2 years (Knighton, 1998), is theoretically the streamflow magnitude that is most effective in moving bedload sediment over time and thus forms the average structural characteristics of channels (Wolman and Miller, 1960; Dunne and Leopold, 1978; Leopold, 1994). The bankfull discharge and bankfull channel geometry characteristics of cross-sectional area, width, and mean depth have been shown to be highly correlated with drainage area (Dunne and Leopold, 1978). Regression relations between drainage area and these bankfull characteristics are often used to calibrate field-identified bankfull dimensions for ungaged stream reaches.

These regression relations are typically called regional curves because they are developed within a particular region, often a physiographic province. The curves are often developed on a regional basis because climatic, physiographic, and geologic factors that dictate the processes that form channels vary regionally (Leopold and Maddock, 1953; Leopold and others, 1964; Montgomery and Buffington, 1998). Changes in land cover may also affect discharge and channel geometry (Hammer, 1972; Dunne and Leopold, 1978).

The drainage basin is considered the "fundamental unit of the fluvial landscape," and many researchers believe that basin characteristics should be analyzed to determine their effect on channel geometry (Ritter and others, 2002). Analysis of the effects of basin characteristics such as type of land cover and bedrock lithology on stream channel geometry may help explain some of the variability in the regional curves that is not explained by drainage area. Analysis of additional factors may identify effects on channel geometry that should be considered by users of regional curves. In some cases, these effects may cover a larger geographic area than a single basin, and it may be necessary to develop multiple sets of regional curves representing subdivisions within a particular physiographic province.

Natural channel design is considered to be an important technology for remediating stream impacts in the Mid-Atlantic Highlands. To support natural channel design efforts in this region, in 2003, the U.S. Geological Survey (USGS), in cooperation with the West Virginia Department of Transportation, Division of Highways; the Natural Resources Conservation Service; and the Canaan Valley Institute began a 2-year study to develop regional curves for the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia. This study is similar to one being conducted by the USGS in Pennsylvania, including the Valley and Ridge Province in that state.

Purpose and Scope

This report describes the development and analysis of regional curves for the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia. The investigation of potential geographic patterns in the regional curves is explained. The regional curves developed in this study are compared to other regional curves data sets, and analyses of basin characteristics that may contribute to regional differences in channel geometry are described. In addition, the regional curves are compared to similar relations developed for the 1.5-year discharge and drainage area throughout Virginia and in the Valley and Ridge Physiographic Province in Virginia.

Description of Study Area

The Valley and Ridge Physiographic Province (the province) is a long, narrow belt of the Appalachian Mountains characterized by folded Paleozoic rocks and bordered primarily by the Blue Ridge and New England Physiographic Provinces to the east and by the Appalachian Plateaus Physiographic Province on the west. The province is geologically and topographically varied and consists of a series of northeast/southwest-trending parallel, even-crested ridges and valleys formed by folding and thrust faulting (Fenneman, 1938). The province stretches from New England to the Gulf Coastal Plain in Alabama and includes large portions of eastern West Virginia, western Virginia, and western Maryland, which comprise the study area for this project (fig. 1).

The study area has been subdivided into two sections—Central Valley and Ridge and Southern Valley and Ridge—that meet at the divide between the New River and Tennessee River Basins west of Wytheville, Va. (Hack, 1989). The Central Valley and Ridge section is part of the Central Appalachians. The southeastern part of the Central Valley and Ridge is referred to as the Great Valley (the Shenandoah Valley in Virginia and West Virginia). This feature is a low, broad valley divided by hills and low ridges and is underlain by Cambrian- to Ordovician-age carbonate rocks where karst features are common. The valley is the product of an erosional cycle that is near completion (Hack, 1965). The northwestern part of the Central Valley and Ridge is composed of high ridges and narrow valleys formed primarily of Silurian- to Pennsylvanian-age sandstones and shales. The Southern Valley and Ridge section, west of Wytheville, Va., is part of the Southern Appalachians and consists entirely of ridges and high, narrow valleys where thrust faulting, rather than folding, has been the dominant mechanism of deformation (Hack, 1989). The bedrock in this section of the province includes Silurian- to Mississippian-age sandstone and Cambrian- to Ordovician-age limestone, dolomite, and shale. Throughout the study area, high ridges are capped by resistant sandstone and the valleys are commonly limestone. Lower ridges and narrower valleys are typically formed of shale and dolomite, which are usually slightly more resistant than the limestone (Bingham, 1991).

The elevation throughout the study area generally increases to the southwest. This corresponds to the prominence of the Great Valley in the central section, which is below 500 ft in elevation at its lowest point. The valley floor itself becomes significantly steeper southwestward (Hack, 1965). The narrow valleys of the southern section are generally between 2,000 and 2,500 ft in elevation. Many ridges that dominate the landscape of the study area outside of the Great Valley are more than 4,000 ft in elevation (Bingham, 1991).

Streams are the major geomorphic agent in the Valley and Ridge, and the landforms are interrelated with the drainage network (Fenneman, 1938; Hack, 1965). Much of the province is drained by streams in a trellis pattern aligned with the parallel arrangement of the valleys and ridges. Streams are now oriented generally longitudinally with the strike of the regional structure, though some major rivers are transverse. The streams are structurally controlled and tend to follow beds of less resistant rock but occasionally cut through harder rock to create water gaps (Fenneman, 1938). Soils are generally thin throughout the province, except where they are protected by colluvial or residual boulders (Hack, 1989). The streams typically flow on or near the bedrock.

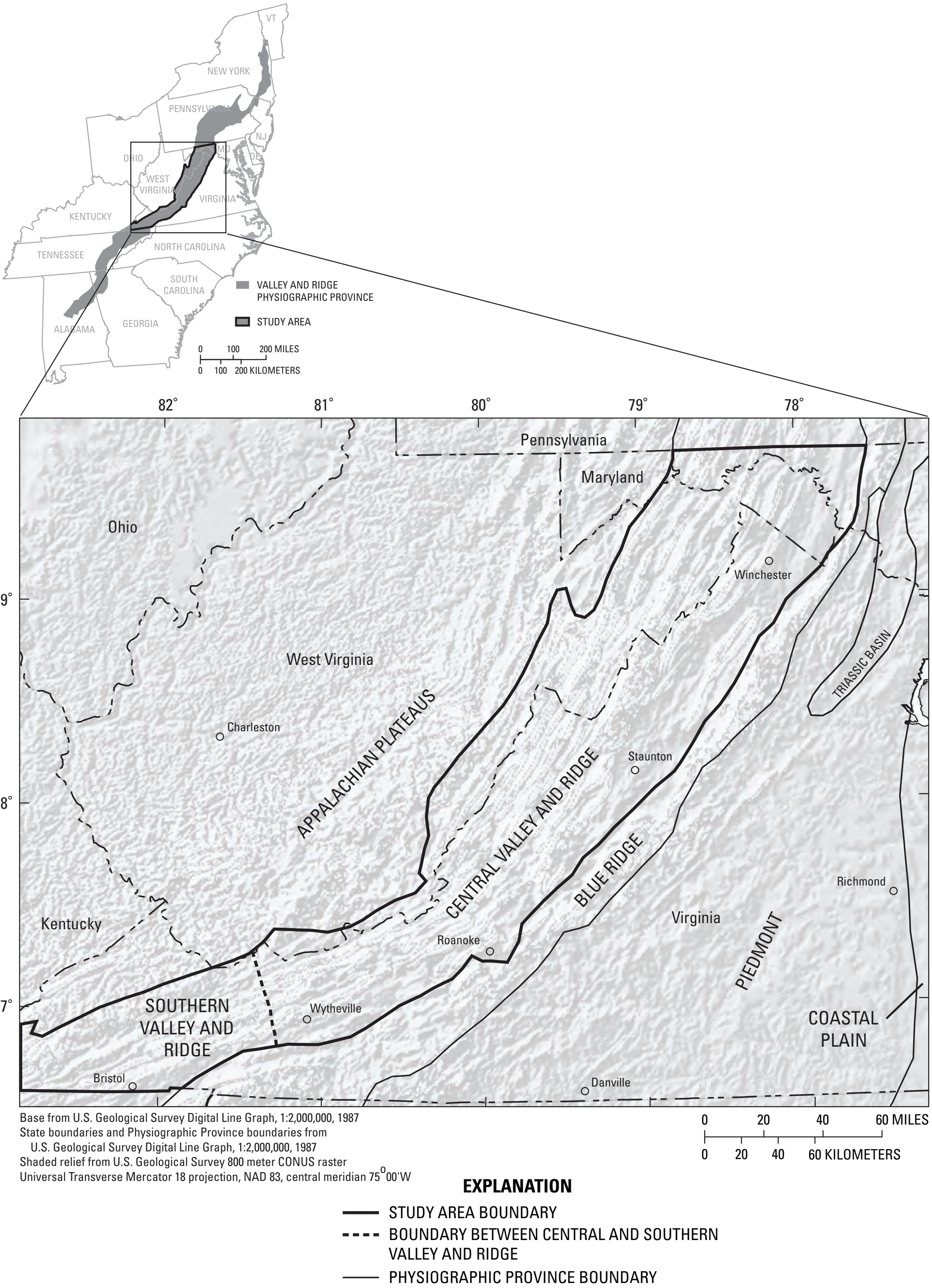
The climate of the region is moderate with typically cold winters and mild to hot summers. In most areas of the province, the growing season averages 180 days (Bingham, 1991). Precipitation amounts tend to decrease from south to north through the region. In Virginia, annual precipitation in the Valley and Ridge ranges from 48 in./yr in the south to 38 in./yr in the north (Nelms and others, 1997). The Maryland Valley and Ridge Physiographic Province has a small rain shadow area near Cumberland where the annual precipitation is 36 in./yr; the remainder of the province in Maryland averages 40 in./yr (Carpenter and Hayes, 1996). In West Virginia, the province has annual rainfall averages ranging from 36 in./yr to 40 in./yr (Wiley and others, 2000). Precipitation is generally distributed throughout the year, but is greatest during the summer months (Bingham, 1991).

The Valley and Ridge Physiographic Province was once covered with forests consisting of a variety of hardwoods and intermittent stands of conifers or mixed forests. Most of the forests have been cut multiple times and the forested areas that remain are typically poor in quality (Bingham, 1991). Much of the land remains cleared for agricultural use. The Great Valley is important for agriculture because of its fertile soils derived from limestone; livestock and poultry are prominent in this region along with small grains and apples. In the southern Valley and Ridge, tobacco is the largest cash crop. The population of the Great Valley region is growing rapidly with expanding urban and suburban areas, while much of the rest of the province is growing at a much slower rate.

Forty-one gaged stream reaches throughout the three-state study area were included in this study (fig. 2). The areal coverage is distributed throughout the study area, with 5 study sites in western Maryland, 31 in western Virginia, and 5 in eastern West Virginia. There were 9 sites in the southern section of the province and 32 in the central section. Streamflow-gaging station names, locations, gage types, and periods of record for all study sites are shown in table 1, and site descriptions are provided in the appendix.

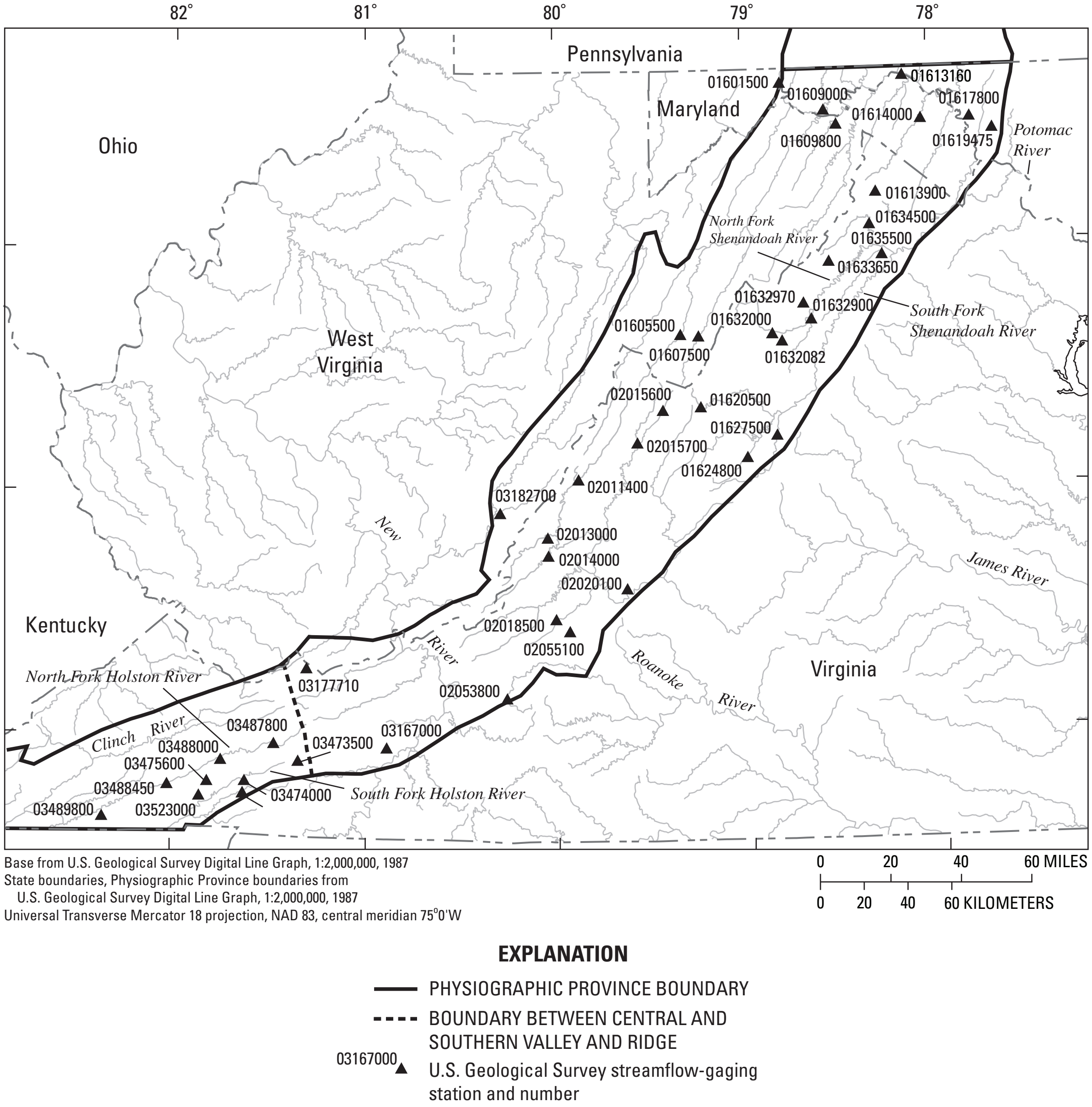
Bankfull Discharge

Wolman and Miller (1960) defined bankfull discharge as the discharge that fills the channel to the beginning of the active flood plain and that typically has a recurrence interval of between 1 and 2 years. They surmised that the bankfull discharge is also the discharge that moves the most sediment in a stream channel over time and is therefore responsible for the average geometric characteristics of the channel that are formed through erosional and depositional processes. The



Base from U.S. Geological Survey Digital Line Graph, 1:2,000,000, 1987
State boundaries and Physiographic Province boundaries from
U.S. Geological Survey Digital Line Graph, 1:2,000,000, 1987
Shaded relief from U.S. Geological Survey 800 meter CONUS raster
Universal Transverse Mercator 18 projection, NAD 83, central meridian 75°00'W

Figure 1. Valley and Ridge Physiographic Province (study area) and adjacent provinces in Maryland, Virginia, and West Virginia.



Base from U.S. Geological Survey Digital Line Graph, 1:2,000,000, 1987
State boundaries, Physiographic Province boundaries from
U.S. Geological Survey Digital Line Graph, 1:2,000,000, 1987
Universal Transverse Mercator 18 projection, NAD 83, central meridian 75°0'W

Figure 2. Location of streamflow-gaging stations used for development of regional curves in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

Table 1. Streamflow-gaging stations used for development of regional curves for the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[dms, degrees, minutes, and seconds; CRG, continuous-record gage; CSG, crest-stage gage]

Station number	Station name	Latitude (dms)	Longitude (dms)	Gage type	Period of record
01601500	Wills Creek near Cumberland, Md.	39 40 11	78 47 17	CRG	1905–1906, 1930–2004
01605500	South Branch Potomac River at Franklin, W.Va.	38 38 14	79 20 14	CRG	1940–20042004
01607500	South Fork South Branch Potomac River at Brandywine, W.Va.	38 37 53	79 14 38	CRG	1943–2004
01609000	Town Creek near OldTown, Md.	39 33 12	78 33 19	CRG	1928–1935, 1967–1981, 2001–2004
01609800	Little Cacapon River near Levels, W.Va.	39 29 55	78 29 20	CRG	1966–1977
01613160	Potomac River Tribuatary near Hancock, Md.	39 41 29	78 07 37	CSG	1965–1976
01613900	Hogue Creek near Hayfield, Va.	39 12 52	78 17 18	CRG	1960–1986, 1992–2004
01614000	Back Creek near Jones Springs, W.Va.	39 30 43	78 02 15	CRG	1928–1975
01617800	Marsh Run at Grimes, Md.	39 30 52	77 46 38	CRG	1963–2004
01619475	Dog Creek tributary at Locust Grove, Md.	39 27 57	77 39 38	CSG	1966–1976
01620500	North River near Stokesville, Va.	38 20 15	79 14 25	CRG	1946–2004
01624800	Christians Creek near Fisherville, Va.	38 07 42	78 59 41	CRG	1967–1997
01627500	South River at Harriston, Va.	38 13 07	78 50 13	CRG	1925–1961, 1968–2004
01632000	North Fork Shenandoah River at Cootes Store, Va.	38 38 13	78 51 11	CRG	1925–2004
01632082	Linville Creek at Broadway, Va.	38 36 24	78 48 13	CRG	1985–2004
01632900	Smith Creek near New Market, Va.	38 41 36	78 38 35	CRG	1960–2004W.Va.
01632970	Crooked Run near Mt. Jackson, Va.	38 45 44	78 41 06	CSG	1972–2004
01633650	Pugh's Run near Woodstock, Va.	38 55 48	78 32 43	CSG	1971–2003
01634500	Cedar Creek near Winchester, Va.	39 04 52	78 19 47	CRG	1937–2004
01635500	Passage Creek near Buckton, Va.	38 57 29	78 16 01	CRG	1932–2004
02011400	Jackson River near Bacova, Va.	38 02 32	79 52 54	CRG	1974–2004
02013000	Dunlap Creek near Covington, Va.	37 48 10	80 02 50	CRG	1928–2004
02014000	Potts Creek near Covington, Va.	37 48 10	80 02 10	CRG	1928–1956, 1965–2004
02015600	Cowpasture River near Head Waters, Va.	38 19 30	79 26 14	CSG	1949–1994, 1996–2001
02015700	Bullpasture River at Williamsville, Va.	38 11 43	79 34 14	CRG	1960–2004
02018500	Catawba Creek near Catawba, Va.	37 28 05	80 00 20	CRG	1943–2004
02020100	Renick Run near Buchanan, Va.	37 35 07	79 38 04	CSG	1967–2003
02053800	South Fork Roanoke River near Shawsville, Va.	37 08 24	80 16 00	CRG	1960–2004
02055100	Tinker Creek near Daleville, Va.	37 25 03	79 56 08	CRG	1956–2004
03167000	Reed Creek at Grahams Forge, Va.	36 56 22	80 53 13	CRG	1927–2004
03177710	Bluestone River at Falls Mills, Va.	37 16 17	81 18 18	CRG	1980–1997
03182700	Anthony Creek near Anthony, W.Va.	37 54 30	80 17 30	CRG	1971–1982
03471500	South Fork Holston River at Riverside, near Chilhowie, Va.	36 45 37	81 37 53	CRG	1920–1931, 1942–2004
03473500	Middle Fork Holston River at Groseclose, Va.	36 53 27	81 31 07	CRG	1948–57, 1958–87, 1988–89, 1990–95, 2001
03474000	Middle Fork Holston River at Seven Mile Ford, Va.	36 48 26	81 37 20	CRG	1942–81, 1982–87, 1987–89, 1989–2004
03487800	Lick Creek near Chatham Hill, Va.	36 57 44	81 28 21	CSG	1966–1968, 1969–2004
03488000	North Fork Holston River near Saltville, Va.	36 53 48	81 44 47	CRG	1920–2004
03488450	Brumley Creek at Brumley Gap, Va.	36 47 30	82 01 10	CSG	1979–1981, 1982–2004
03489800	Cove Creek near Shelleys, Va.	36 39 13	82 21 16	CSG	1951–2001
03475600	Cedar Creek near Meadowview, Va.	36 44 50	81 51 19	CSG	1967–2004
03523000	Big Cedar Creek near Lebanon, Va.	36 54 29	82 02 20	CSG	1953–1959, 1960–1977, 1991–1994, 2001

streamflow magnitude that moves the most sediment over time has been referred to as the effective discharge (Andrews, 1980).

The concepts that the bankfull discharge and effective discharge are equivalent, that they consistently recur every 1 to 2 years on a variety of rivers, and that they are responsible for the size and shape of channels have been disputed by some researchers and supported by others. Bankfull discharge may not, in all cases, be the effective discharge. Furthermore, the channel-forming discharge is likely representative of a range of flows that are responsible for the size and shape characteristics of the channel (Knighton, 1998). However, under certain conditions, the bankfull-as-channel-forming-discharge theory may apply. Emmett and Wolman (2001) state that in streams where the bedload is not composed of "very large-size particles" and streamflow is not highly variable, a large body of evidence suggests that the effective discharge is the bankfull discharge and the recurrence interval is often between 1 and 2 years. Knighton (1998) concludes that, although the standard assumptions may not hold for all conditions, for perennial rivers that do not have "very resistant boundaries" and occur in humid, temperate regions, the bankfull-as-effective-discharge model is the standard for channel design and river studies.

Development of Regional Curves

Forty-one stream reaches at streamflow-gaging stations were studied to develop regional curves for the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia. Bankfull discharge and channel geometry data were collected at each site. These data were thoroughly analyzed to ensure that bankfull characteristics of each site were valid. The bankfull discharge and channel geometry values were then regressed with drainage area using the ordinary least squares method to construct the regional curves.

Site Selection

All sites in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia were evaluated for inclusion in the study if they met the following criteria:

- At least 10 years of data for annual peak flows collected after 1985 (or before 1985 if major land-use change has not occurred in the basin);
- Drainage basins of less than 250 mi^2;
- Drainage basins of less than 20-percent developed land use (non-urban);
- Flow regulated from less than 20-percent of the drainage area; and
- Minimal effects from interbasin flow (flow into or out of basins due to factors such as water use or drainage ditches).

A total of 58 sites in the study area met the criteria: 7 in Maryland, 44 in Virginia, and 7 in West Virginia.

No reconnaissance was performed before the sites were visited. However, if upon arrival to a site, the study team determined that stable morphologic features were not present or that the stream was too deep to wade, the site was removed from the study. At this stage 17 sites were excluded; the remaining 41 sites were included in the study.

Identification of Bankfull Stage

The 41 selected stream reaches were evaluated to estimate the bankfull stage using a combination of statistical analysis of annual peak discharges in conjunction with the streamflow-gaging station stage-discharge relation and morphologic characteristics of the channel. Frequency analysis was performed for each station by fitting a Pearson Type III frequency distribution to the logarithms of the annual peak discharges in the station record. This procedure generates recurrence intervals for a variety of discharges and is outlined in Bulletin 17B, Guidelines for Determining Flood-Flow Frequency (Hydrology Subcommittee of the Interagency Advisory Committee on Water Data, 1982). This information was used along with the stage-discharge rating to determine the gage heights (stage at the streamflow-gaging station relative to gage datum) that correspond to the 1- and 2-year discharges at the station. Historic stream channel geometry data including width, mean depth, and cross-sectional area collected at discharge measurement cross sections were plotted against discharge. These plots and results of peak discharge analyses were used to help verify that field-identified bankfull features correspond to a discharge of approximately the 1- to 2-year recurrence interval.

Before surveying the stream channels, the field team walked each reach for a distance of at least 20 times the estimated bankfull width and identified morphologic features that can be indicators of the bankfull stage. These bankfull features typically included one or more of the following:

- Top of bank where active flood plain begins;
- A bench feature on the bank; or,
- A prominent break in slope of bank.

At most sites, the top of bank feature or a bench feature below the top of the bank defined the bankfull features. At some sites a prominent break in slope was used if it continued at a consistent level along a large portion of the study reach. If consistent bankfull features of the types listed above were not identifiable, the site was eliminated from the study. In some cases, however, few of these types of features were at a consistent elevation but the sites were used in the study to maximize the number of sites in the data set.

Bankfull features in the approximate range of elevations near the 1- and 2- year stages were flagged along the length of the reach. If more than one set of possible bankfull features was observed at different stages along the channel, all sets of features were surveyed.

Field Data Collection

Channel Surveys

In this study, all measurements of channel geometry (cross-sectional area, width, and mean depth) were made with regard to the bankfull stage. A two-person crew used survey instruments to perform a vertical and horizontal survey of the morphologic features of each site. At sites in Virginia and West Virginia, total station instruments were used to collect the survey data. The instruments automatically calculated elevation, horizontal distance, and horizontal angle for each feature surveyed. A global positioning system was often used to establish the coordinates of the beginning survey points. At sites in Maryland, an optical level was used to determine the vertical position of morphologic features and a field tape was used to measure horizontal distances between features. All surveys were tied into the gage datum (the datum on which stage-discharge relations are based).

Two riffle cross sections were surveyed along with the longitudinal profile of each reach. To perform the cross-section surveys, the crew typically set up the instrument at a level spot on the flood plain or a point bar and made measurements of selected features including, but not limited to bankfull indicators, slope breaks, edge of water, thalweg, point bars, top of bank, and terraces. In most cases, flood plains of cross sections were surveyed to the elevation of the floodprone stage, or twice bankfull maximum depth (Rosgen, 1996), or up to 200 ft from top of bank for flat conditions. Longitudinal profiles were surveyed for a distance of up to 20 times the bankfull width. Measurements were taken of the thalweg, potential bankfull features, and water surface at each successive bed feature in the downstream direction. Bed features surveyed included riffles, runs, pools, and glides, where all four features existed. In most cases, the longitudinal profile survey extended past the streamflow-gaging station location. At some sites this was not possible, usually due to a very deep, unwadable pool at the station.

Pebble Counts

A modified version of the Wolman (1954) pebble count was conducted to evaluate bed material particle-size distributions at each riffle cross section. At each cross-section, 100 bed material particles were collected from the surface of the streambed. The particles were selected randomly at equal intervals across the channel from edge of water to edge of water. Particles were measured with a ruler or sand gage designed for sizing very small particles. The diameter of each particle was recorded.

Basin Characteristics

The upstream drainage network and drainage basin of each stream reach in the study were delineated using ArcGIS version 8.3 and ArcHydro (Environmental Systems Research Institute, 2002a, 2002b) Geographic Information System (GIS) software. The stream network and basins were delineated based on 30-meter digital elevation model grid files (U.S. Geological Survey, 2001). The area of each basin was compared to USGS published values (Bisese, 1995; Wiley and others, 2000) and, if necessary, redelineated until the area matched the published value. These digital drainage basins were converted to GIS coverages that were then used alone or with other GIS data to quantify characteristics of the basin and drainage network. The National Land Cover Dataset (U.S. Environmental Protection Agency, 1996) was used to calculate the percentage of each basin that is forested. Digital representations of the geologic maps of the three states in the study area were used to estimate the percentage of each basin underlain by carbonate bedrock. The geologic map of Maryland was generated using data created by Swain and others (2004). Digital versions of the state geologic maps of Virginia (Virginia Division of Mineral Resources, 2003) and West Virginia (West Virginia Department of Environmental Protection, 1998) were used for basins in those states. Drainage density was calculated for each basin by dividing the total length of the stream network delineated with ArcHydro by the basin drainage area. The other basin characteristics (mean basin elevation, mean annual precipitation, and 24-hour, 2-year rainfall) are from published values (Bisese, 1995; Wiley and others, 2000). Basin characteristics for each site are in table 2.

Analysis of Channel Data

After the survey data and pebble count data were compiled, each site was analyzed individually. Longitudinal profiles of the bankfull features, the water surface at the time of the survey, and the channel bed were plotted. The distances of all surveyed bankfull features above the water surface were calculated and compared to each other and to the estimated stage of the 1.5-year discharge throughout the reach. Only those surveyed features with a consistent stage relative to the water surface at the time of the survey were included in the final plots. A best-fit line was fitted through the bankfull feature points for the entire reach to develop a continuous representation of the bankfull profile. This technique allowed the bankfull profile to represent the average bankfull stage throughout the reach and provided a means to base the bankfull stage on all of the bankfull data collected. It is important to use all of the bankfull data because any individual feature is identified subjectively and is potentially erroneous (Leopold, 1994). The bankfull profile typically extended past the streamflow-gaging station, and the bankfull gage height was estimated to be where the best-fit line crossed the station location. This estimated bankfull gage height was used to deter-

Table 2. Basin characteristics for study sites in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[Drainage density, total length divided by drainage area; mi^2, square mile; mi/mi^2, miles per square mile; ft, feet; in., inch; n.d., no data]

Station number	Drainage area (mi^2)	Area forested[1] (percent)	Area carbonate bedrock (percent)	Drainage density (mi/mi^2)	Mean basin elevation[1] (ft)	Mean annual precipitation[1] (in.)	24-hour, 2-year rainfall[2] (in.)
01601500	247	70	2.30	1.49	1,880	36	2.75
01605500	179	80	19.8	1.59	2,940	40	2.9
01607500	103	80	5.60	2.03	2,370	38	2.9
01609000	148	79	14.30	1.70	1,310	36	2.85
01609800	108	70	0.00	1.61	1,220	34	2.9
01613160	1.20	40	.00	2.04	683	37.5	2.9
01613900	15.0	70	34.0	2.08	1,200	37	2.80
01614000	235	70	11.9	1.71	890	39	3.0
01617800	18.9	n.d.	100	1.66	509	39.5	3.1
01619475	0.10	26	7.10	n.d.	n.d.	40	3.15
01620500	17.2	98	.00	1.76	3,300	42.1	3.65
01624800	70.1	40	77.9	1.95	1,550	38.9	3.19
01627500	212	61	60.2	1.82	1,750	43.9	3.85
01632000	210	89	4.60	1.60	2,020	35.8	3.09
01632082	45.5	n.d.	71.6	1.79	n.d.	n.d.	n.d.
01632900	93.2	50	61.9	1.91	1,400	38	3.58
01632970	6.49	45	81.9	1.74	1,200	35.3	2.78
01633650	3.66	60	41.6	2.24	1,510	35.2	2.52
01634500	103	86	22.9	1.69	1,350	34.6	2.87
01635500	87.8	81	33.3	1.67	1,490	38.7	3.25
02011400	158	n.d.	36.4	1.64	n.d.	n.d.	n.d.
02013000	164	87	.00	1.58	2,230	38.5	2.56
02014000	153	85	11.0	1.72	2,320	38.6	2.62
02015600	11.3	81	28.4	1.38	n.d.	n.d.	n.d.
02015700	110	80	47.7	1.75	2,200	40.1	2.90
02018500	34.3	88	.90	1.51	1,880	42.6	3.30
02020100	2.06	70	28.7	2.13	1,660	42.8	3.19
02053800	110	25	3.40	1.68	2,300	42.8	2.97
02055100	11.7	26	82.1	1.75	1,470	42.0	3.36
03167000	247	43	41.6	1.71	2,500	38.6	2.68
03177710	44.2	n.d.	40.8	1.40	n.d.	44.0	2.50
03182700	144	95	2.80	1.77	2,480	40.0	2.90
03471500	76.1	83	38.0	1.70	2,870	42.0	2.83
03473500	7.39	49	18.9	1.99	2,710	39.0	2.69
03474000	132	64	37.0	1.74	2,480	40.0	2.50
03487800	25.5	96	.00	1.66	2,770	42.6	2.65
03488000	222	63	33.9	1.64	2,730	43.4	2.58
03488450	21.1	n.d.	.20	1.92	n.d.	n.d.	n.d.
03489800	17.3	70	68.1	1.60	1,500	45.9	2.52
03523000	51.5	40	33.8	1.80	2,400	43.5	2.48

[1] From Bisese (1995) and Wiley and others (2000).

[2] Maximum rainfall in 24 hours during any 2-year period.

mine the corresponding bankfull discharge from the stage–discharge rating. This estimated discharge was compared to the results of the peak flow analysis to ensure that the recurrence interval was approximately 1 to 2 years. Diagnostic statistics were calculated for the bankfull best-fit lines (table 3). The bankfull features surveyed in each cross section were included on the bankfull profile to verify that the cross-section bankfull features fit the profile of the entire study reach.

Each of the two riffle cross sections was then plotted and the bankfull stage identified on the plots. The bankfull cross-sectional area, bankfull width, and bankfull mean depth were calculated for each cross section and the geometries of the two were compared. One of the cross sections was selected to represent the study reach. In most cases, the primary criterion for selecting a cross section was the significance of the bankfull feature(s). For example, the top of a channel where the active flood plain begins was considered to be more significant than a break in slope on the channel below the top of the bank.

The pebble count data were grouped into size categories according to the particle-size classification system published by Rosgen (1996). A cumulative frequency distribution of the particle sizes was constructed by plotting cumulative percentages against the size categories. From this information the D84 and D50 (the particle sizes that are larger than 84 percent and 50 percent, respectively, of the material sampled) were determined. The D50 is the median particle size and the D84 represents the particle size that is two standard deviations larger than the median (Leopold and others, 1964).

Stream channel characteristics were then compiled for every site in the reach (table 4). These characteristics include the bankfull channel geometry used in the regional curves, the D50 and D84 from the riffle pebble counts, the classification parameters based on Rosgen's (1996) classification system, and the classification stream type. The classification parameters include the reach slope, the bankfull width to bankfull depth ratio, the entrenchment ratio (ratio of bankfull width to flood prone width) and the sinuosity (ratio of stream length to valley length). Plots of longitudinal profiles, cross sections, and particle-size distributions are included with site descriptions for each study site in the appendix.

Regional Curve Simple Linear Regression Relations

Linear regression techniques were used to develop regional curves for the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia using S-Plus version 6.1 statistics software (Insightful Corporation, 2002). The bankfull channel geometry data (table 4) and estimated bankfull discharge data (table 4) for all 41 sites were plotted against drainage area on a log-log scale. A power function best-fit line was fitted through each plot using the ordinary least squares method. The regional curves for cross-sectional area, width, mean depth, and discharge are shown in figures 3 through 6, respectively. The equations and test statistics for

Table 3. Diagnostic statistics for bankfull best-fit lines in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[R^2, correlation coefficient]

Station number	R^2	Residual standard error
01601500	0.985	0.229
01605500	.951	.805
01607500	.955	.502
01609000	.926	.518
01609800	.721	.448
01613160	.980	.307
01613900	.946	.268
01614000	.490	1.444
01617800	.925	.226
01619475	.994	.034
01620500	.991	.523
01624800	.442	.680
01627500	.984	.441
01632000	.865	.749
01632082	.902	.373
01632900	.887	.386
01632970	.962	.337
01633650	.980	.594
01634500	.918	.443
01635500	.987	.115
02011400	.954	.391
02013000	.963	.496
02014000	.828	.497
02015600	.957	.273
02015700	.989	.353
02018500	.810	.250
02020100	.990	.530
02053800	.892	.892
02055100	.982	.174
03167000	.971	.236
03177710	.909	.270
03182700	.904	.316
03471500	.925	.376
03473500	.910	.196
03474000	1.000	.003
03487800	.973	.169
03488000	.966	.314
03488450	.969	.895
03489800	.901	.267
03523000	.861	.955
03475600	.926	.190

Table 4. Bankfull stream channel characteristics of study sites in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[mi², square mile; ft², square feet; ft, feet; ft³/s, cubic feet per second; mm, millimeter; ft/ft, foot per foot; <, less than]

Station number	Drainage area (mi²)	Cross-sectional area (ft²)	Width (ft)	Mean depth (ft)	Estimated discharge (ft³/s)	Recurrence interval (years)	1.5-year discharge (ft³/s)	D_{50}[1] (mm)	D_{84}[2] (mm)	Width: Depth ratio	Entrenchment	Slope (ft/ft)	Sinuosity	Rosgen stream type[3]
01601500	247	621	165	3.8	3,220	1.1	4,580	120	393	44.1	1.2	0.0035	1.10	F
01605500	179	441	103	4.3	2,960	1.4	3,340	103	188	24.0	5.3	.0052	1.03	C
01607500	103	324	94.7	3.4	1,200	<1.1	2,610	109	189	27.7	2.0	.0035	1.04	C
01609000	148	484	132	3.7	2,770	1.4	2,900	48.9	117	35.9	3.6	.0028	1.06	C
01609800	108	393	90.9	4.3	2,840	1.4	3,060	73.1	168	21.0	2.2	.0013	1.11	C
01613160	1.20	9.70	9.90	1.0	57.0	1.3	77.0	54.7	121	10.2	1.5	.0241	1.07	G
01613900	15.0	118	43.8	2.7	629	1.5	629	50.3	103	16.3	2.3	.0054	1.20	C
01614000	235	646	121	5.3	3,630	1.3	4,380	36.8	80.0	22.8	1.2	.0030	1.26	C
01617800	18.9	42.6	25.2	1.7	112	2.3	72.0	15.1	98.0	14.8	1.3	.0047	1.32	B
01619475	0.10	4.50	8.70	0.5	13.5	1.4	14.0	7.60	16.0	16.7	1.3	.0123	1.33	B
01620500	17.2	110	55.3	2.0	464	1.4	495	108	173	27.8	1.1	.0119	1.27	B
01624800	70.1	325	63.8	5.1	1,580	1.3	1,930	47.2	101	12.5	15	.0011	1.14	C
01627500	212	60	134	4.5	3,340	1.4	3,700	123	183	30.0	2.2	.0048	1.11	C
01632000	210	832	149	5.6	3,700	1.2	6,010	55.8	108	26.5	3.4	.0016	1.12	C
01632082	45.5	164	58.6	2.8	782	1.3	951	19.8	74.0	20.9	2.8	.0027	1.08	C
01632900	93.2	431	91.5	4.7	1,350	1.3	1,574	21.9	54.0	21.1	5.1	.0022	1.14	C
01632970	6.49	53.3	27.9	1.9	179	<1.1	508	32.4	116	14.6	3.1	.0059	1.04	C
01633650	3.66	38.4	26.1	1.5	110	2.0	75.1	61.6	89.0	17.7	7.7	.0228	1.07	C
01634500	103	459	102	5.3	2,650	1.7	2,300	32.9	65.0	20.2	4.2	.0026	1.05	C
01635500	87.8	336	78.0	4.3	2,110	1.9	1,680	137	268	18.1	2.6	.0124	1.23	C
02011400	158	539	107	5.0	2,190	1.3	2,750	149	423	21.2	1.6	.0038	1.01	B
02013000	164	565	117	4.8	2,880	1.2	4,060	82.8	195	24.2	2.0	.0035	1.37	C
02014000	153	555	117	5.0	2,380	1.2	3,040	50.6	134	22.4	2.2	.0022	1.21	C
02015600	11.3	50.2	35.6	1.4	143	<1.2	202	73	180	25.3	3.0	.0055	1.35	C
02015700	110	338	92.4	3.7	2,250	1.1	3,330	200	470	25.3	2.2	.0095	1.24	C
02018500	34.3	137	56.6	2.3	1,050	1.4	1,160	28.0	127	24.9	2.0	.0053	1.23	C

Table 4. Bankfull stream channel characteristics of study sites in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.—Continued

[mi², square mile; ft², square feet; ft, feet; ft³/s, cubic feet per second; mm, millimeter; ft/ft, foot per foot; <, less than]

Station number	Drainage area (mi^2)	Cross-sectional area (ft^2)	Width (ft)	Mean depth (ft)	Estimated discharge (ft^3/s)	Recurrence interval (years)	1.5-year discharge (ft^3/s)	D_{50}[1] (mm)	D_{84}[2] (mm)	Width: Depth ratio	Entrenchment	Slope (ft/ft)	Sinuosity	Rosgen stream type[3]
02020100	2.06	30.5	23.3	1.3	235	1.3	187	75.9	166	17.8	1.8	.0220	1.14	B
02053800	110	519	113	4.6	2,390	1.8	1,913	65.7	119	24.4	4.0	.0024	1.13	C
02055100	11.7	90.8	38.6	2.4	266	1.1	516	37.4	144	16.4	7.1	.0044	1.21	C
03167000	247	536	153	3.5	3,010	1.4	3,290	65.2	202	43.8	1.3	.0033	1.09	B
03177710	44.2	198	56.5	3.5	681	1.5	675	25.6	58.0	16.2	4.4	.0017	1.40	C
03182700	144	547	122	4.5	2,350	1.1	3,850	176	368	27.0	2.2	.0031	1.23	C
03471500	76.1	234	72.8	3.2	1,150	1.2	1,560	62.7	116	22.6	2.5	.0022	1.02	C
03473500	7.39	25.4	17.3	1.5	93.2	1.2	129	32.3	69.0	11.8	1.5	.0035	1.07	B
03474000	132	336	83.0	4.1	2,420	1.4	2,620	46.1	84.0	26.1	1.5	.0033	1.06	B
03487800	25.5	166	67.6	2.5	519	<1.1	1,040	63.6	120	27.6	1.6	.0036	1.01	B
03488000	222	641	218	2.9	2,360	<1.1	4,950	55.2	115	74.4	2.3	.0016	1.22	C
03488450	21.1	129	52.1	2.5	540	1.4	570	135	332	21.1	1.5	.0190	1.01	B
03489800	17.3	107	36.8	2.9	325	<1.1	685	22.0	122	12.6	3.5	.0036	1.02	C
03523000	51.5	257	88.9	2.9	1,210	1.1	1,944	51.4	123	30.7	1.6	.0073	1.03	B
03475600	3.38	15.8	9.90	1.6	39.4	1.9	35.8	14.1	31.0	6.2.0	15	.0066	1.06	E

[1] Median particle size of streambed material.

[2] Particle size larger than 84 percent of streambed material.

[3] From Rosgen, 1996.

the regional curves are shown in table 5. Bankfull mean depth refers to bankfull cross-sectional area divided by bankfull width; however, the equation for bankfull mean depth relation is included for convenience.

The regional curves (figs. 3 through 6, table 3) include 95-percent prediction intervals for individual estimates of the dependent variable. Prediction intervals are often confused with confidence intervals, but the calculations to determine the range of the two sets of intervals are different (Helsel and Hirsch, 1992). The 95-percent prediction interval on a regression relation represents a 95-percent certainty that an individual observed value of y for a given x will fall within the upper and lower limits of the interval (Helsel and Hirsch, 1992; G.E. Schwarz, written communs., 2005).

Each regional curve relation between the dependent variables and drainage area is strongly linear and indicates that discharge and channel geometry have a positive relation with increasing drainage area. Visual inspection of the residuals plots indicates minor changes in the variance of the dependent variables (heteroscedasticity) as drainage area increases. No effects from influential outliers were found through an examination of the Cook's Distance statistic. Kolmogorov-Smirnov (K-S) goodness-of-fit tests (alpha = 0.05) indicate that, although the residuals of the width and mean depth regional curves are log-normally distributed (p = 0.113 and 0.613, for K-S tests, respectively), the residuals of cross-sectional area and discharge regional curves do not fit that distribution (p = 0.018 and 0.008, for K-S tests, respectively). This may be due to the mild heteroscedasticity mentioned above. However, the R^2 values and F-statistics indicate that an uncommon transformation of the data is not warranted. Table 5 includes p-values for the bankfull discharge and cross-sectional area relations despite the fact that the assumption of normality of the residuals is required for that calculation. Users should be aware that these p-values may be erroneous.

Analysis of Regional Curves

Simple linear regression was used to develop regional curves useful in calibrating bankfull characteristics of streams. The regional curve relations and diagnostic statistics were analyzed. A considerable amount of variability remains in the relations and this variability changes with drainage basin size. Additional analysis was conducted to further evaluate this variability. The relations were evaluated to see if regional curves should be subdivided geographically. In addition, the regional curves were compared to similar data sets from other studies in the Valley and Ridge Physiographic Province and to larger data sets of 1.5-yr discharge data.

Variability of Dependent Variables in Regional Curves Relation

The correlation coefficient (R^2) is a measure of the fit of the data to the regression line, that is, how well the independent variable accounts for the variability of the dependent variable. The R^2 values for the regional curves indicate that drainage area accounts for more variability in bankfull cross-sectional area than for any other dependent variable, although it only accounts for slightly more variability than discharge (table 5). The width relation has a somewhat lower R^2 value than discharge and the mean depth relation has the poorest fit of the four (table 5). Discharge is controlled primarily by basin characteristics, with drainage area being the most significant; cross-sectional area is controlled by multiple variables including discharge, slope, and channel roughness (Knighton, 1998). These additional factors affecting cross-sectional area should, in theory, cause the cross-sectional area relation to have a lower R^2 value than the discharge relation. However, in this study, the R^2 values for the regional curves (table 5) and the multivariate models (table 6) indicate that drainage area

Table 5. Equations and diagnostic statistics for regional curves relating bankfull discharge and channel geometry to drainage area in the Valley and Ridge Physiographic Province in Maryland, Virginia and West Virginia.

[R^2, correlation coefficient; CSA, bankfull cross-sectional area; DA, drainage area; W, bankfull width; D, bankfull depth; Q, estimated bankfull discharge]

Equation	p-value[1]	R^2	Residual standard error (Log_{10})	Residual standard error (percent)	F-statistic
$CSA = 12.595*(DA)^{0.7221}$	0.00	0.9448	0.1327	30.6	667.8
$W = 12.445(DA)^{0.4362}$	.00	.8939	.1143	25.7	328.5
$D = 1.001(DA)^{0.2881}$	.00	.8705	.0845	20.9	262.0
$Q = 43.249(DA)^{0.7938}$	.00	.9066	.1937	45.9	378.8

[1] p-value shown although assumption of log-normal distribution is not met.

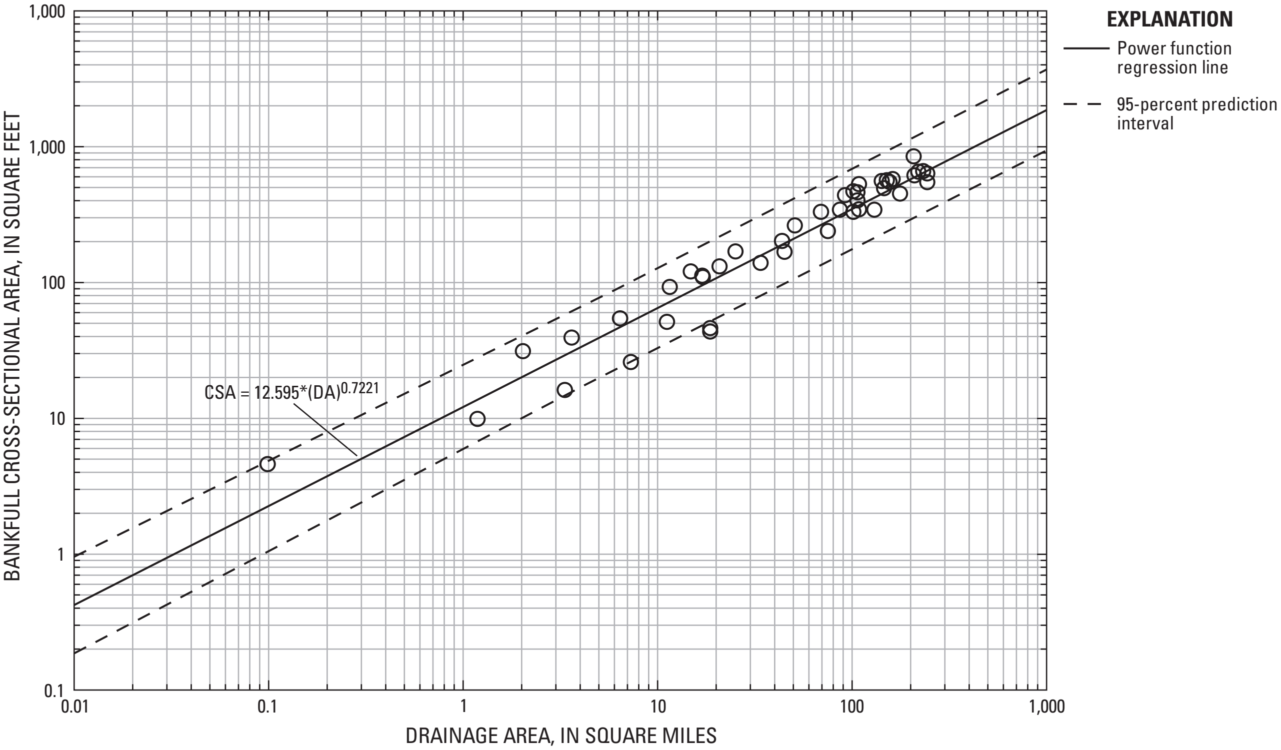


Figure 3. Regional curve relating bankfull cross-sectional area (CSA) to drainage area (DA) in the non-urban Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

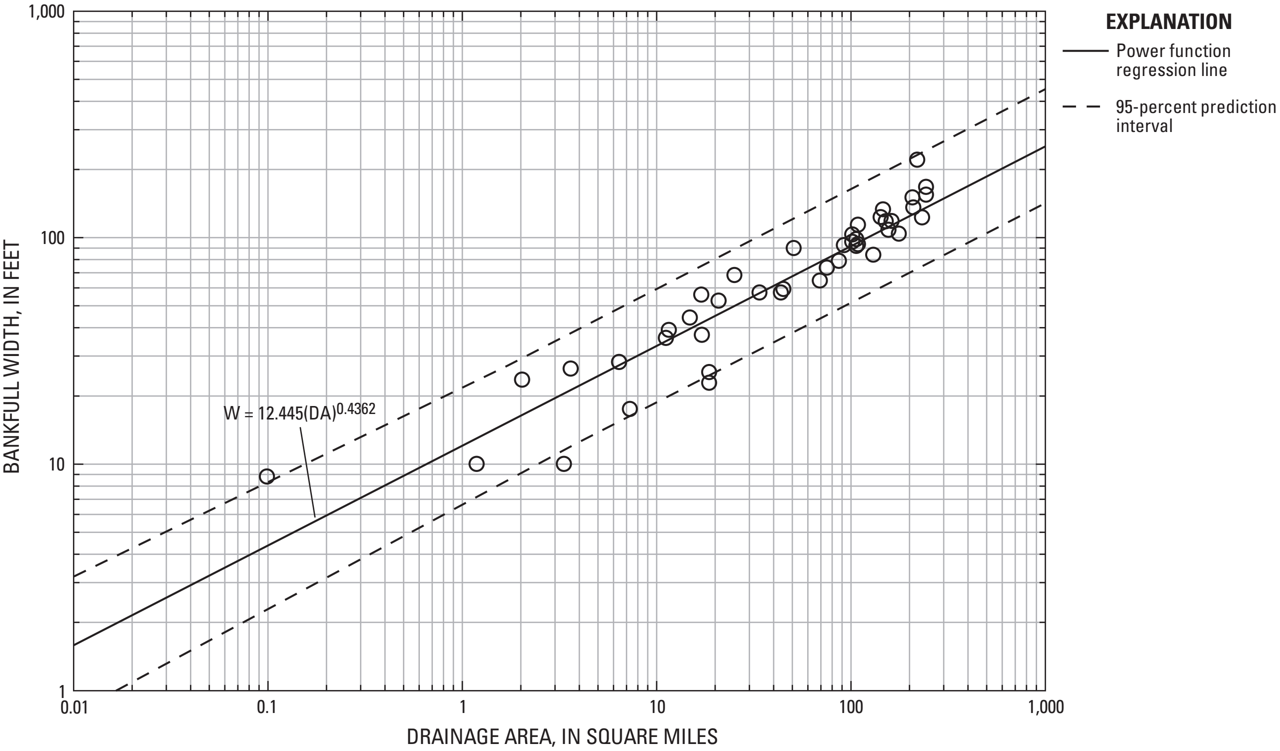


Figure 4. Regional curve relating bankfull width (W) to drainage area (DA) in the non-urban Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

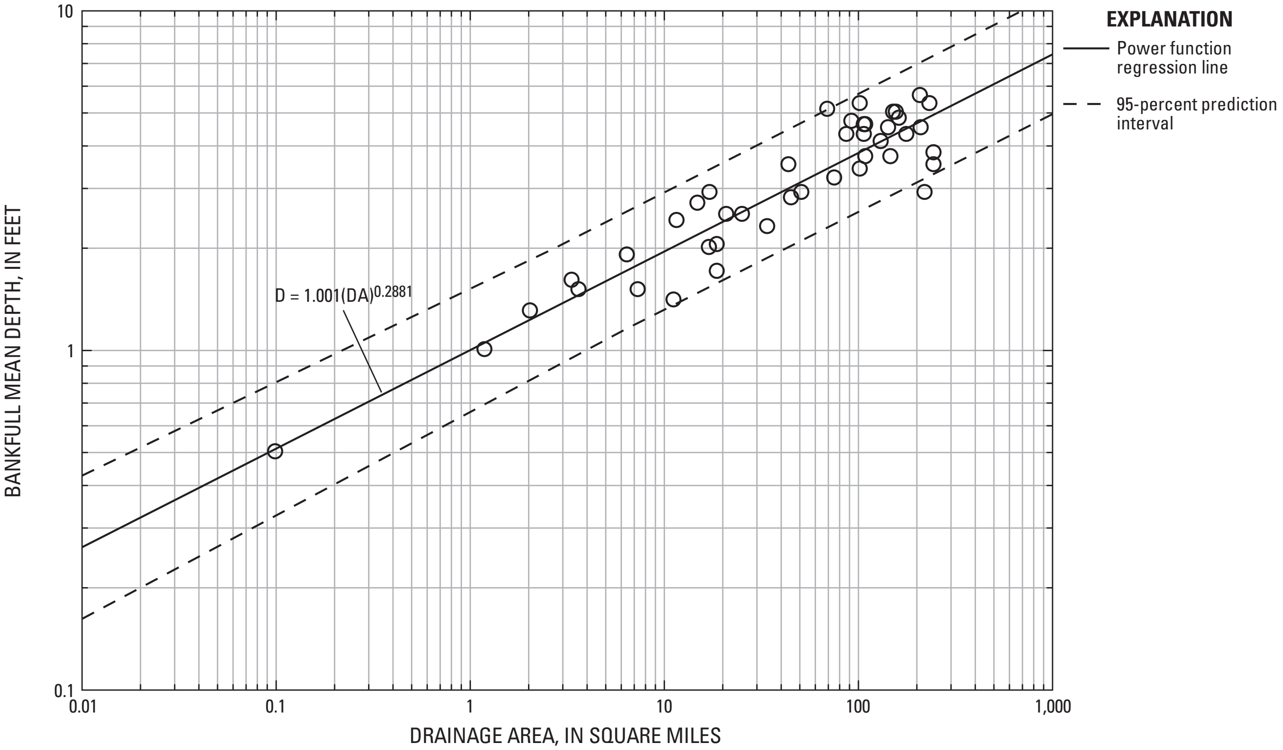


Figure 5. Regional curve relating bankfull mean depth (D) to drainage area (DA) in the non-urban Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

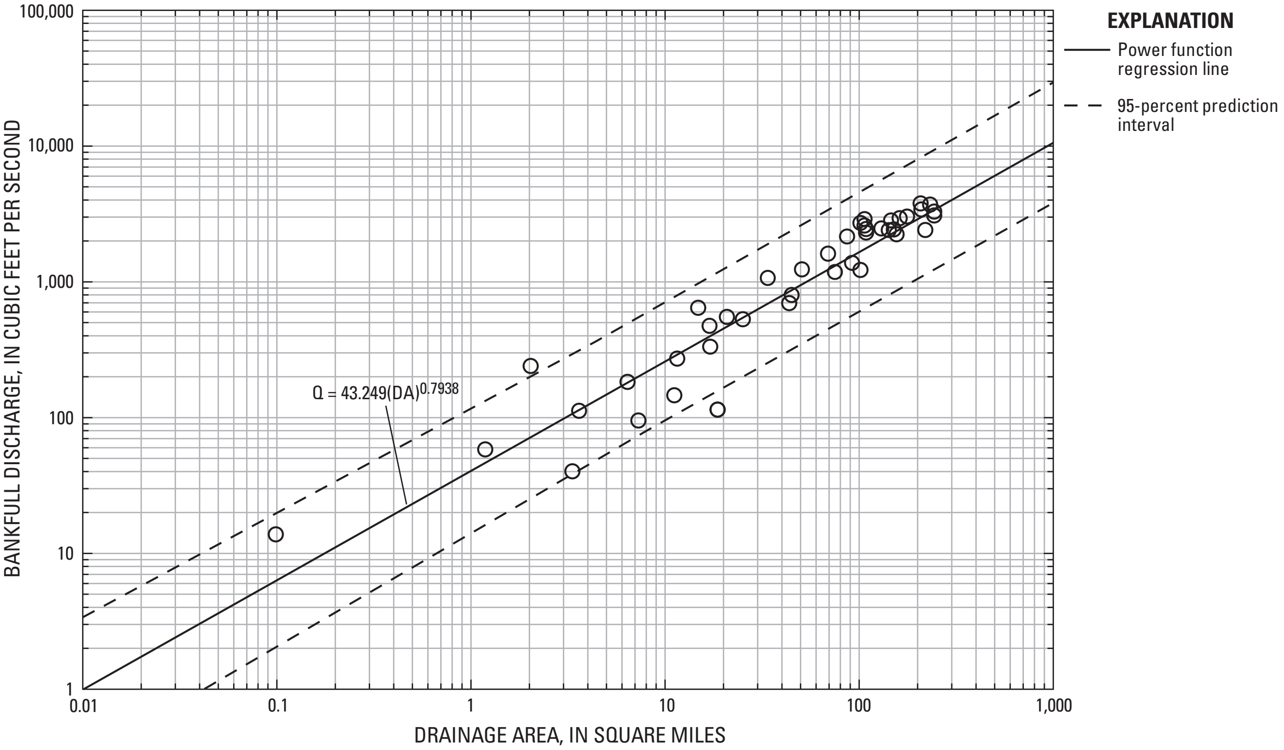


Figure 6. Regional curve relating estimated bankfull discharge (Q) to drainage area (DA) in the non-urban Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

explains more of the variability in cross-sectional area than in discharge. A possible reason for this is that the discharge values are estimated, in some cases on the basis of poor stage-discharge ratings, although all of the other variables are measured directly. Therefore, error is more likely to exist in the discharge values than in the other dependent variables. The width and mean depth regional curves have lower R^2 values than discharge and cross-sectional area because these variables are strongly affected by local factors such as resistance of bed and bank materials to erosion (Knighton, 1987) and bank vegetation (Smith, 1976). Schumm (1960) found that width-to-depth ratios of streams are related to particle size of the bank material. Miller (1984) found a similar relation to the size of the bedload material. In other words, two streams with the same cross-sectional area and similar discharges could have substantially different width-to-depth ratios.

Multiple Linear Regression Models Including Basin Characteristics

Multiple linear regression techniques were used to evaluate whether the inclusion of individual basin characteristics (table 2) would improve the predictive ability of the regional curve relations by explaining a portion of the remaining variability in the dependent variables. Log-transformed and untransformed basin characteristics (table 2) of each site were used to test multiple linear regression models (models with multiple explanatory variables) for predicting bankfull discharge and channel geometry; each basin characteristic was included with drainage area as an independent variable, one at a time. The untransformed independent variable percentage of carbonate bedrock underlying the drainage basin, hereafter referred to as "percent carbonate," was significant at the 5-percent level for bankfull cross-sectional area, bankfull width, and bankfull discharge. The p-values for the significance tests for these terms were 0.042, 0.002, and 0.002, respectively. The logarithm to base 10 (log) of percent carbonate was somewhat less significant, and only for bankfull width ($p = 0.036$). Multivariate models for predicting bankfull cross-sectional area, width, and discharge were developed including the untransformed percent carbonate term (table 6). The addition of this term does statistically improve the models as can be seen from reductions in standard error (table 6), Mallow's Cp, and the PRESS statistic (table 7). The Cp and PRESS statistics allow for the analysis of improvements to a regression model from the addition of specific explanatory variables beyond that attributable to simply including more variables. The log-transformed variable percentage of basin forested (hereafter referred to as "percent forested") had a p-value of 0.03 when regressed with bankfull discharge; however, the exponent was positive, indicating increasing discharge with increasing percentage of basin forested. Adding this variable to the multivariate model for discharge slightly improved the R^2 value; however, regression diagnostics showed that it lowers the Mallow's Cp value but raises the PRESS statistic. The weak statistical improvement and the fact that the positive coefficient conflicts with understood behavior indicate that percent forested should not be included in a multivariate regression model for discharge. None of the other basin characteristics analyzed were significant.

The multivariate regression models for bankfull cross-sectional area, width, and discharge that include the percent carbonate term produce smaller estimates of the independent variables than do the regional curves (for example calculations, see table 8). This difference occurs because the percent carbonate term has a negative coefficient. The percent carbonate coefficients in the three multivariate equations indicate that the additional variable has the most effect on bankfull discharge. The effect on the width and cross-sectional area relations was approximately the same. The mean depth model was not improved by adding the percent carbonate term. Because cross-sectional area is the product of width and depth, randomness in the mean depth model is incorporated into the cross-sectional area model, thus diluting its power.

The most likely reason that the percent carbonate term has a negative correlation with discharge, and therefore cross-sectional dimensions, is that many of the basins underlain by carbonate bedrock in the Valley and Ridge Physiographic Province have karst landforms. Karst landforms are defined as "topography that is formed over limestone, dolomite, and gypsum by dissolution, and is characterized by sinkholes, caves, and underground drainage" (Bates and Jackson, 1984). Drainage systems in karst areas are often disrupted with all or portions of the streamflow diverted to the underground system. Even when streams are not disrupted in karst areas, the underlying geology has an effect on streamflow. White and Reich (1970) studied 114 basins of various size in Pennsylvania and found that those underlain by carbonate rock had mean annual floods that were considerably smaller in magnitude than those in noncarbonate basins.

In this study, the percentage of carbonate rock underlying the drainage basins of the study sites ranges from 0 percent to 100 percent. Many of the points with high percent carbonate values plot below the regression lines, although others do not. Percent carbonate values of 30 percent or less were observed at 21 of 41 sites. The remaining 20 sites had percent carbonate values ranging from 30 percent to 100 percent. An analysis of covariance between these two groups of data showed no significant difference in slope or intercept between the regression lines of the two groups for any of the dependent variables at the 5-percent significance level (all p-values were greater than 0.05). Nor is there a difference in terms of trend line slope and intercept between the regression lines of those sites with greater than 50 percent of the basin underlain by carbonate bedrock and those with less than 50 percent underlain by carbonate bedrock. For this reason, all 41 sites were used to create a single set of regional curves.

The variability in the effects of carbonate bedrock on bankfull discharge and cross-sectional geometry for the sites in this study is expected because the effects of karst landforms on surface hydrology depend on the development of

Table 6. Equations and diagnostic statistics for multivariate regression models in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[R^2, correlation coefficient; CSA, bankfull cross-sectional area; Log, Log_{10}; DA, drainage area; PC, percent carbonate; W, bankfull width; Q, estimated bankfull discharge]

Equation	p-value[1]	R^2	Residual standard error (Log_{10})	Residual standard error (percent)	F-statistic
Log(CSA) = 1.162 + 0.7112 log(DA) - 0.0015(PC)	0.00	0.9481	0.1303	30.6	347.3
Log(W) = 1.171 + 0.42442 log(DA) - 0.0018(PC)	.00	.9155	.1033	23.3	205.8
Log(Q) = 1.765 + 0.7739 log(DA) - 0.0031(PC)	.00	.9259	.1748	43.3	237.4

[1] p-value shown although assumption of log-normal distribution is not met.

Table 7. Calculations for bankfull discharge and channel geometry using regional curves and multivariate models with 75-percent carbonate bedrock in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[CSA, bankfull cross-sectional area; DA, drainage area; W, bankfull width; Q, estimated bankfull discharge; Log, Log_{10}; PC, percent carbonate; Cp, Mallow's Cp; PRESS; prediction error sum of squares]

Equation	Cp	PRESS
$CSA = 12.595*(DA)^{0.7221}$	6.2	0.83
$W = 12.445(DA)^{0.4362}$	14.0	.64
$Q = 43.249(DA)^{0.7938}$	10.5	1.76
Log(CSA) = 1.162 + 0.7112 log(DA) - 0.0015(PC)	3.0	.76
Log(W) = 1.171 + 0.42442 log(DA) - 0.0018(PC)	3.0	.47
Log(Q) = 1.765 + 0.7739 log(DA) - 0.0031(PC)	3.0	1.42

Table 8. Calculations of regional curves and multivariate models with 75-percent carbonate bedrock in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

[mi^2, square mile; CSA, bankfull cross-sectional area; W, bankfull width; Q, estimated bankfull discharge]

Drainage area mi^2	CSA regional curve	CSA multivariate model	W regional curve	W multivariate model	Q regional curve	Q multivariate model
2	20.8	18.3	16.8	14.6	75.1	58.3
10	66.4	57.6	34.0	28.9	268	202
25	129	111	50.7	42.6	554	412
50	212	181	68.6	57.2	958	704
100	350	296	92.8	76.7	1,670	1,200
200	578	485	126	103	2,900	2,060

the underground drainage system, particularly the connectivity of the fractures (Ede, 1975). These conditions, along with the effects of local geology, may differ greatly from basin to basin. In addition, some carbonate lithologies are more subject to dissolution than others. In this study, calcareous shale and sandstone units were included with limestone and dolomite units as carbonate. Users of the regional curves should be aware that basins underlain by carbonate bedrock may have different runoff responses than those underlain by noncarbonate bedrock. Therefore, the regional curves may over-predict bankfull discharges and cross-sectional geometry for streams underlain by carbonate bedrock.

The multivariate regression models that include a term for percent carbonate may not be more useful in calibrating bankfull discharge and geometry of channels than the regional curves. Because of the variability in hydrologic response among drainage basins, it is unlikely that either the regional curves or the multivariate models will predict bankfull characteristics precisely. However, the multivariate models illustrate that drainage basin characteristics affect hydrologic regimes and thus impact the bankfull discharge and what the possible magnitude of these impacts may be.

Geographic Analysis of Regional Curves

Residuals of each of the regional curves were plotted on maps of the Valley and Ridge Physiographic Province to determine whether there are geographic variations in bankfull discharge and cross-sectional geometry. Though there were small groupings of positive or negative residuals, no definitive geographic patterns were apparent for any of the four data sets.

Because the southern and central sections of the Valley and Ridge Physiographic Province (fig. 1) are somewhat different geologically, data on bankfull characteristics of sites in the two sections were compared. Separate power function relations were developed for bankfull discharge and channel geometry data from the two sections, and analysis of covariance was performed to identify any statistical differences between the two data sets. A difference between the two data sets for slope and intercept was identified for the width relation at the 95-percent confidence level (all p-values were greater than 0.05), and a difference in intercept was identified at the 95-percent confidence level for the discharge relation (all p-values were greater than 0.05). For the other two dependent variables, there were no differences.

Diagnostic statistics for the power function relations developed for the southern and central sections were compared to regional curves (for all 41 sites) for the same dependent variables. The R^2 values for the width relations were 0.88 and 0.93 for the southern and central sections, respectively, and the F-statistics were 52.56 and 423.6, respectively. These values represent a small decrease in model fit and statistical significance for the southern section data set and a small increase in both for the central section data set. For the bankfull discharge relations, the R^2 values were 0.9386 and 0.9167 and the F-statistics were 106.9 and 330.1 for the southern and central sections, respectively. These values represent a small increase in model fit but a small decrease in model significance in both cases. These small statistical differences in slope and intercept between the southern and central section data sets are inconclusive due to the small number of sites in the southern section (9). Because a significant statistical improvement is not gained by separating the data into two models, the regional curves for width and discharge have not been split between the two sections. Therefore, separate equations for bankfull width and discharge for the southern and central sections are not included in this report.

Drainage Basin Size and Variability of Bankfull Characteristics

Variability in the residuals of the regional curves was examined in relation to drainage basin size. In this study, the drainage basins ranged in size from 0.10 mi^2 to 247 mi^2. Plots of the residuals from the regional curves relating bankfull cross-sectional area, width, mean depth, and discharge to drainage area (fig. 7A–D) indicate changes in variability of residuals in relation to basin size. The presence of this variability, called heteroscedasticity, violates an assumption of simple linear regression that there is constant variance of the dependent variable in relation to the independent variable (Helsel and Hirsch, 1992). The variability of bankfull discharge residuals decreases as drainage area increases (fig. 7D). The variability is not as evident in the cross-sectional area residuals (fig. 7A) and width residuals (fig. 7B) relations and is reversed in the mean depth residuals (fig. 7C) relation. The increasing variability of depth as drainage area increases, which can be seen on the mean depth regional curve (fig. 5), is incorporated into the cross-sectional area relation (width x mean depth) thus increasing the variability in that relation for larger basins.

These patterns in variability are expected and may be due to a variety of potential causes. Small drainage basins are more responsive to storms with limited areal coverage than larger basins where the effects of small storms are dampened by the larger contributing drainage area. In a similar manner, small changes in land cover may increase discharges in small basins but have little effect on large basins. There are also potential problems with discharge records in small basins. Often, the rapid rise and fall of water levels (commonly called “flashiness”) in small streams makes it difficult to measure peak discharge; therefore, stage–discharge ratings for small streams are often theoretical. In addition, the period of record for streamflow-gaging stations on small streams is often shorter resulting in less reliable discharge frequency analysis.

The patterns illustrated in figure 7A–D are not definitive; however, the significance of this variability would possibly become clearer with a larger data set. Potential changes in variability of residuals in regional curves related to basin size may be an important factor in the application of these tools.

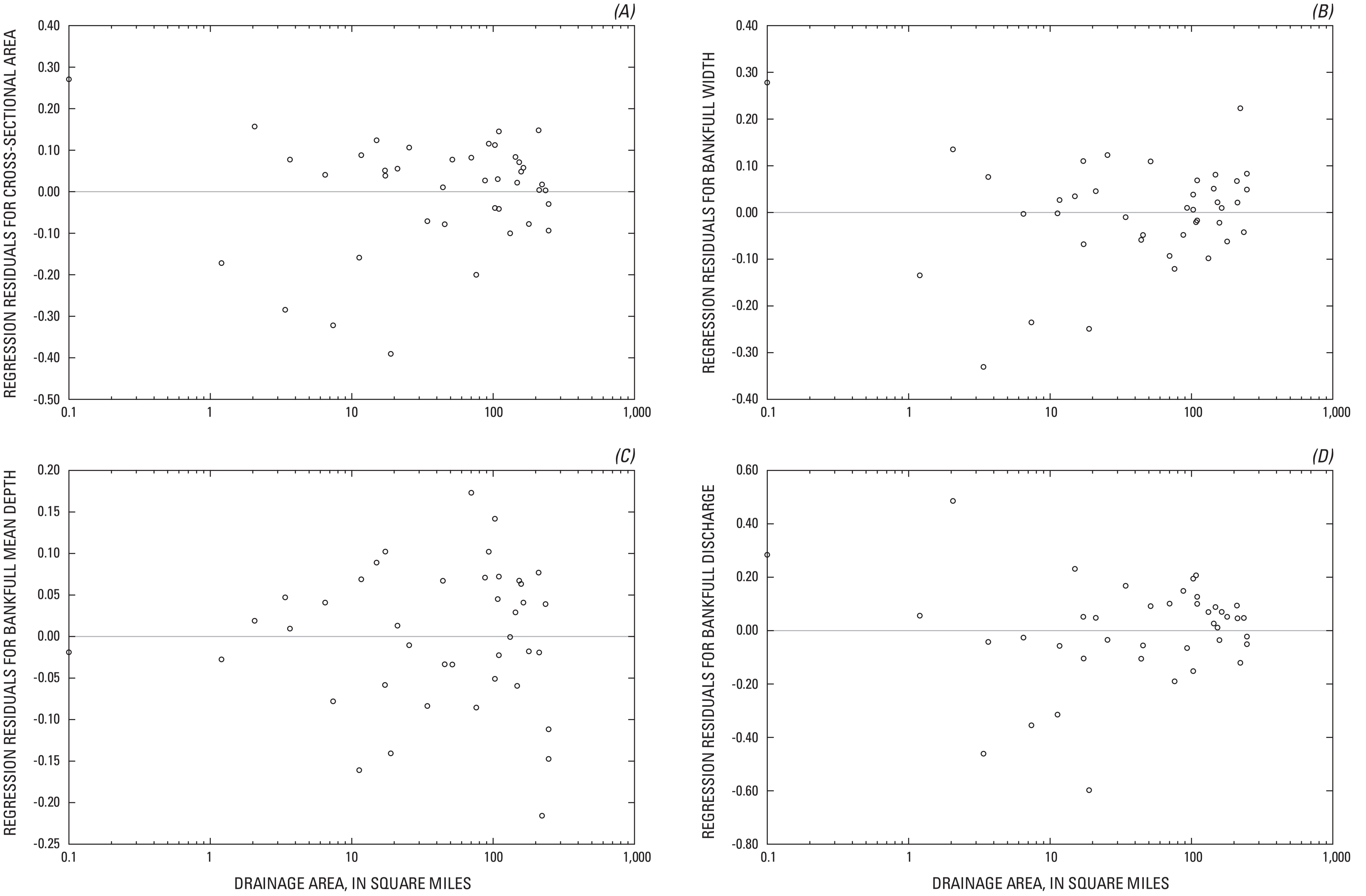


Figure 7. Regression residuals for regional curve models in relation to drainage area for bankfull cross-sectional area *(A)*, bankfull width *(B)*, bankfull mean depth *(C)*, and bankfull discharge *(D)*.

Heteroscedasticity may cause the prediction intervals on the regional curves plots to be erroneous. Users should be aware of the potential for greater variability in the magnitude of observed bankfull characteristics in relation to regional curve best-fit lines for smaller streams.

Comparison of 1.5-Year Discharge Data to Bankfull Discharge Data

In this study, regional curves were developed to estimate bankfull discharge and cross-sectional channel geometry for a large region. The protocol followed required that the field-identified bankfull stage relate to a discharge with a recurrence interval of approximately 1 to 2 years. Leopold and others (1964) and Dunne and Leopold (1978) state that the bankfull discharge has a recurrence interval of approximately 1.5 years. The 1.5-year discharge data from a large number of USGS streamflow-gaging stations in Virginia were regressed against drainage area as a comparison to the discharge regional curve. The benefits of this analysis are two-fold. First, the statistics and trends described in this report for bankfull discharge can be compared to this larger, more robust data set of measured values with greater spatial coverage. Second, the variability in hydrologic data of a discharge approximating bankfull for a large area can be analyzed by comparison with a well-populated data set. This analysis is relevant not only for the discharge regional curve, but for the regional curves developed in this study for other dependent variables that are inherently related to discharge.

Regression Model for the 1.5-Year Discharge for Streamflow-Gaging Stations Throughout Virginia

A frequency analysis was performed for every station in Virginia for which peak flow data have been collected ($n = 486$) following procedures described in the section “Identification of Bankfull Stage.” A regression model relating the 1.5-year discharge to drainage area was developed for this data set (fig. 8). The power function for this relation is:

$$Q_{1.5} = 75.200(DA)^{0.7243} \qquad (1)$$

Where $Q_{1.5}$ is the 1.5-year discharge, in ft^3/s, and
DA is drainage area, in mi^2.

The R^2 value for this relation is 0.8717, the residual standard error is 78.2 percent, and the F-statistic is 3,214. A K-S goodness-of-fit test reveals that the residuals of this data set are not log-normally distributed ($p < 0.001$). These diagnostics are similar to those of the regional curve relating bankfull discharge to drainage area, except for a higher F-statistic, which indicates a more significant model, and a higher residual standard error, which indicates more dispersion of data around the regression line. These results support the assumption that the regional curve for discharge is representative of the relation between drainage area and discharge. The R^2 value is lower for equation 1 than for the bankfull discharge regional curve because the latter represents only one physiographic province, but the former represents an entire state.

Basin characteristics for many of the basins included in the Virginia statewide model are not available. However, it is possible to examine the variability in discharge related to drainage area for this model. A plot of the residuals of the 1.5-year discharge regression model in relation to drainage area (fig. 9) shows that as drainage area increases, the variability in residuals decreases. In other words, the variability of residuals is greater in the 1.5-year discharge regression model for smaller basins. A similar pattern can be seen when the bankfull discharge regional curve residuals are plotted against drainage area (fig. 7D). Although the size of the data set used for development of the regional curves is insufficient to properly analyze this phenomenon, analysis of the larger data set of 1.5-year discharges indicates that the relation between basin size and residuals variability should be considered by users of regional curves (see “Drainage Basin Size and Variability of Bankfull Characteristics”).

1.5-Year Discharge Regression Model for Streamflow-Gaging Stations in the Southern and Central Sections of the Valley and Ridge Physiographic Province

It was not possible to determine if the regional curves developed in this study should be divided into separate sets of equations for the southern and central sections of the Valley and Ridge Physiographic Province because of the limited data set available. A larger data set ($n = 147$) of 1.5-year discharge data for all stations in the Valley and Ridge Physiographic Province in Virginia was analyzed to determine if there was a difference in this variable in relation to drainage area between the southern and central sections. A regression model was developed for the 1.5-year discharge for every station in the province in Virginia. A plot of the regression model with unique symbols for points in the southern and central sections is shown in figure 10. The equation for this model is:

$$Q_{1.5} = 41.076(DA)^{0.8563} \qquad (2)$$

Where $Q_{1.5}$ is the 1.5-year discharge, in ft^3/s, and
DA is drainage area, in mi^2.

The R^2 value for this model is 0.9257, the F-statistic is 1806.0, and the residual standard error is 22.3 percent. The regression diagnostics indicate a highly significant model that fits the 1.5-year data set. A K-S goodness-of-fit test indicates that the residuals of this data set are not log-normally distributed ($p = 0.07$). The R^2 value of this model is higher than the model for stations throughout Virginia (equation 1) most likely because this model was developed with data from a particular physiographic province.

This data set includes 1.5-year discharge values for 107 stations in the central section and 40 stations in the south-

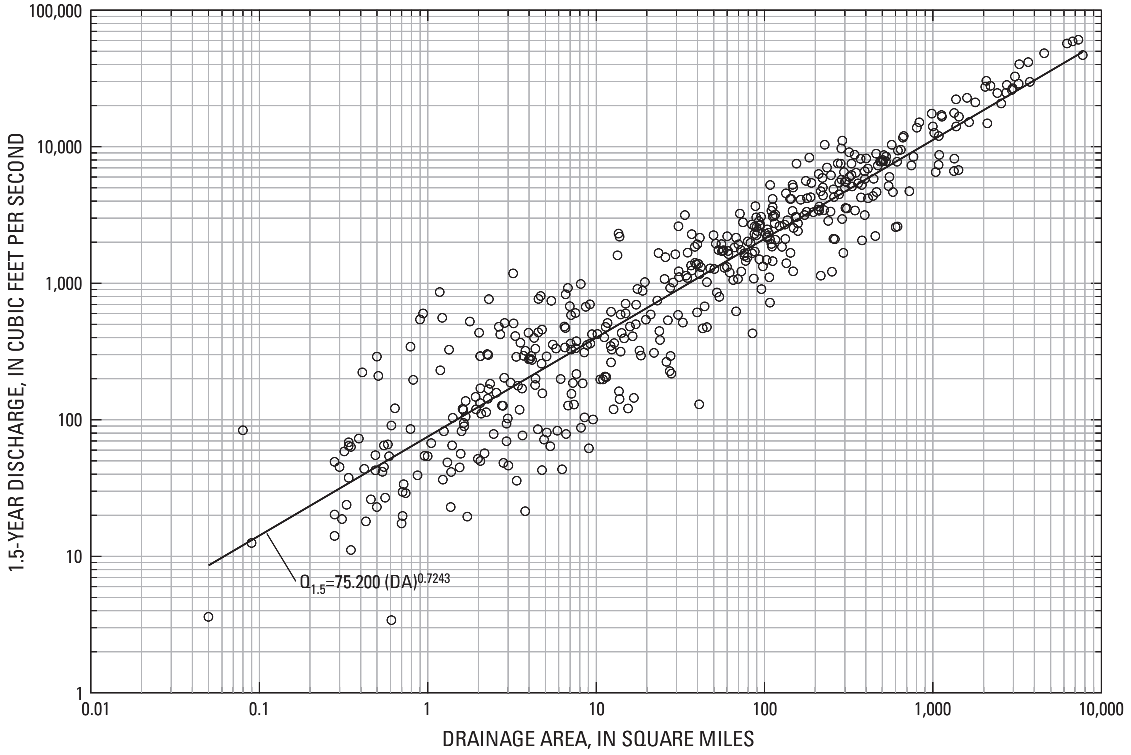


Figure 8. Regression model of 1.5-year discharge in relation to drainage area for every streamflow-gaging station with peak flow data in Virginia.

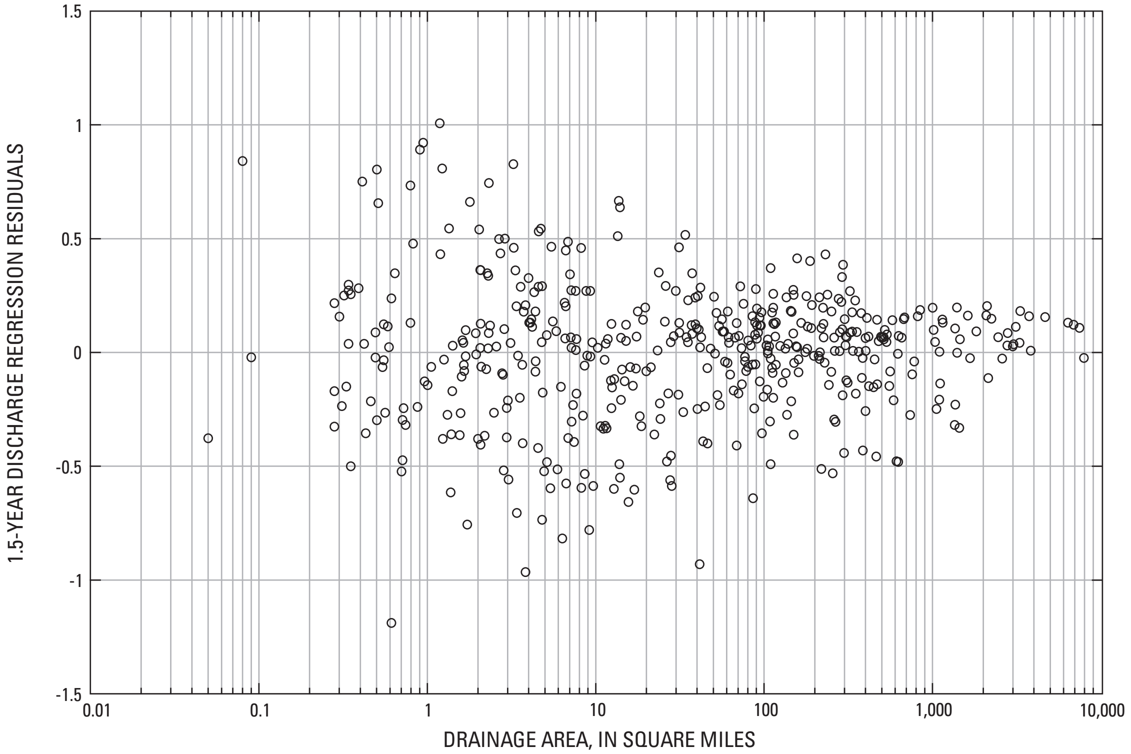


Figure 9. Regression residuals of 1.5-year discharge model in relation to drainage area.

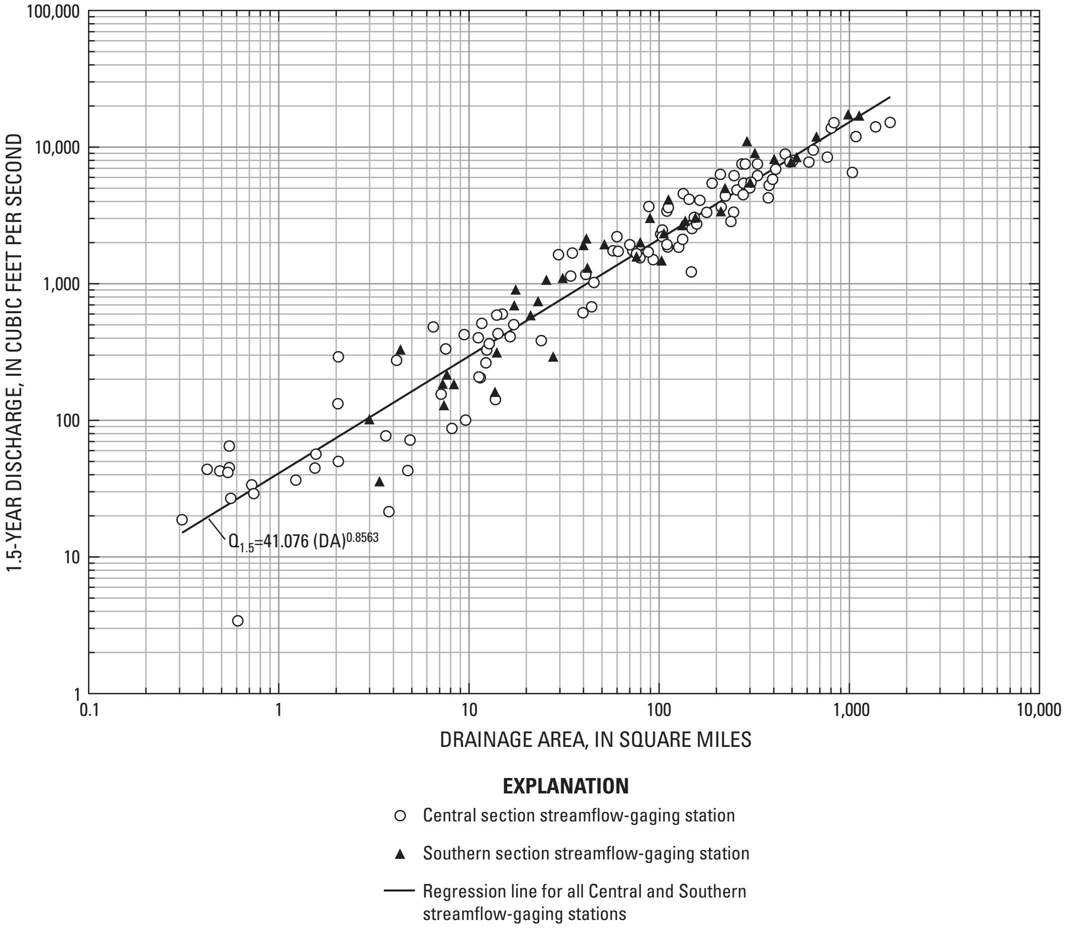


Figure 10. Regression model of 1.5-year discharge in relation to drainage area for streamflow-gaging stations in the Southern and Central Valley and Ridge Physiographic Province in Virginia.

ern section of the province. An analysis of covariance was performed between 1.5-year discharge regression models for these two data sets to determine if there was a difference in intercept or slope between the two. Results indicate that there is no statistical difference in either slope or intercept between the two data sets at the 95-percent confidence level (all p-values were greater than 0.05). Although the 1.5-year discharge is only an approximation of the bankfull discharge, the results of this analysis support the conclusion that the regional curve for discharge developed in this study should not be separated into two separate models for the southern and central sections. Because the other independent variables for which regional curves were developed are related to discharge, these results also support combining the other regional curves for the central and southern sections.

Comparison of Regional Curves with Other Data Sets of Bankfull Characteristics

The regional curves developed in this study were compared to other discharge and channel geometry regression models for the Valley and Ridge Physiographic Province. Specifically, the four regional curves were compared to data collected for bankfull discharge and cross-sectional geometry for the Valley and Ridge Physiographic Province in Pennsylvania (J. C. Chaplin, USGS, written commun., 2004) and to the Valley and Ridge Physiographic Province data points from a recent study of Maryland streams conducted by the U.S. Fish and Wildlife Service (USFWS) (McCandless, 2003). Analysis of covariance was performed to determine if there were differences in slope or intercept between the regional curves developed for the present study and those of the regression models developed from data from either of the other studies.

Regression models developed with the USFWS data ($n = 5$) were compared to the regional curves developed for this study because the current study area included the Maryland Valley and Ridge Physiographic Province. There was no statistical difference in slope or intercept at the 5-percent significance level (all p-values were greater than 0.05) between the regression lines for USFWS data for cross-sectional area, width, mean depth, and discharge and the regional curves for the same parameters developed for the current study.

The USGS Pennsylvania data (n = 28) were compared in a similar manner to the current study data and to the current study data combined with the USFWS data. This was done to allow for a statistical comparison of all available data for the Valley and Ridge Province in the four states (Maryland, Pennsylvania, Virginia, and West Virginia) to determine if a single set of regional curves would be appropriate to describe channel geometry and discharge for the large region. In all cases, there was no statistical difference in slope or intercept at the 5-percent significance level (all p-values were greater than 0.05).

The similarity of the regional curves of the current study to regression models developed for data sets of the USFWS in Maryland and the USGS in Pennsylvania has two important implications. First, these data sets were collected independently by at least five separate field teams, which suggests that the methods used are consistent and repeatable. Second, these results indicate that, in general, the relations of bankfull discharge and cross-sectional geometry to drainage area are similar throughout the Valley and Ridge Physiographic Province in these four states.

Quality Assurance

A quality-assurance protocol was established for this project to assess the variability in the measurements that were made by various field teams. Three sites were resurveyed by a different field team. Specifically, a team from each USGS office surveyed one of the sites originally studied by another office. The USGS Maryland team resurveyed a site originally surveyed for the Pennsylvania regional curves study. Two sites from the present study were resurveyed–the USGS Virginia team resurveyed a site in West Virginia and the USGS West Virginia team resurveyed a site in Virginia. Results of the quality-assurance surveys show that, except for the bankfull cross-sectional area at station 02053800, South Fork Roanoke River near Shawsville, Va., all quality-assurance measurements were within plus or minus 26 percent of the original values (table 9).

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the West Virginia Department of Transportation, Division of Highways; the Natural Resources Conservation Service; and Canaan Valley Institute, undertook a two-year study to develop regional curves that relate bankfull discharge and channel geometry to drainage area for the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia. This study took place from 2002 to 2004 and included an assessment of 41 stream reaches at streamflow-gaging stations. Each assessment included a channel geometry survey, estimation of bankfull discharge, and analysis of riffle bed material. From the data collected, simple linear regression models were developed for bankfull cross-sectional area, width, mean depth, and discharge with respect to drainage area for the Valley and Ridge Province in these three states. These regression models, called regional curves, may be used to calibrate field-identified bankfull characteristics of ungaged streams.

Geographic analysis of regional curve residuals indicated that there were no further subdivisions within the Valley and Ridge Physiographic Province in the three-state study area for which individual sets of regional curves should be developed. In addition, two separate sets of regional curves were developed with data from the 41 sites to examine potential differences in the relations between the southern (n = 9) and central (n = 32) sections of the province. There were differences in slope and intercept between the two bankfull discharge test relations and a difference in intercept for the width test relations at the 95-percent confidence level. However, the results of this analysis were inconclusive and therefore separate regional curves were not developed for the Central and Southern Valley and Ridge.

The regional curves developed for this study show that drainage area explained from 86 to 95 percent of the variability in bankfull characteristics. Basin characteristics of each stream in the study, such as percentage basin forested and percentage of basin underlain by carbonate bedrock, were analyzed to determine potential causes of the remaining variability in the regional curves. The only basin characteristic that was significant in the study data set was percentage of

Table 9. Results of bankfull discharge, bankfull channel geometry, and D_{50} (median particle size of streambed material) for quality-assurance (QA) surveys and surveys for three study sites in the Valley and Ridge Physiographic Province in Maryland, Virginia, and West Virginia.

Station number	Bankfull cross-sectional area			Bankfull width			Bankfull depth			Bankfull discharge			D_{50}		
	Study survey	Quality assurance	Percent difference	Study survey	Quality assurance	Percent difference	Study survey	Quality assurance	Percent difference	Study survey	Quality assurance	Percent difference	Study survey	Quality assurance	Percent difference
01567500	108	101	-6.85	43.2	32.1	-25.7	2.5	3.1	25.2	424	376	-11.3	71.0	57.0	-19.7
01609800	393	452	14.9	90.9	97.4	7.15	4.3	4.6	6.98	2,830	2,540	-10.2	73.1	68.3	-6.6
02053800	519	315	-39.3	113	82.9	-26.4	4.6	3.8	-17.4	2,390	1,840	-23.0	65.7	52.6	-19.9

basin underlain by carbonate bedrock (percent carbonate). Multivariate regression equations including a term for percent carbonate were developed and had higher R^2 values and lower residual standard error than the regional curves. However, these small improvements did not warrant separation of the regional curves in terms of the amount of carbonate bedrock in the basin. Users of the regional curves should be aware that basins underlain by carbonate bedrock may have different runoff responses than those underlain by noncarbonate bedrock. Therefore, the regional curves may over-predict bankfull discharges and cross-sectional geometry for streams underlain by carbonate bedrock.

A relation between size of the drainage basin and the variability of residuals was also demonstrated in two regression models relating a specific discharge to drainage area. The residuals of regression models developed for this study for bankfull discharge and the 1.5-year discharge of every station in Virginia with peak flow data were plotted against drainage area. These plots indicated that as drainage area increases, variability in the discharge (and, potentially, channel geometry variables) decreases. Users should be aware of the potential for greater variability in the magnitude of observed bankfull characteristics in relation to regional curve best-fit lines for smaller streams.

The regional curves were compared to similar regression models developed for data collected in Maryland by the USFWS and in Pennsylvania by the USGS. The regional curves developed for the current study were not significantly different from those developed for the other data sets. Although the regional curves developed in this study should not be expected to identify bankfull characteristics with precision, they are an important tool for stream assessment. The curves may be used in conjunction with detailed studies of fluvial systems and their drainage basins to estimate bankfull discharge and channel geometry characteristics.

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Appendix

Station Descriptions and Photographs, Longitudinal Profiles, Riffle Cross Sections, and Bed Material Particle-Size Distributions of Study Reaches

Station 01601500
Wills Creek near Cumberland, Md.

View looking downstream at reach for Willis Creek near Cumberland, Md.

The continuous-record streamflow-gaging station is located approximately 500 ft downstream of a highway bridge. Low-flow data show some slight fluctuations caused by work at an upstream quarry.

The stream was entrenched by a roadway embankment on the right and a railroad embankment on the left. This site is the most entrenched site in the study and the only site classified as an F stream type according to the Rosgen (1996) classification system. The bankfull discharge is constricted on the right bank by a high embankment and a roadway, and unconstricted on the left bank. Flows significantly greater than bankfull are also constricted on the left bank by a railroad embankment. The main bankfull features in the channel were breaks in bank slope and the top of the bank. The bed was mostly cobble with some small boulders. Both banks were heavily forested with trees and small woody vegetation and there were few signs of bank erosion. The study reach was wide and shallow, fairly straight, and had a mild slope.

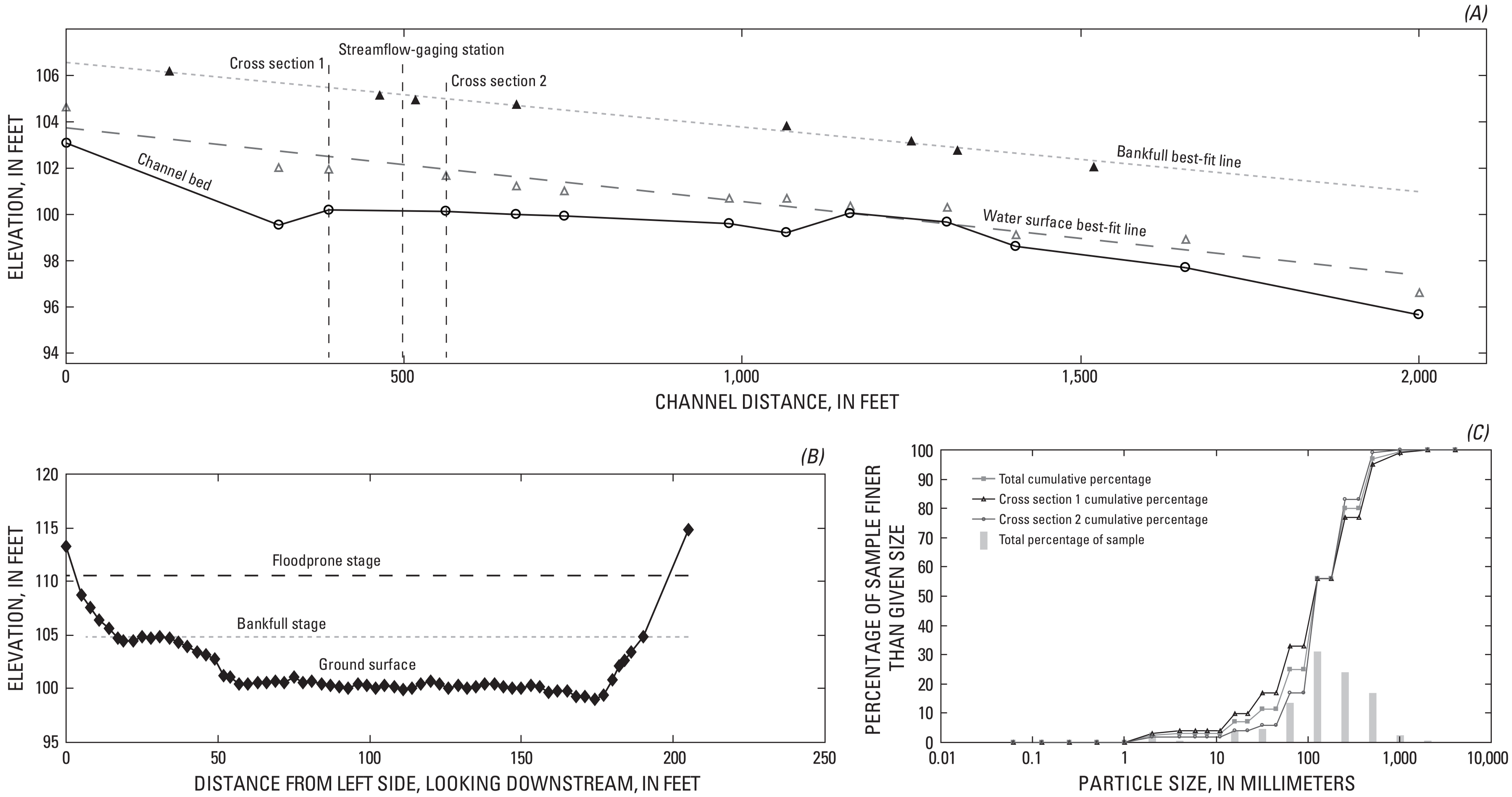

Figure A1. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Wills Creek near Cumberland, Md., August 5, 2003.

Station 01605500
South Branch Potomac River at Franklin, W. Va.

View looking downstream at reach of South Branch Potomac River at Franklin, W.Va.

The continuous record streamflow-gaging station is approximately 150 ft upstream from a bridge that may have a slight backwater effect at the bankfull discharge.

The bankfull channel was well defined through the upstream half of the reach, primarily by the top of the bank. In the downstream half of the reach, which included the station location, bankfull channel indicators were poorly defined. The banks of the upstream half of the reach were low and showed little erosion. In this section, the right bank vegetation was predominantly grass and the left bank was wooded. The downstream half of the reach was a gorge, with steep rocky banks on both sides. In the upstream half of the reach, the flood plain on the right side of the stream channel was a wide pasture. The left side of the stream channel was bordered by a steep hill. In the downstream part of the reach, no flood plain was present. The hill on the left side of the channel contained riprap from the adjacent highway. The bed material was predominantly bedrock with some coarse gravel and cobble. The reach was very straight and had a mild slope.

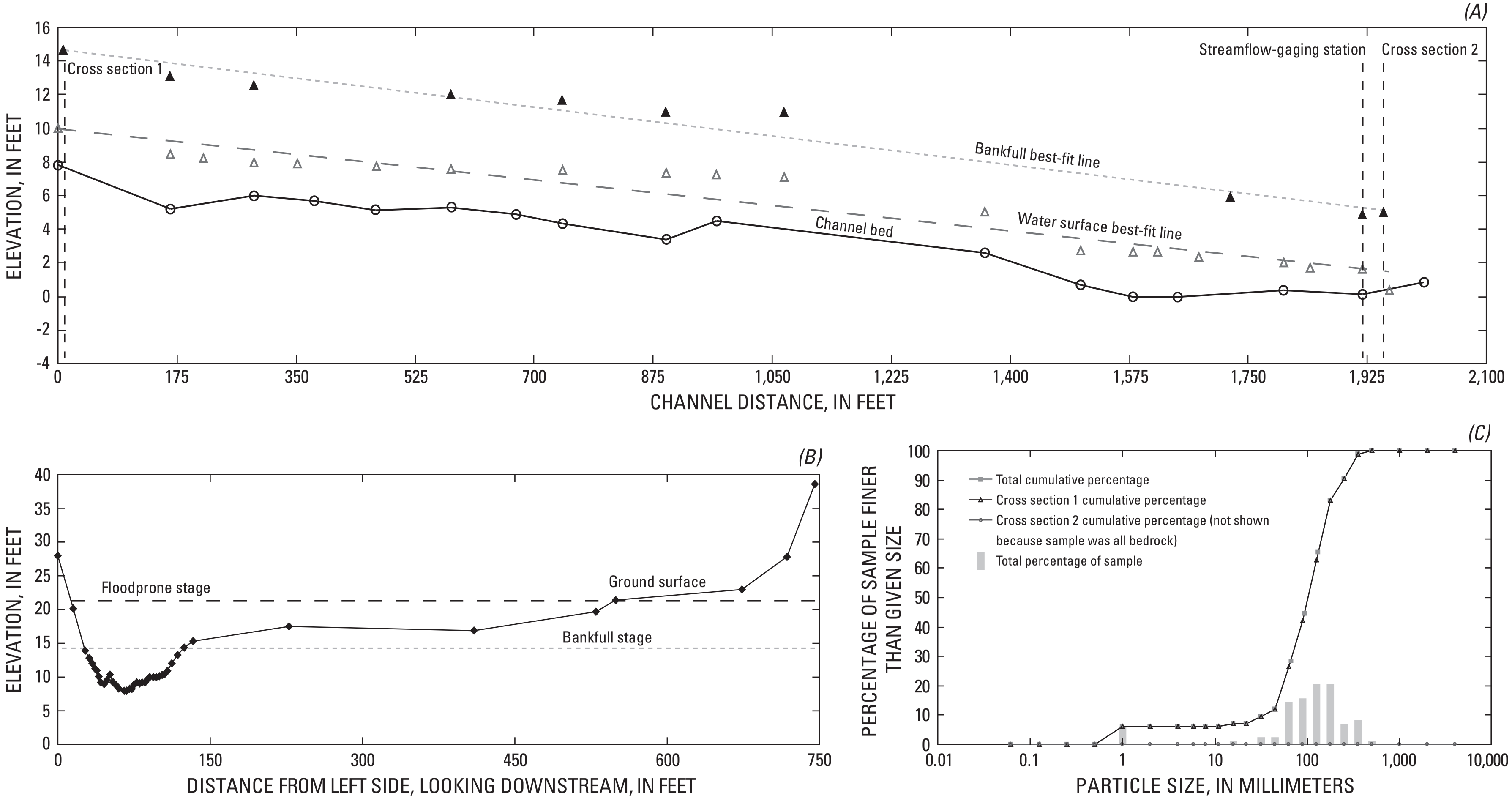

Figure A2. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of South Branch Potomac River at Franklin, W.Va., October 31, 2003.

Station 01607500
South Fork South Branch Potomac River at Brandywine, W. Va.

View looking downstream at reach of South Fork South Branch Potomac River at Brandywine, W.Va.

The continuous-record streamflow-gaging station was approximately 100 ft upstream from a bridge that may have had a slight backwater effect on the bankfull discharge. The stage-discharge relation for this station was changed substantially in February 2003, when a flow event deposited a significant amount of coarse sediment on a mid-channel bar. Prior to this event, the discharge for the bankfull stage (gage height of 4.09 ft) was 1,529 cfs. Following this event, discharge at the same gage height was 1,195 cfs. The latter discharge is reported as bankfull in this report because it was current at the time of the survey. However, the channel may be adjusted to a larger discharge.

The channel was relatively wide and shallow. The main bankfull features in the reach were the top of the bank and changes in bank slope. Several changes in slope were present in the stream banks through most of the reach. The banks showed little erosion, and were rocky and well vegetated, primarily with trees. The bed material was primarily coarse gravel and cobble with sections of exposed bedrock. The flood plain on the right side of the stream channel was a wide field with houses, yards, and a school. The left side of the stream channel was bordered by a steep hill. The study reach was very straight and had a mild slope.

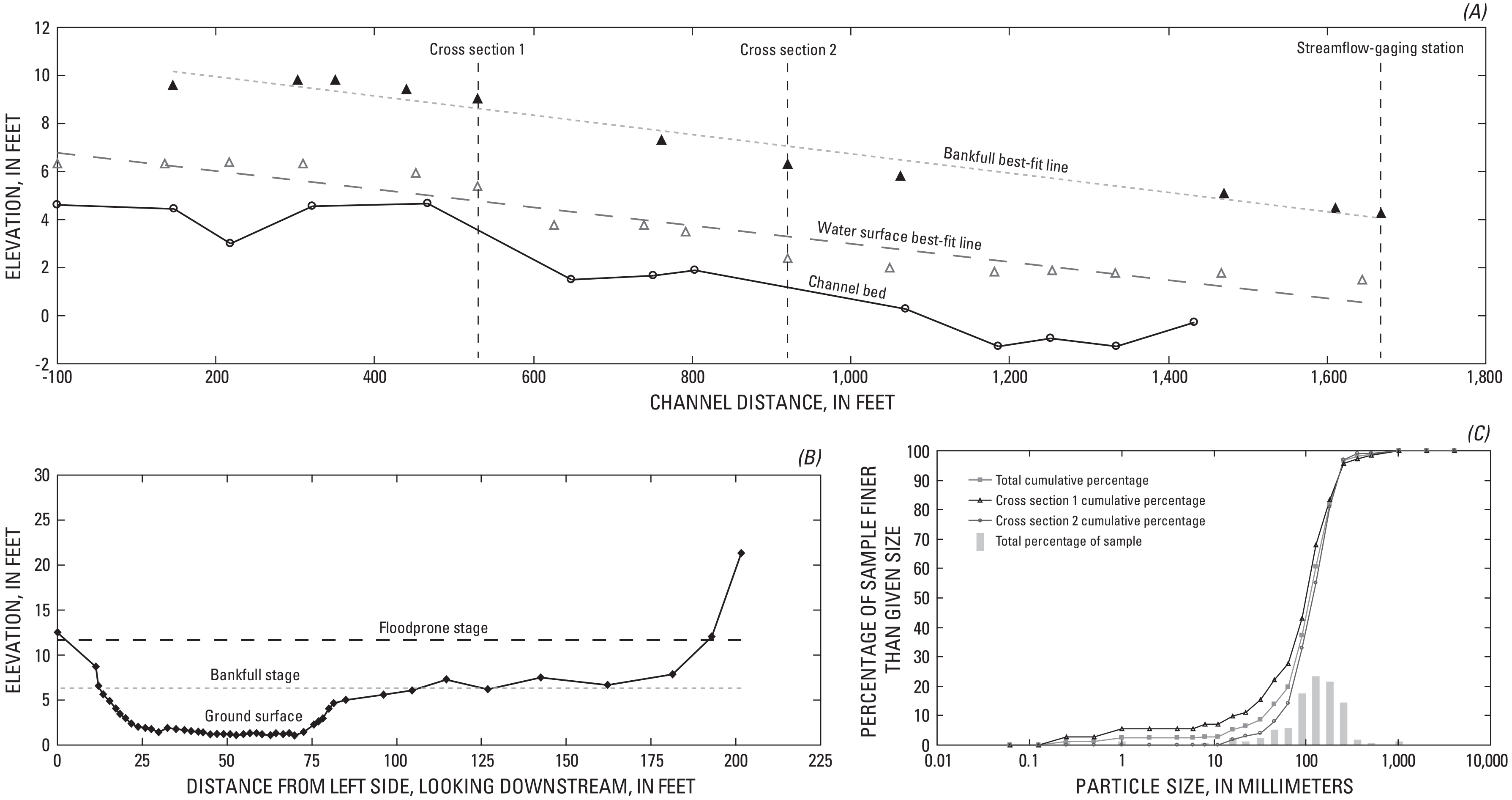

Figure A3. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of South Fork South Branch Potomac River at Brandywine, W.Va., May 1, 2003.

Station 01609000
Town Creek near Oldtown, Md.

View looking downstream at reach of Town Creek near Oldtown, Md.

The continuous-record streamflow-gaging station is located 2,000 ft downstream of a single-span highway bridge. The bankfull discharge is unconstricted downstream from the bridge.

The study reach was very straight. The main bankfull features in the study reach were breaks in bank slope and the top of the bank. Much of the bed material consisted of large cobbles and very coarse gravel. Bedrock outcrops were present in many areas of the channel bed and all along the right bank. The stream banks were vegetated with grass, small woody vegetation, and some trees. There was little evidence of erosion on the banks. The flood plain on the left side was flat to gently sloping and mostly cleared for residential land use. The stream was bordered on the right by wooded, rocky bluffs. The stream was wide and shallow and in some places had vegetation growing from the stream bed. The study reach had a mild slope.

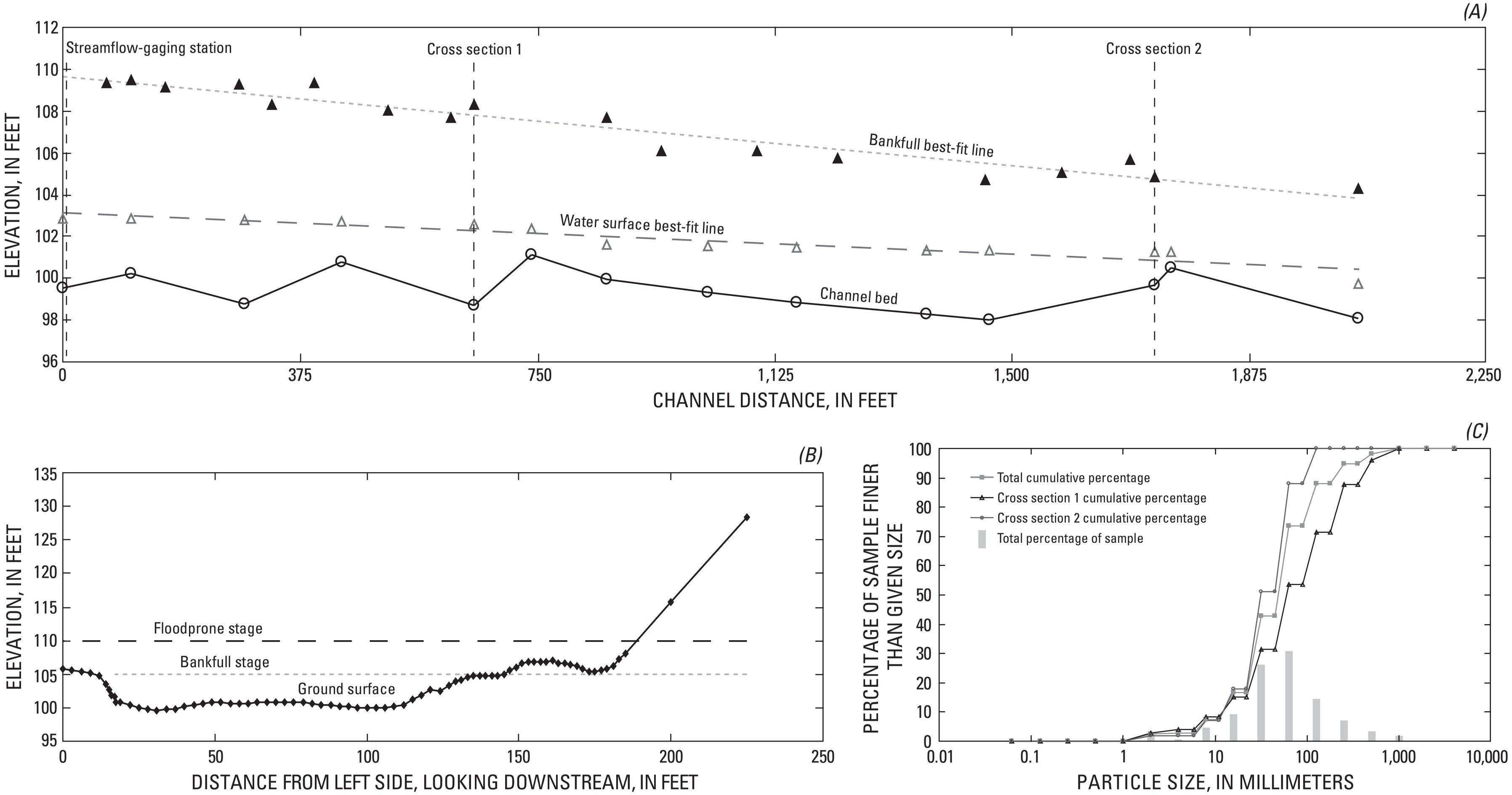

Figure A4. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Town Creek near Oldtown, Md., April 29, 2003.

Station 01609800
Little Cacapon River near Levels, W. Va.

No photo available

The continuous-record streamflow-gaging station is approximately 20 ft downstream from a bridge that is not likely to affect the bankfull. The station was last active in 1977, and the last discharge measurement above a wading stage was made in 1972.

The bankfull channel was not clearly defined throughout most of the reach. The primary bankfull indicators used were breaks in bank slope. Several changes in slope were present at different elevations in the stream banks through most of the reach. Those that were the most consistent and fell within the range of stages representing the 1- and 2-year discharges were used to define bankfull stage. The banks showed little erosion, and were well vegetated with trees and bushes. The flood plain on the right side of the stream channel was a wide field that was planted in corn at the time of the survey. The left side of the stream channel was bordered by a steep hill. The channel was mostly straight and the bed was predominantly made up of small cobble and some gravel, and bedrock was exposed in some sections of the channel. The slope of the study reach was mild.

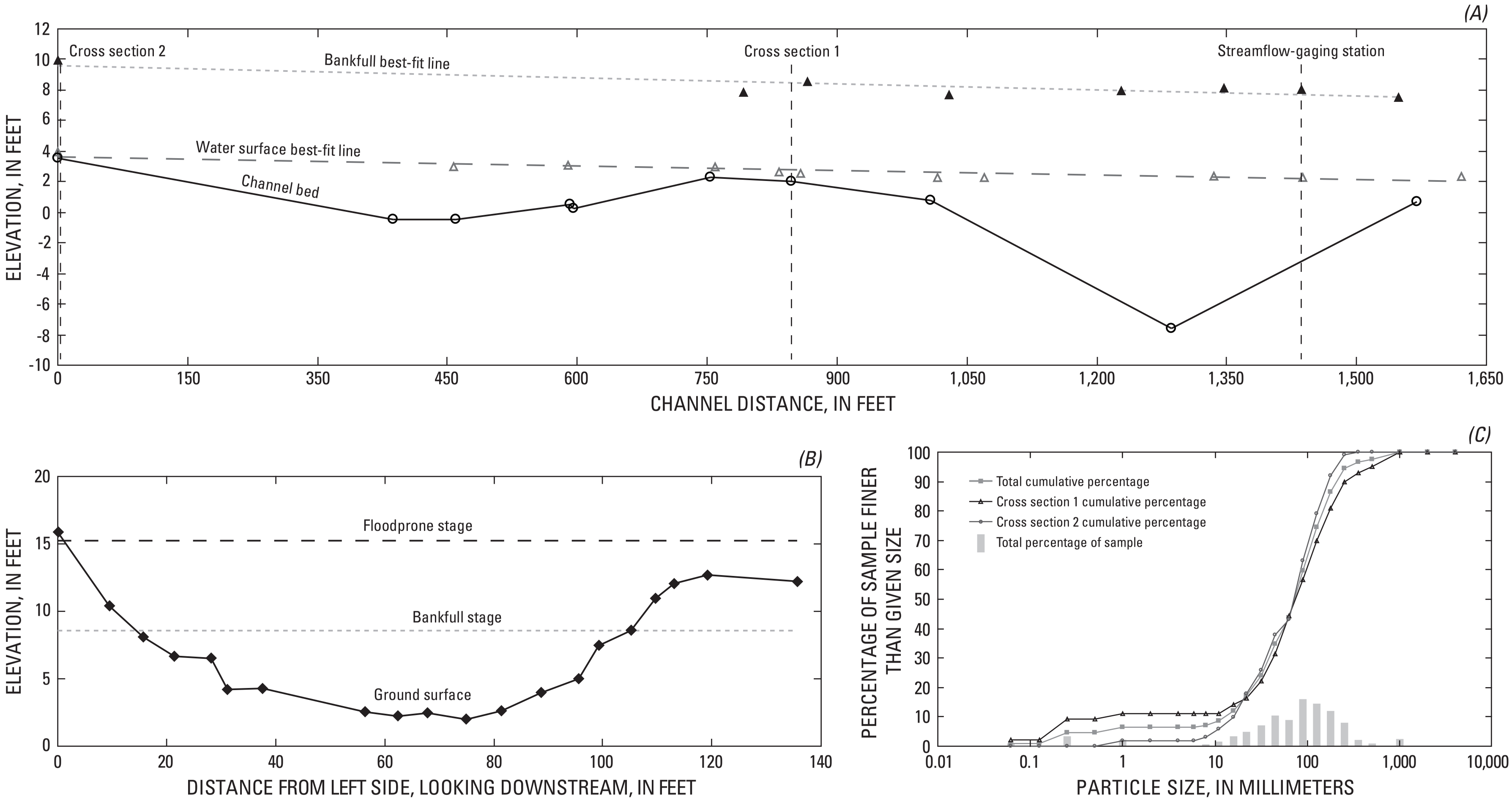

Figure A5. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Little Cacapon River near Levels, W.Va., August 26, 2004.

Station 01613160
Potomac River tributary near Hancock, Md.

View looking upstream at reach of Potomac River tributary near Hancock, Md.

The crest-stage partial-record streamflow-gaging station on Potomac River tributary was used to monitor peak gage heights and discharge during water years 1965 to 1976. The station is located just upstream of a circular concrete pipe culvert. The culvert may constrict the bankfull discharge slightly. However, backwater should be minimal due to a water-surface slope that typically exceeds 2 percent. Streamflow-measurement data indicate a combination of conventional discharge measurements and flow-through-culvert indirect discharge measurements that were used to calibrate a theoretical culvert rating for the site.

This stream was narrow and entrenched and is the only stream in the study classified as a G type according to the Rosgen (1996) classification system. However, it is very only slightly too entrenched to be a B. The bankfull channel was defined throughout the reach by field indicators such as breaks in bank slope or top of bank. The bankfull channel in the vicinity of the station location was clearly defined by these indicators. The stream bed was primarily composed of gravel and small cobble. There were some boulders and bedrock present and a large amount of woody debris. The channel was very straight and both banks were well vegetated with trees and small woody vegetation. The flood plains on either side were quite steep and wooded.

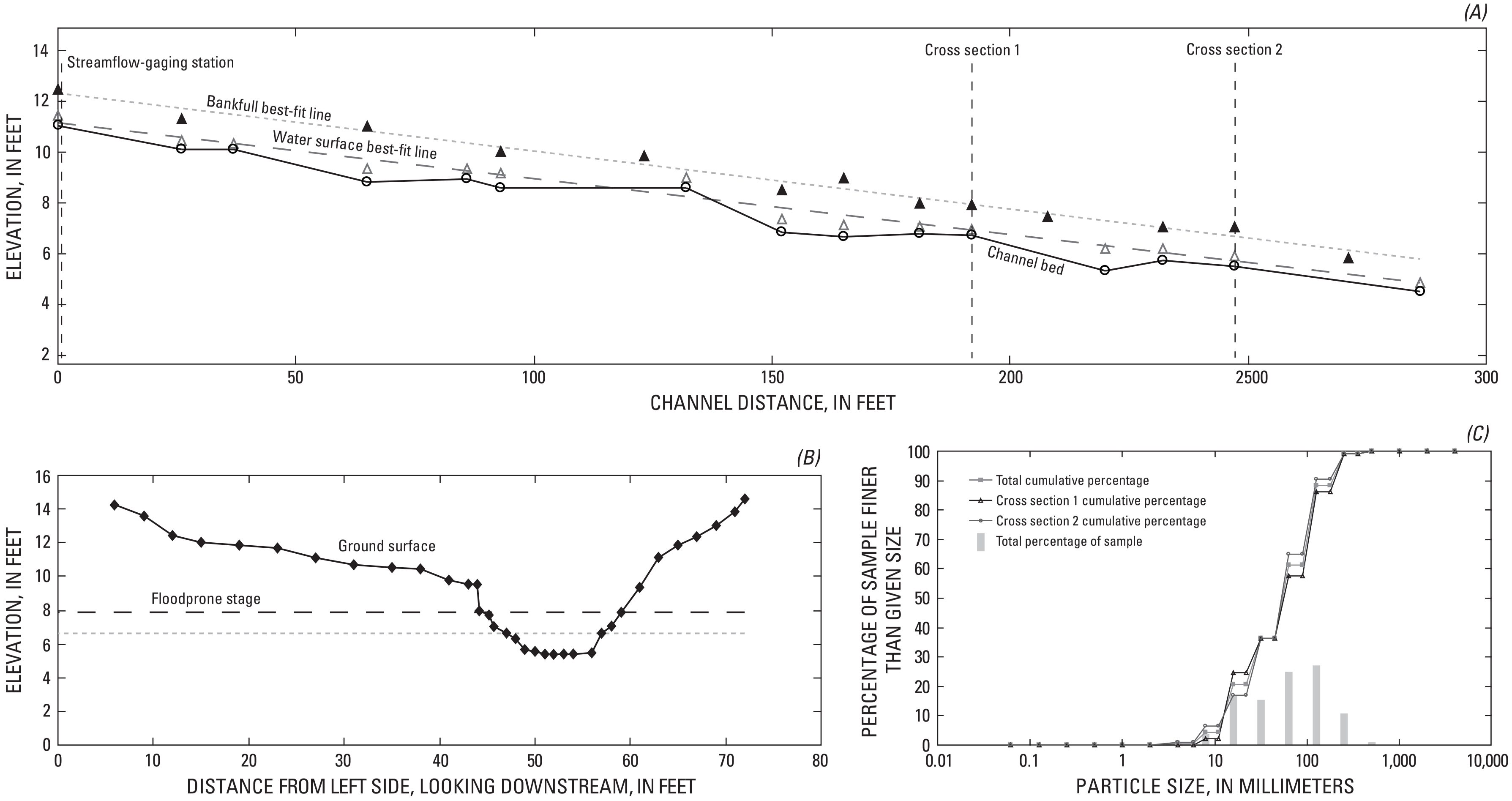

Figure A6. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Potomac River tributary near Hancock, Md., May 1, 2003.

Station 01613900
Hogue Creek near Hayfield, Va.

View looking upstream at reach of Hogue Creek near Hayfield, Va.

The streamflow-gaging station at this site was originally operated as a continuous-record station but was discontinued in 1986. Operation began again as a continuous-record station in 1992. The station is on the right bank just upstream of a concrete bridge. A tributary enters the stream between the bridge and the station. There are no bridge piers in the channel and the bridge does not appear to restrict flow at bankfull stage.

The stream was a relatively narrow riffle–run dominated system with few pools. The dominant bed material was large gravel. The slope of the channel was mild. In many places in the channel bedrock was exposed, sometimes resulting in cascades. There was significant erosion along the channel, especially where buffers were absent. Some sections, however, had as much as 15 ft of buffer with woody and herbaceous vegetation. The primary bankfull feature at the site was the top of the bank. There were few stable bankfull indicators at riffles, most of which are bedrock cascades. The downstream portion of the study reach included a sizable secondary channel. Erosion, cascade riffles, dense vegetation, and the secondary channel made identification of bankfull features at the site difficult. The flood plains were mostly flat and used for home sites and farm lands.

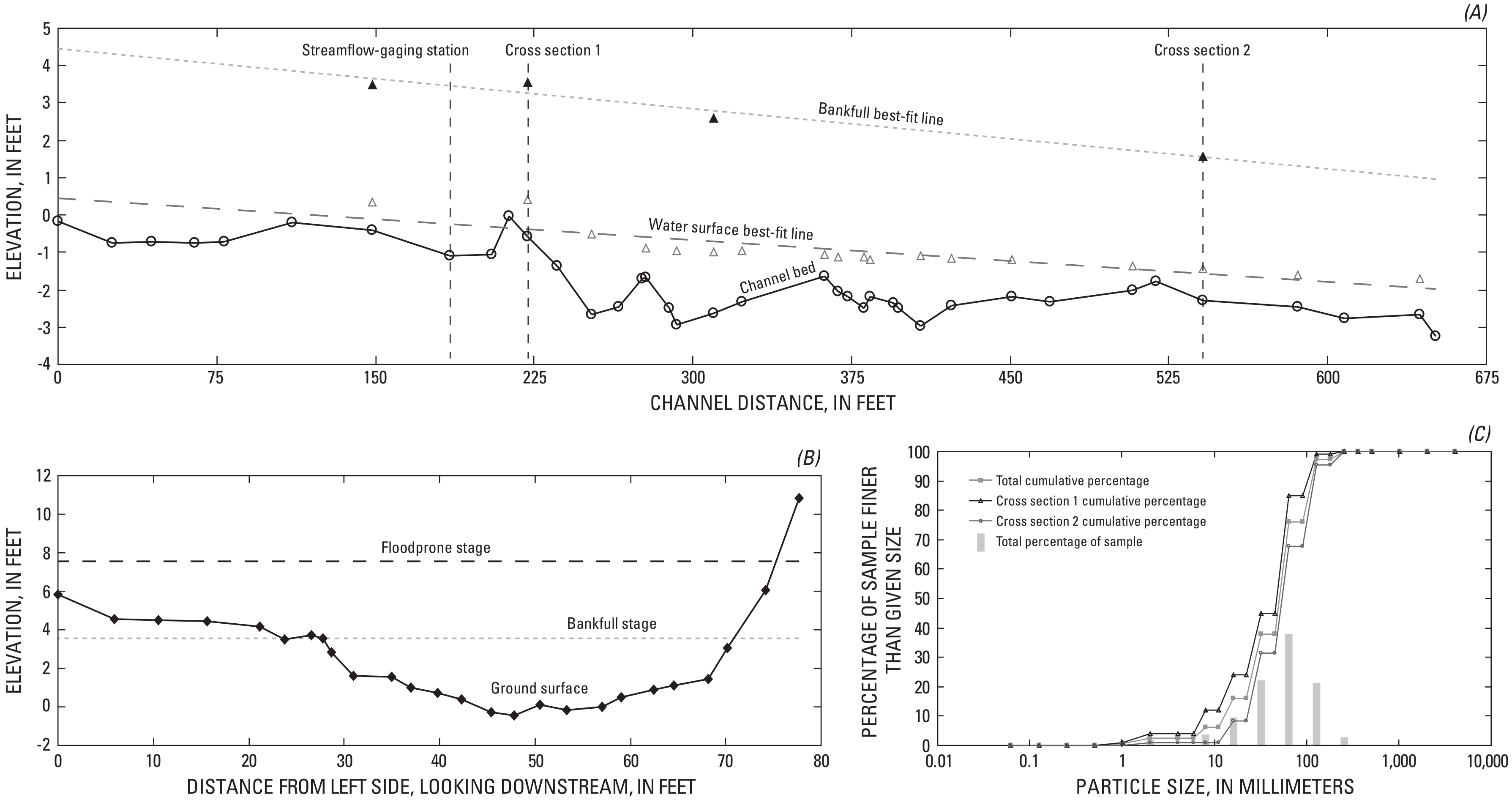

Figure A7. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Hogue Creek near Hayfield, Va., June 12, 2003.

Station 01614000
Back Creek near Jones Springs, W. Va.

No photo available

This continuous record streamflow-gaging station is approximately 50 ft downstream from a bridge that has a likely effect on the bankfull discharge due to constriction of higher flows causing a backwater effect. Therefore, the study reach did not include any points upstream from the bridge. The station has been discontinued since 1975.

Bankfull features were difficult to identify in the study reach but the most common ones used were changes in bank slope. The flood plain on the left side of the stream channel was a wide field, used as a hayfield at the time of the study. The right side of the stream channel was bordered by a steep hill. The channel banks were vegetated with trees and small woody vegetation. The study reach was sinuous and had a gentle slope. The channel was relatively narrow and deep and much of it was a long pool. The bed material was composed primarily of gravel. Some areas of exposed bedrock were observed in the study reach.

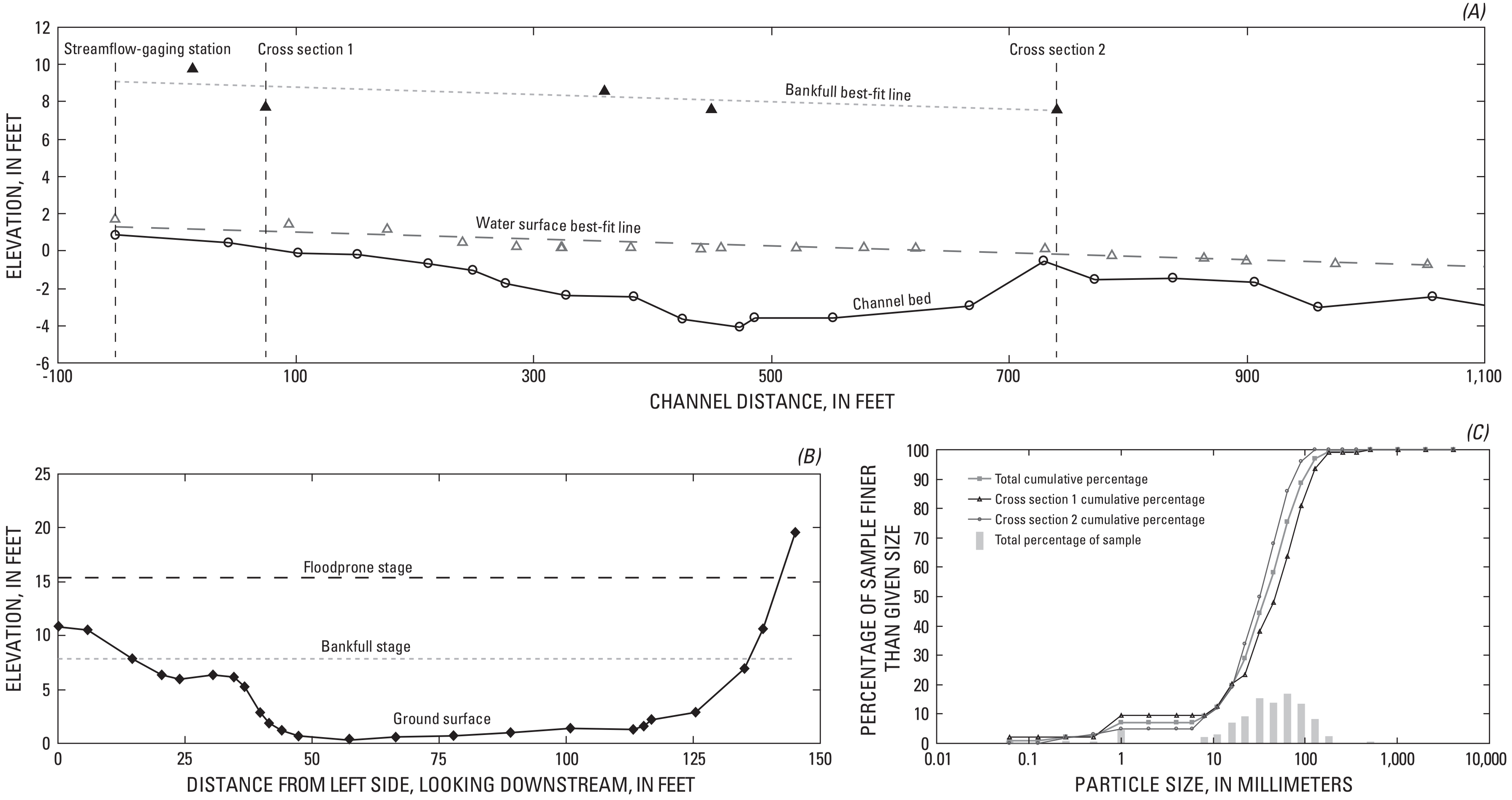

Figure A8. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Back Creek near Jones Spring, W.Va., September 17, 2003.

Station 01617800
Marsh Run at Grimes, Md.

View looking downstream at reach of Marsh Run at Grimes, Md.

The continuous-record streamflow-gaging station is located approximately 250 ft upstream from a highway bridge. The bridge does not appear to constrict the bankfull discharge.

The reach was fairly straight and ran along a road. The primary bankfull indicators at the site included breaks in bank slope. The size of the bed material varied significantly throughout the reach and included sand, gravel, cobble, and bedrock. In some locations, soft limestone bedrock was visible. At the upper end of the study reach, the channel seemed to be actively adjusting to a drop structure located upstream of a foot bridge. The banks were tree-lined in many areas, but where they were not vegetated, scouring had occurred. The study reach was relatively narrow and deep, moderately sinuous, and had a mild slope. The flood plains were flat on both sides.

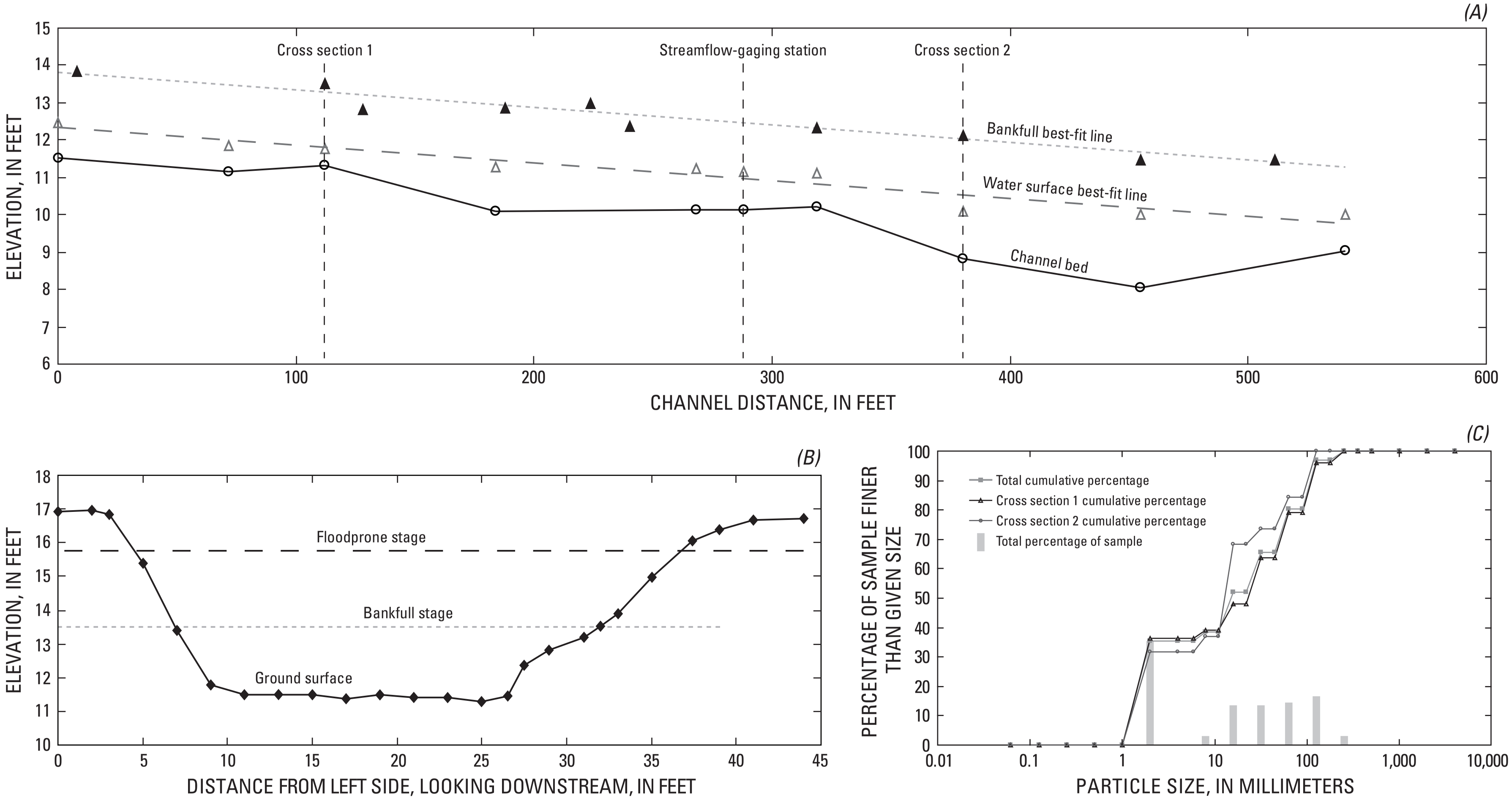

Figure A9. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Marsh Run at Grimes, Md., January 13, 2003.

Station 01619475
Dog Creek Tributary near Locust Grove, Md.

View looking upstream at reach of Dog Creek Tributary near Locust Grove, Md.

The crest-stage streamflow-gaging station is located just upstream from a circular concrete pipe culvert. The culvert will constrict the bankfull discharge with a small amount of backwater upstream of the station. Flow-through-culvert indirect discharge measurements were used to calibrate a theoretical culvert rating.

The bankfull channel was defined throughout most of the reach by field indicators such as breaks in bank slope. The bankfull channel in the vicinity of the crest-stage streamflow-gaging station was poorly defined because of the hydraulic effects of the culvert, and a road drain near the culvert opening. The study reach began approximately 32 ft upstream of the culvert and extended upstream to a spring head, where the stream channel ends. Some bank erosion was present in the channel. The channel is relatively narrow and deep. The study reach was fairly sinuous and the slope was mild to moderate. The bed was gravel dominated and both banks were very well forested. There was no bedrock observed in the channel. The flood plains beyond the buffer were mostly flat and used as pastures.

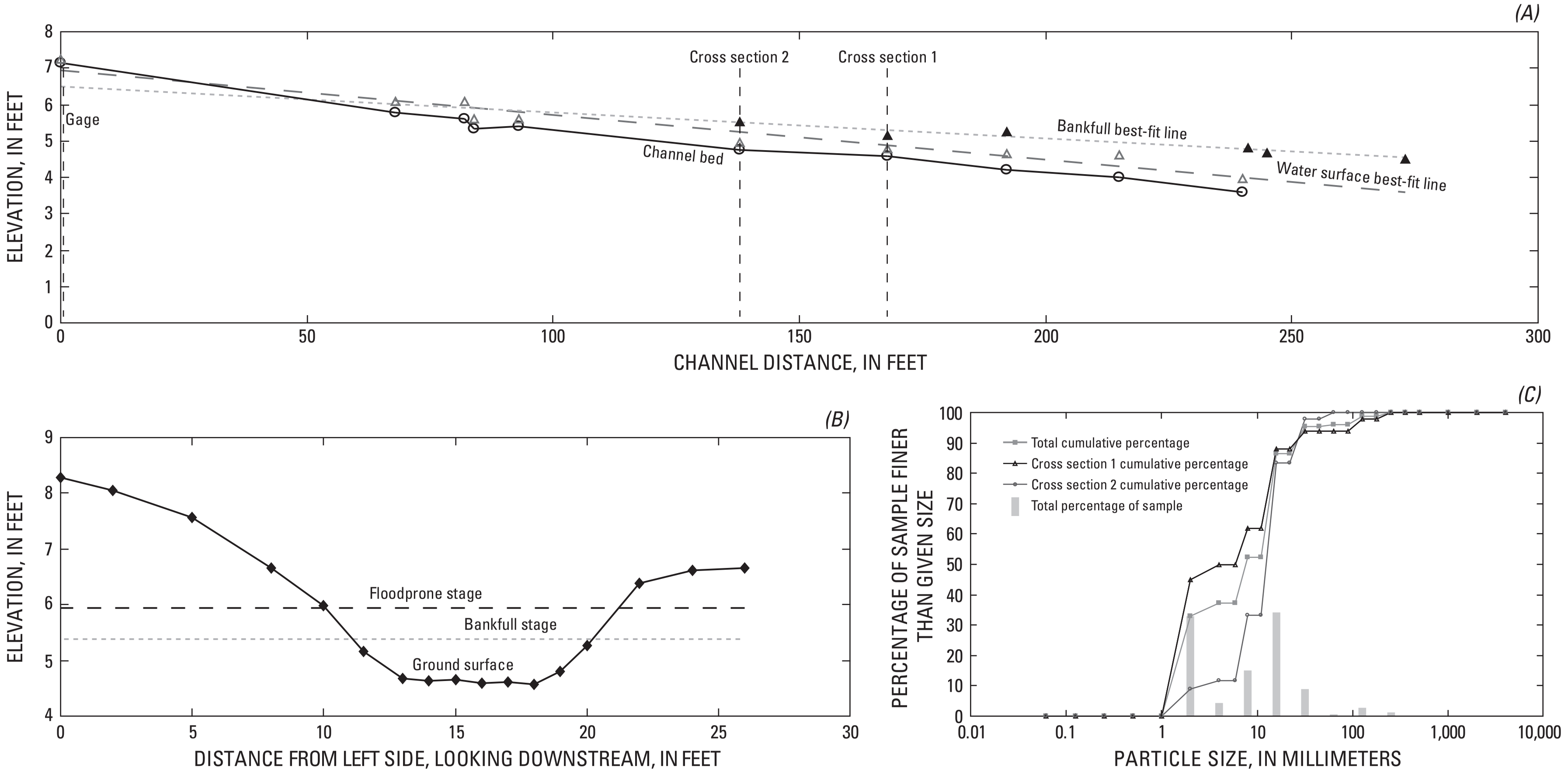

Figure A10. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Dog Creek tributary near Locust Grove, Md., January 6, 2003.

Station 01620500
North River near Stokesville, Va.

View looking downstream at reach of North River near Stokesville, Va.

This site is a continuous-record streamflow-gaging station. The station is approximately 250 ft upstream from a bridge. The bridge may cause slight backwater effect at bankfull discharge.

The channel had been modified following a major flood in 1985, and, in some sections, the top of the bank appeared to have been formed by heavy equipment. The bankfull channel was wide and shallow but poorly defined throughout most of the study reach. The main bankfull indicator used was change in bank slope. In some sections, the bankfull channel appeared to have been formed by the stream inside the larger, artificial channel. Several changes in slope were present at different elevations in the stream banks through most of the reach, and the true bankfull feature was difficult to identify. Although the banks were well vegetated with trees in some parts of the reach, they were poorly vegetated in others. In these areas, the banks were eroded and showed signs of mass wasting. The bed material was primarily cobble with no exposed bedrock. The flood plain on the right side of the stream channel was a wide forested field. The left side of the stream channel was bordered by a forested flood plain in the upstream three-fourths of the reach, and by a cliff at the downstream end of the reach. The channel was fairly straight and had a mild to moderate slope.

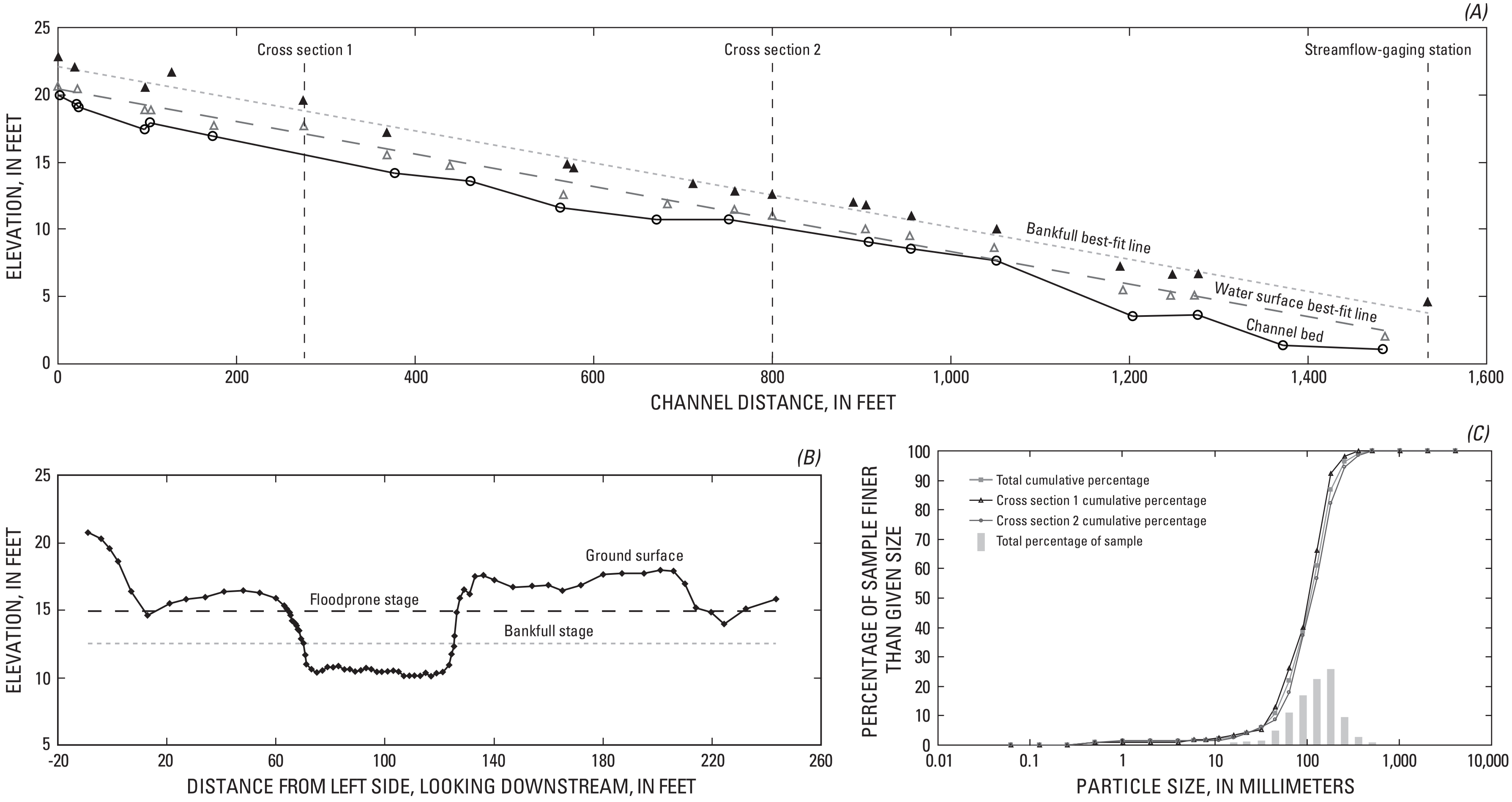

Figure A11. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material (C), in study reach of North River near Stokesville, Va., August 5, 2003.

Station 01624800
Christians Creek near Fishersville, Va.

View looking downstream at reach of Christians Creek near Fishersville, Va.

The streamflow-gaging station at this site was discontinued in 1997. It is located on the right bank in a bend adjacent to an old bridge. There is not likely any effect from the bridge on the bankfull discharge.

The site was surrounded by farm lands including an active horse farm adjacent to the upstream end of the reach. The channel was fairly narrow and deep. There was very little riparian buffer on either side of the reach because cleared farm lands extend to the channel on both sides. There was significant herbaceous and some woody vegetation on both banks. The banks are relatively stable but there were some areas of scour, especially under the bridge near the station. The flood plains on both sides were flat. The stream bed was mostly coarse gravel and small cobble with a significant number of riffles and pools. There were sections of exposed bedrock along the stream bed throughout the reach. Many of the riffles were located in bends and had adjacent gravely point bars. The primary bankfull indicator at the site was the top of the bank. The study reach had a few mild bends but was mostly straight. The slope was mild.

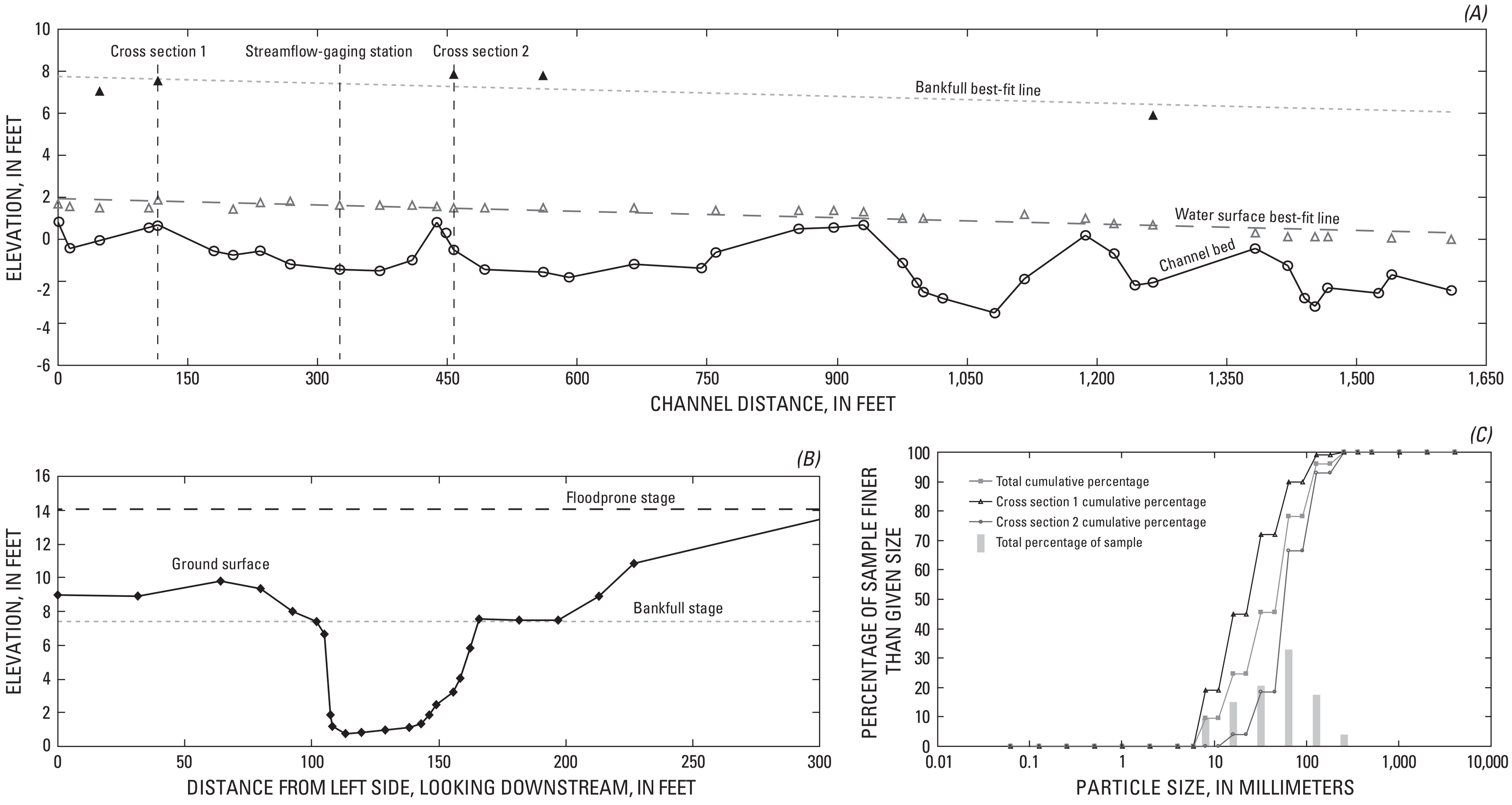

Figure A12. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Christians Creek near Fishersville, Va., November 3, 2003.

Station 01627500
South River at Harriston, Va.

View looking upstream at reach of South River at Harriston, Va.

The streamflow-gaging station at this site is located approximately 100 ft downstream of a highway bridge. The bridge may impede high flows somewhat, but should not cause a significant backwater effect at bankfull discharge. The study reach did not include the station location because of a deep, unwadable pool at the bridge.

The study reach was a relatively wide, shallow, riffle–run dominated system with large boulders and outcrops of bedrock. There was also a significant amount of cobble bed material throughout the reach. The channel banks were densely vegetated on either side with trees and other woody and herbaceous vegetation and there was little indication of erosion. The flood plains were mostly flat and cleared for farm and residential use beyond the buffers. The reach was straight except for one large bend and the slope was mild. The primary bankfull features throughout the site were the top of bank or a bench feature below a terrace.

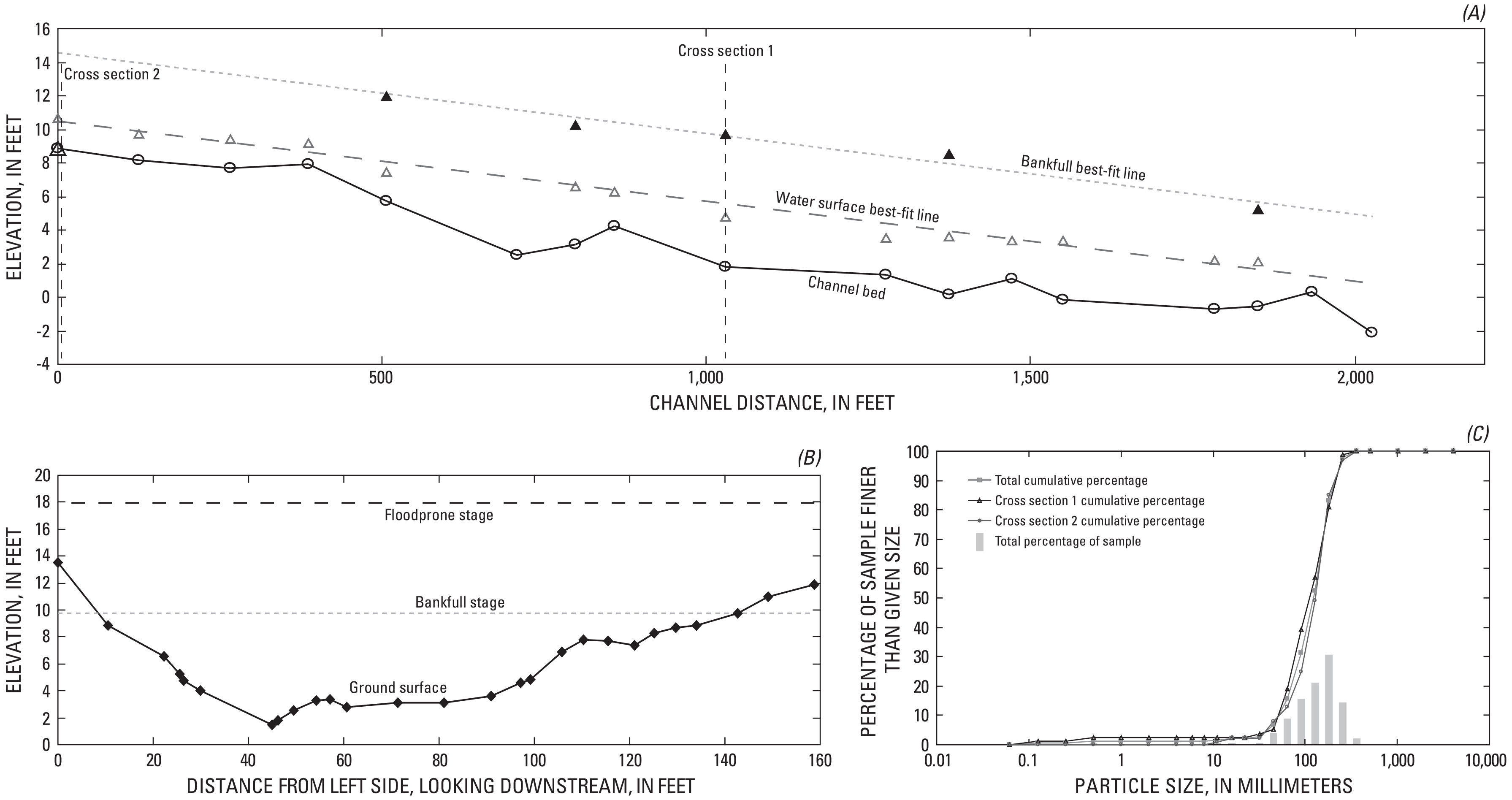

Figure A13. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of South River at Harriston, Va., July 8, 2004.

Station 01632000
North Fork Shenandoah River at Cootes Store, Va.

View looking upstream at reach of North Fork Shenandoah River at Cootes Store, Va.

The continuous record streamflow-gaging station is located on the left bank near a bridge. The bridge deck is far above the water surface but there are two piers in the channel. The bridge may cause minimal backwater effects on bankfull flows.

The study reach was wide and relatively deep. The width of the riparian buffers on either side varied and consisted of trees, and small woody and herbaceous vegetation. The banks were relatively stable but there were some areas of scour, especially under the bridge near the station. The stream bed was mostly coarse gravel and small cobble with a significant number of riffles and pools. The downstream section was a very long, deep pool created by a natural dam held up by bedrock. There were sections of exposed bedrock along the stream bed throughout the reach. There were point bars and mid-channel bars of cobble throughout the reach. The primary bankfull indicator at the site was the top of the bank. The flood plains were gently sloping and became flat farther from the channel. The study reach was surrounded by development including an auto repair shop. The upstream section was adjacent to a field with row crops. The study reach was very straight and the slope was mild.

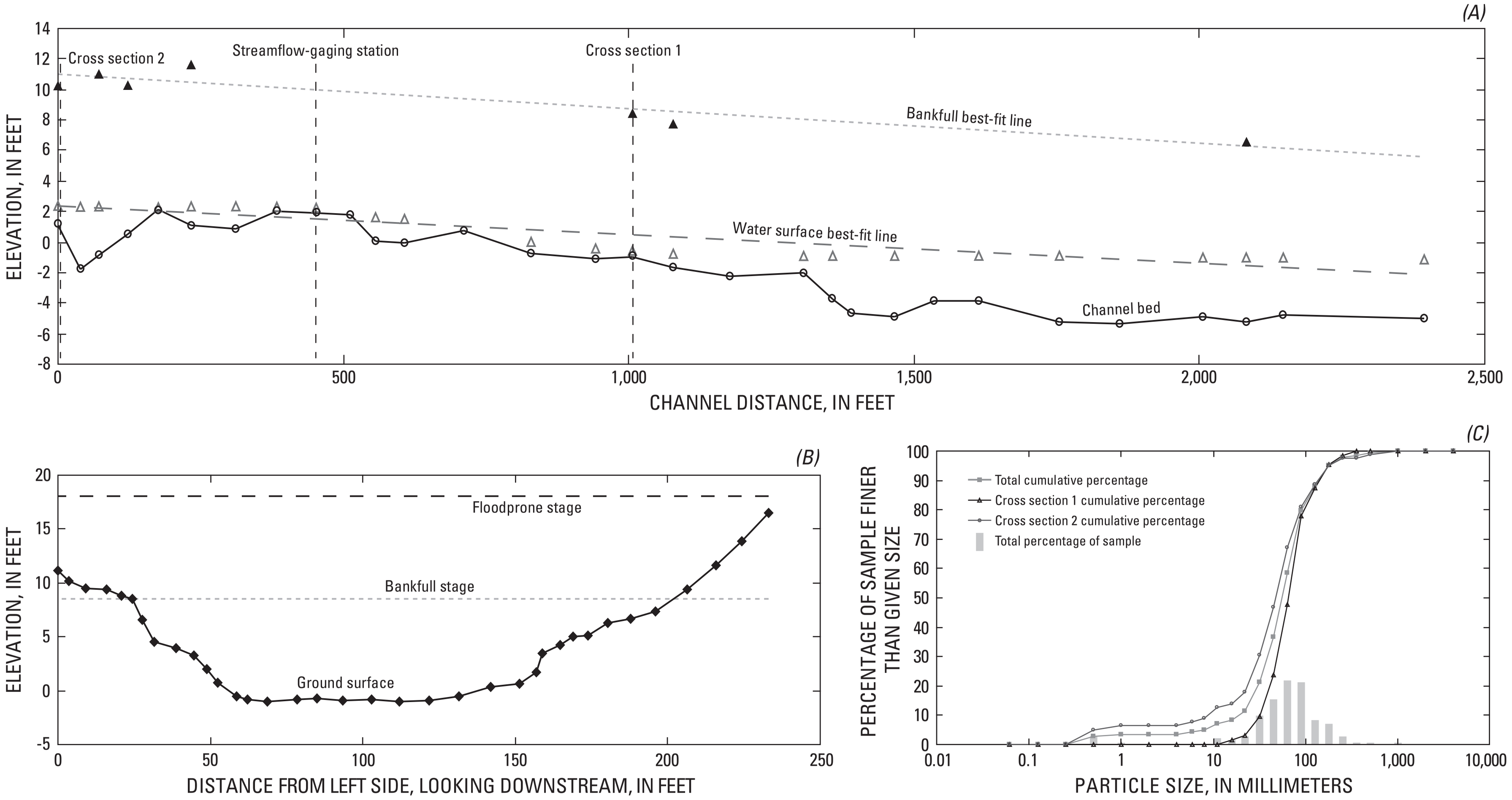

Figure A14. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of the North Fork Shenandoah River at Cootes Store, Va., August 9, 2004.

Station 01632082
Linville Creek at Broadway, Va.

View looking upstream at reach of Linville Creek at Broadway, Va.

This continuous-record streamflow-gaging station is located on the left bank approximately 200 ft downstream of a bridge. The bridge is a steel suspension bridge and is not likely to impact flows.

The channel was a fairly straight, bedrock-controlled channel with some cobbles and gravel. A large terrace ran along the left side of the channel. The main bankfull features were a bench below the top of the bank in places where the stream is entrenched, and the top of the bank in other places. The banks of the channel were poorly vegetated with sparse trees and grass. However, very little bank erosion was observed. The flood plain was flat and cleared on both sides. The upstream portion of the reach ran next to a factory that is situated approximately 300 ft upstream of the bridge. The study reach was very straight and had a mild slope.

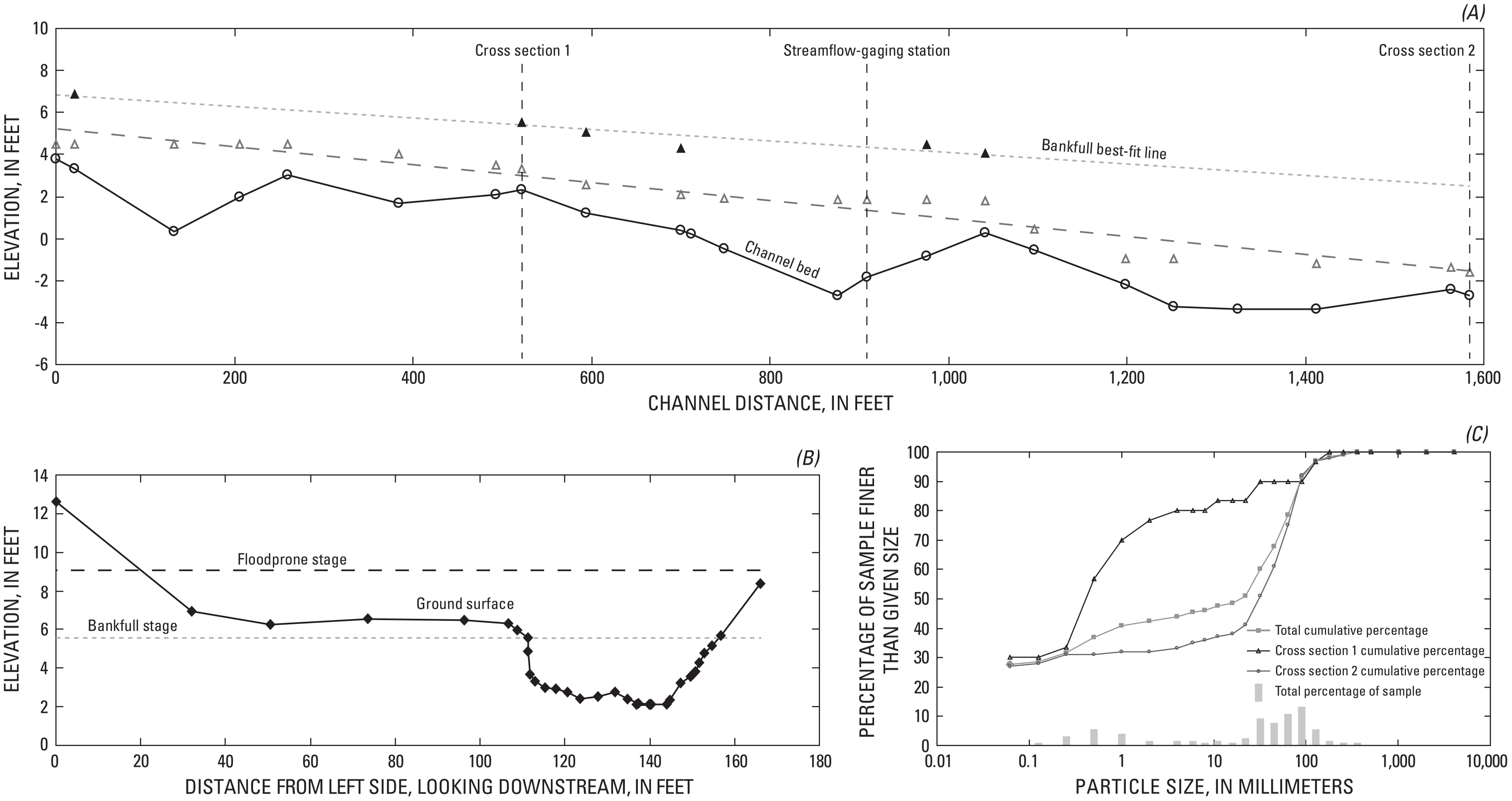

Figure A15. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Linville Creek at Broadway, Va., February 1, 2004.

Station 01632900
Smith Creek near New Market, Va.

View looking upstream at reach of Smith Creek near New Market, Va.

This streamflow-gaging station is located just upstream of a highway bridge. The bridge has a pier at both edges of the stream that does not likely cause a significant backwater effect.

The stream was a fairly wide, shallow channel with nearly vertical banks on both sides. The banks were fairly stable but there was evidence of mild erosion. The stream bed was composed of bedrock covered with gravel and some small cobble. Many separate riffles were present in the reach surveyed with fewer well-defined pools. A large pool at the downstream end of the survey was too deep to wade (possibly 5 to 6 ft deep). The stream has mild to moderate sinuosity at this location and a mild slope. A 60- to 150-ft buffer of trees and small woody and herbaceous vegetation ran along the entire left bank, but the right bank had much less riparian vegetation. Crop fields extended to within 20 ft of the left bank. The primary bankfull indicator at the site was the top of the bank. At some locations, the top of the bank was 1 to 2 ft lower than most sections. A moderately sloped flood plain existed on the left side while the right flood plain was fairly flat.

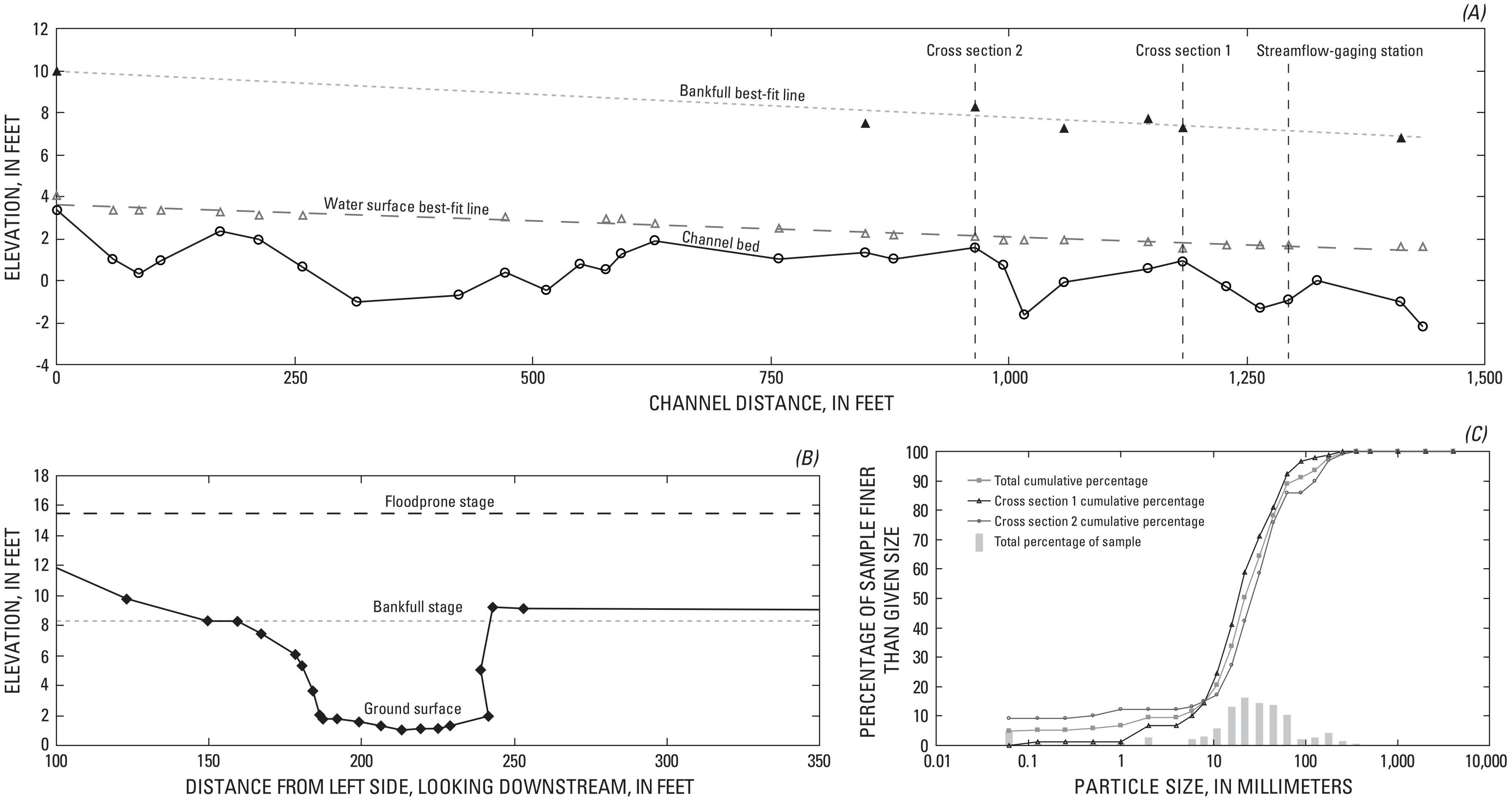

Figure A16. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Smith Creek near New Market, Va., November 4, 2003.

Station 01632970
Crooked Run near Mt. Jackson, Va.

View looking upstream at reach of Crooked Run near Mt. Jackson, Va.

This site has a crest-stage streamflow-gaging station on both the upstream and downstream side of a set of four box culverts. The right two box culverts are silted in and the right side of the channel downstream of the culverts has narrowed so that only two of the box culverts convey any of the flow. The culverts are likely to restrict flow at higher discharges including bankfull.

The stream channel downstream of the culverts had mostly stable banks and was more narrow and deep than the upstream section. Upstream of the culverts, the channel was less stable with significant erosion on the banks and short sections of failing banks. Most of the channel had pools, riffles, runs, and glides. Approximately 600 ft downstream of the culverts, the slope of the channel increased significantly and became dominated by riffle and run bed morphology. The stream was not surveyed beyond this point. The study reach bed material was mostly gravel with some cobble and a few instances of exposed bedrock. Most of the length of the study reach had a 10- to 20-ft wide buffer of herbaceous and woody vegetation. Land beyond the buffer on both sides of the channel was mostly flat and has been cleared for use as pastures. The primary bankfull indicators along the reach were the top of bank and a stable bankfull bench. The study reach was relatively narrow and deep, very straight, and had a mild slope.

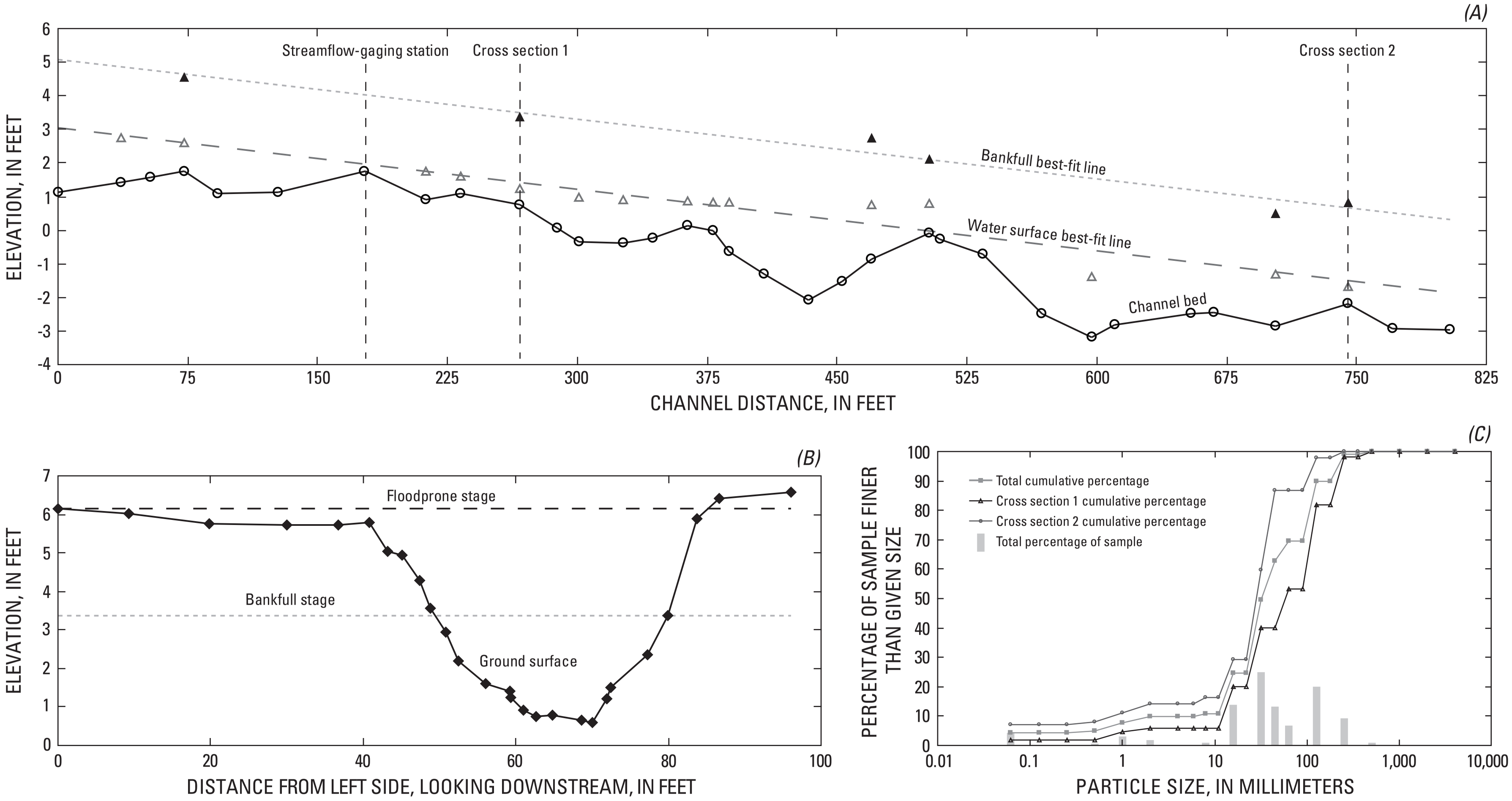

Figure A17. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Crooked Run near Mt. Jackson, Va., June 13, 2003.

Station 01633650
Pugh’s Run near Woodstock, Va.

View looking upstream at reach of Pugh’s Run near Woodstock, Va.

This site has a crest-stage streamflow-gaging station installed on both the upstream and downstream side of a box culvert. The rating for this station is theoretical, which results in a greater uncertainty in the relation of stage to discharge.

There were strong bankfull features at the site, primarily the top of a stable bench. The study reach was straight, fairly wide and shallow and had predominantly very large gravel and small cobble bed material. The overall slope of the stream was moderate but there was a break in slope where the gradient became less steep about halfway through the study reach. The stream was a riffle–run dominated system. Of the few pools present, the pool just downstream of the culvert was by far the largest in area and the deepest. Sections of the channel had exposed bedrock forming cascades. In these sections the local slope was very steep. Both sides had buffers with plentiful woody and herbaceous vegetation and flat to gently sloping floodplains. Portions of the banks above the bankfull stage had significant erosion, most likely caused by bank sloughing. Below bankfull stage there was little erosion.

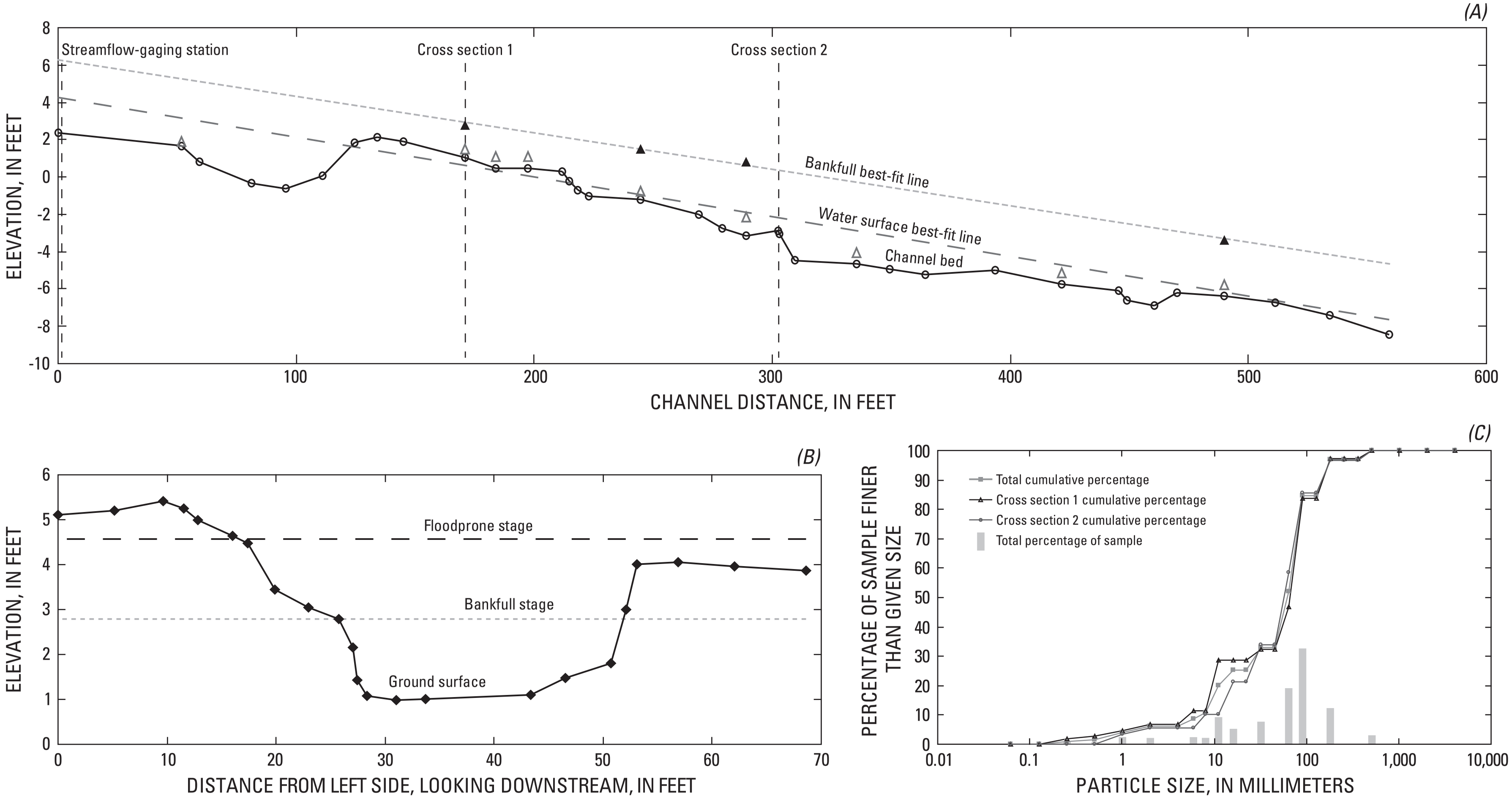

Figure A18. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Pugh's Run near Woodstock, Va., June 12, 2003.

Station 01634500
Cedar Creek near Winchester, Va.

View looking upstream at reach of Cedar Creek near Winchester, Va.

The streamflow-gaging station at this site is located 1600 ft upstream of the bridge. This station is a long running continuous-record station.

Between the bridge and the station there was a section of gorge with large boulders in the channel and deep, slow-moving water. The gorge ended approximately 750 ft downstream of the bridge. The channel upstream of the gorge for several thousand feet was similar to the section near the station. The banks through the study reach were fairly high, indicating that the channel was somewhat incised. There was significant erosion on the banks, making it difficult to find bankfull features. The only bankfull feature found was a break in slope near the top of the bank. The channel had a riparian buffer on either side 5 to 20 ft wide which consisted of woody and herbaceous vegetation. On either side of the channel, pasture lands extended for hundreds of feet beyond the buffers. The bed material in the channel was primarily large gravel and small cobbles. No exposed bedrock was observed. The stream was a riffle/run dominated system with few pools. At the downstream end of the study reach a large steep riffle ended in a long, deep section of pool. The stream was fairly straight through the study section and had a mild gradient.

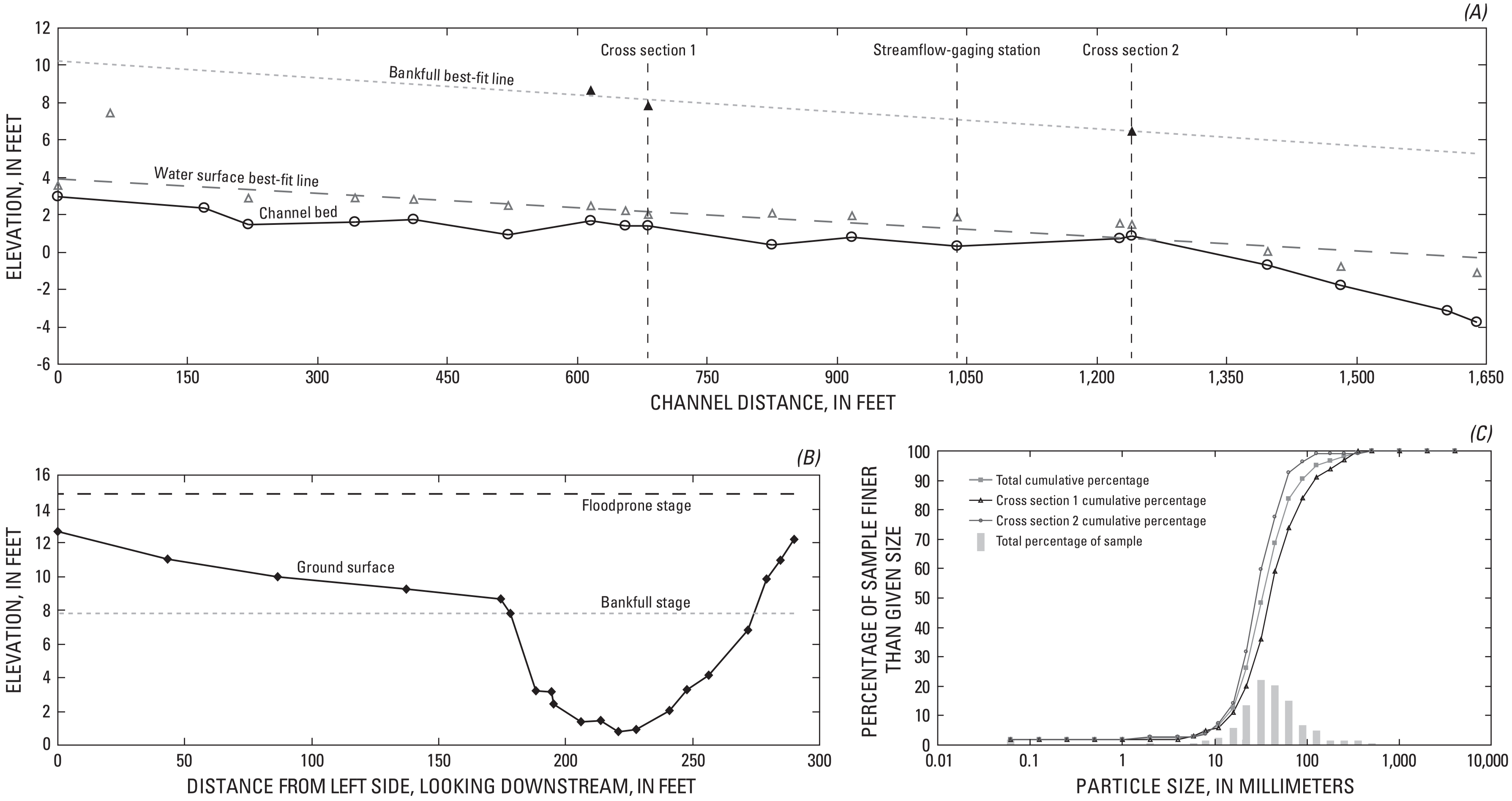

Figure A19. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Cedar Creek near Winchester, Va., January 21, 2004.

Station 01635500
Passage Creek near Buckton, Va.

View looking downstream at reach of Passage Creek near Buckton, Va.

The continuous-record streamflow-gaging station at this site is approximately 300 ft upstream of a bridge which is not likely to impede flow at bankfull discharge.

The stream was fairly deep, including a pool at the bridge that was not wadable. The few riffles in the stream were long. There were very few pools. The upstream portion of the study reach was braided, though on the day of the survey only the main channel conveyed water. Bankfull features were difficult to find in the braided section. In the downstream section, near the station, the primary bankfull feature was the top of the bank. The bed material was composed primarily of cobble with some gravel, small boulders, and bedrock. Both banks were heavily vegetated with trees and other woody vegetation. The flood plains bordering the channel were mostly flat and wooded or cleared and used as a home site. There was one major bend in the study reach; otherwise it was very straight. The slope of the channel was mild.

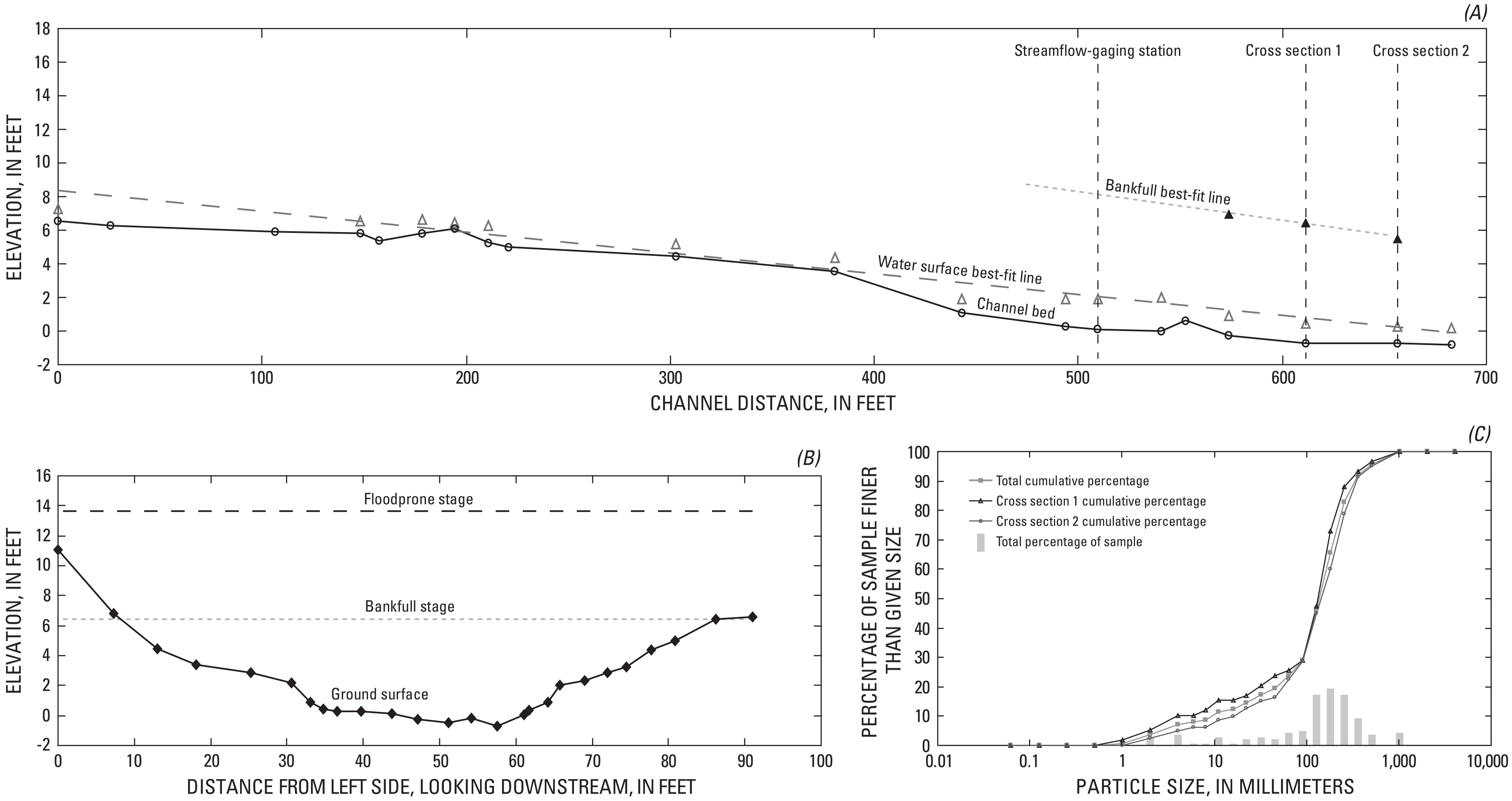

Figure A20. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of the Passage Creek near Buckton, Va., July 7, 2004.

Station 02011400
Jackson River near Bacova, Va.

View looking downstream at reach of Jackson River near Bacova, Va.

The continuous–record streamflow-gaging station at this site is approximately 2,000 ft downstream from a low-water bridge and there are no other structures in the reach.

The channel was riffle–run dominated. The bankfull channel was well defined throughout most of the reach primarily by changes in bank slope or the top of the bank. Several changes in slope were present in the stream banks through most of the reach, although a primary indicator was often clearly defined. The banks were vegetated with trees but there was little undergrowth. They were rocky and stable. The channel bed was cobble and small boulders with some bedrock outcrops. The study reach was very straight with a mild slope. The flood plains were mildly sloped and mostly forested.

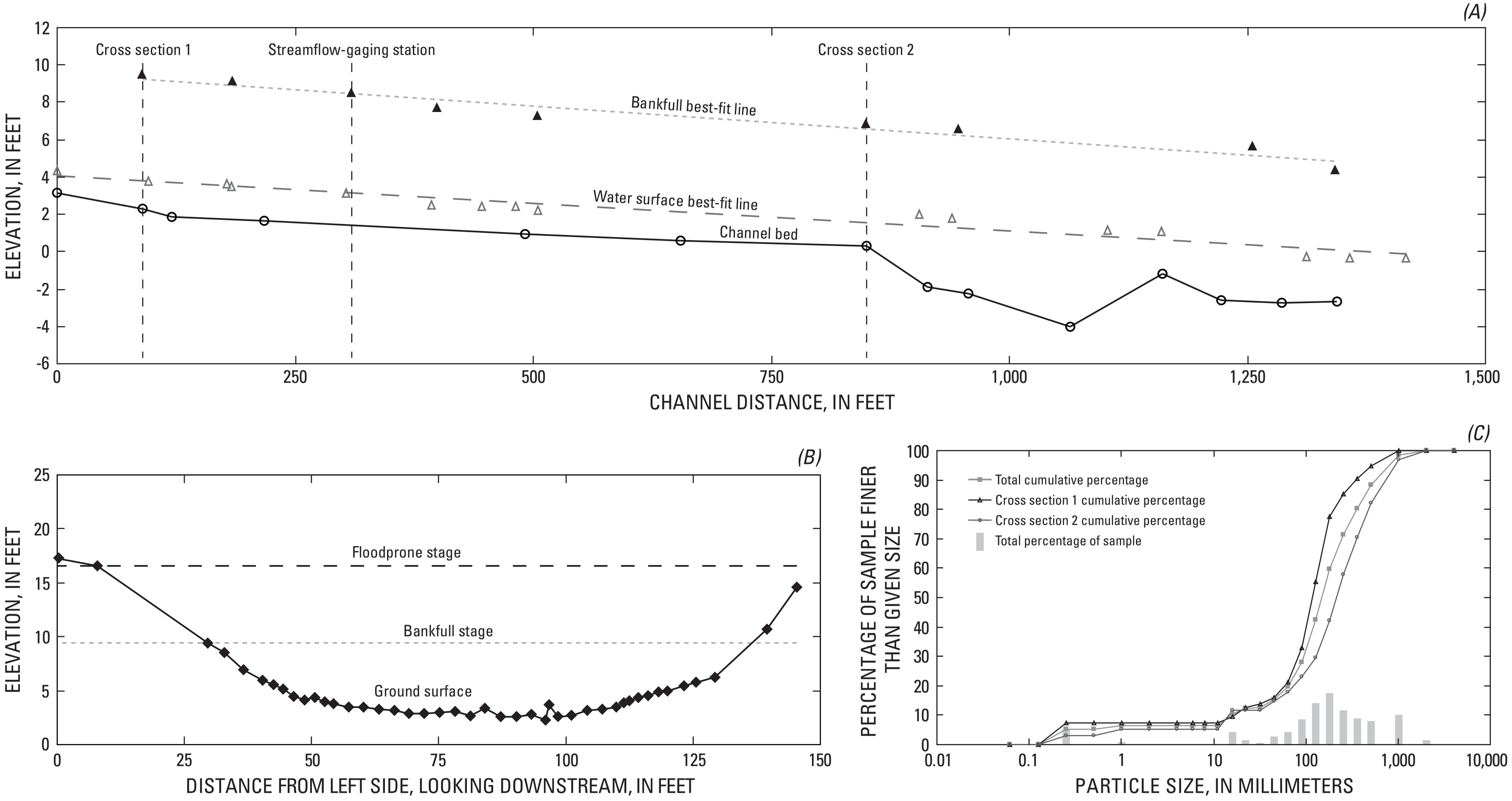

Figure A21. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Jackson River near Bacova, Va., September 18, 2003.

Station 02013000
Dunlap Creek near Covington, Va.

View looking downstream at reach of Dunlap Creek near Covington, Va.

The continuous-record streamflow-gaging station is approximately 50 ft downstream from a bridge that likely has little effect on the bankfull discharge in the survey reach.

The bankfull channel was fairly well defined throughout most of the reach primarily by changes in bank slope. Several changes in slope were present in the stream banks through most of the reach, but a consistent break was surveyed as the bankfull feature. The banks were forested with trees but there was little undergrowth. They were rocky and appeared stable. The channel bed was mostly cobble and some gravel with sections of exposed bedrock. The study reach was fairly sinuous and the slope was mild. The channel was bordered on the right side by steep hills, and on the left side by a wide, forested flood plain.

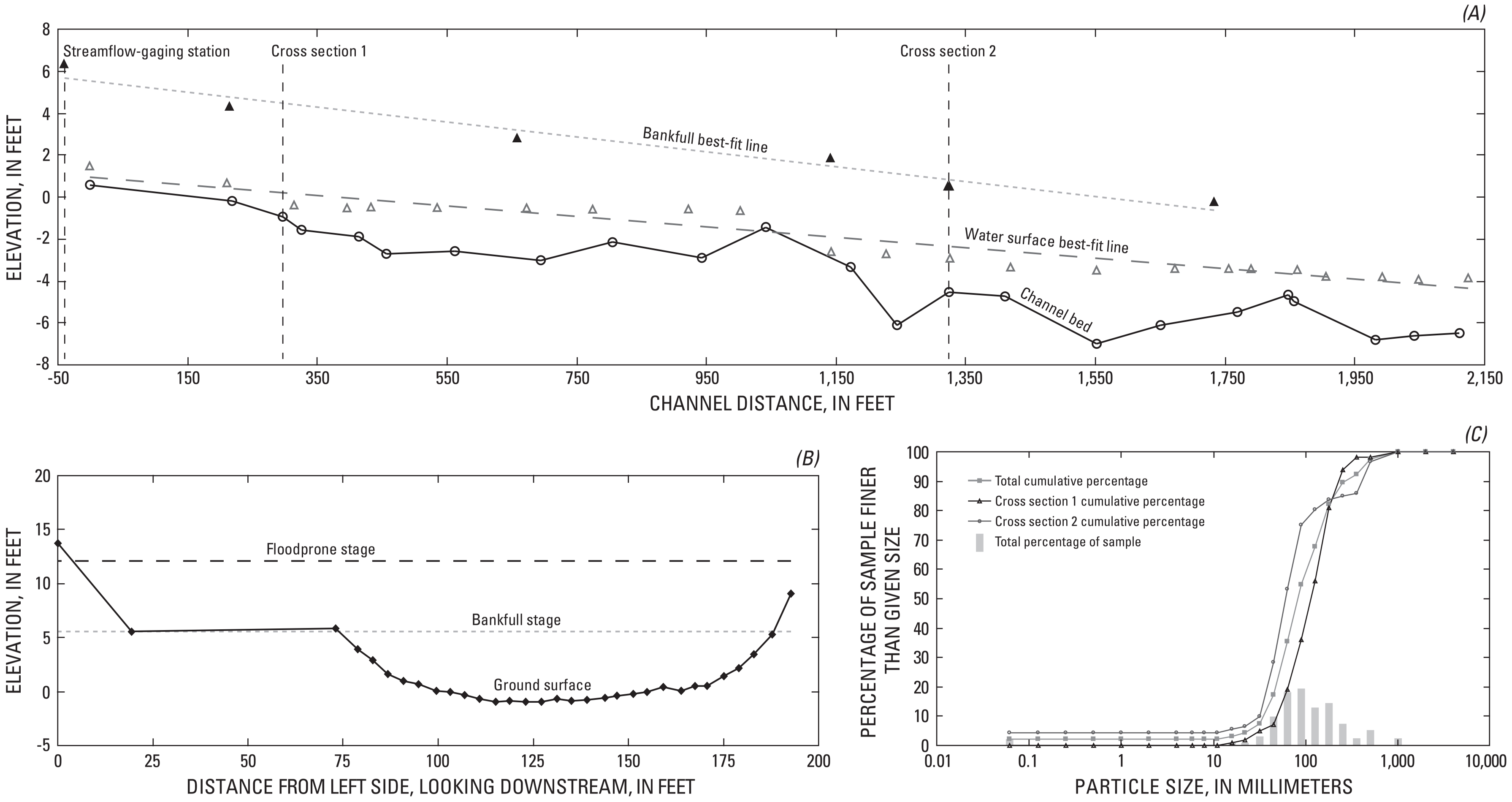

Figure A22. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Dunlap Creek near Covington, Va., August 7, 2003.

Station 02014000
Potts Creek near Covington, Va.

View looking upstream at reach of Potts Creek near Covington, Va.

The streamflow-gaging station is approximately 50 ft downstream from a bridge that likely has little effect on the stage-discharge relation at bankfull discharge.

The bankfull features were difficult to identify throughout most of the reach. Field indicators used included changes in bank slope and top of the bank. Several breaks in slope of benches were present along the banks through most of the reach. The banks were lightly forested with dense undergrowth. The banks upstream from the bridge showed little erosion, but the banks downstream from the bridge had several slumps and rotational failures. The study reach was moderately sinuous and had a mild slope. The bed material was mostly coarse gravel and cobble. The stream channel upstream from the bridge was bordered on the right side by a narrow flood plain, and on the left side by a hill with a flat shelf about 25 ft above the stream bed. The stream channel downstream from the bridge also had narrow flood plains on both sides.

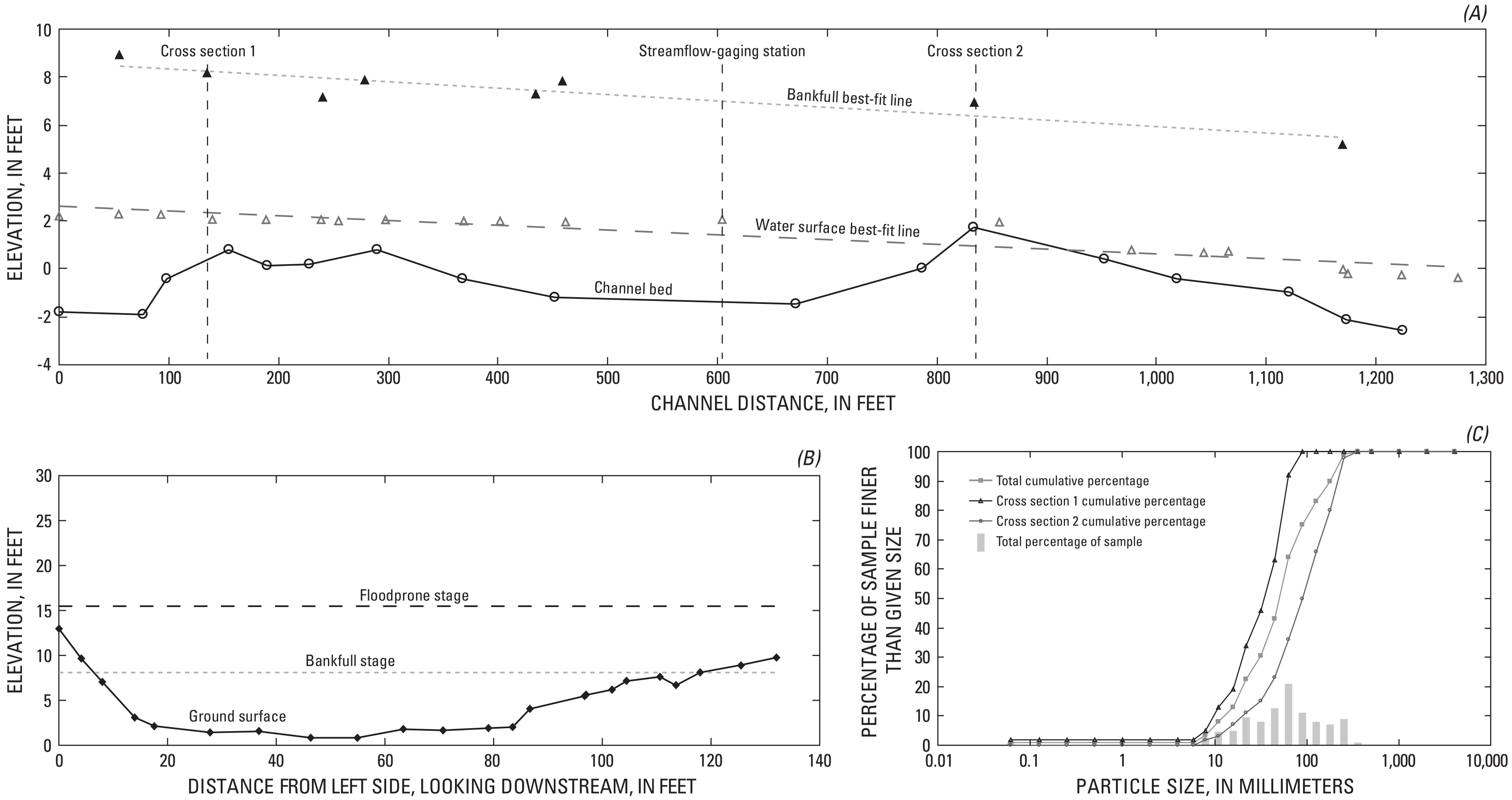

Figure A23. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Potts Creek near Covington, Va., September 16, 2003.

Station 02015600
Cowpasture River near Head Waters, Va.

View looking downstream at reach of Cowpasture River near Head Waters, Va.

The crest-stage streamflow-gaging station was attached to the downstream wing wall of the left-descending abutment of a now removed bridge. The constriction of flow at the old bridge span probably results in backwater at higher flows. The station was in operation as a crest-stage station at the time of the survey.

The bankfull channel was well defined below the abandoned bridge abutment, but not above the abutment, due to construction of a newer bridge and cattle grazing in the riparian zone and channel. The bankfull channel was well defined throughout most of the reach by field indicators such as changes in substrate and bank slope. The banks showed little erosion. The stream channel was bordered on the right side by a flood plain, which was wooded and with a dense understory. The stream channel was bordered on the left side by a hillside which became very steep in the lower section of the reach. The study reach was fairly sinuous and had a mild slope. The bed material was primarily cobble. No bedrock was observed in the study reach.

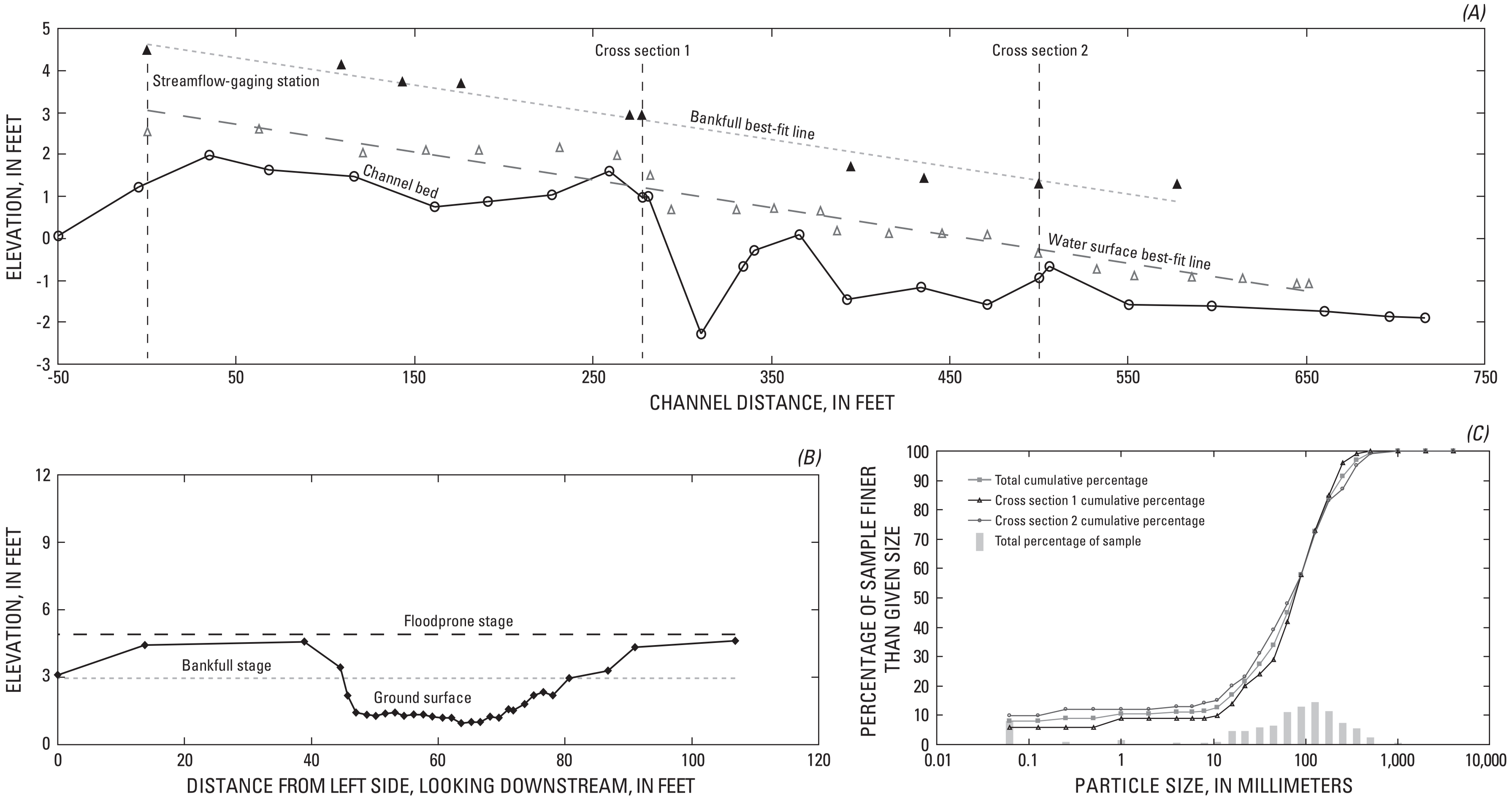

Figure A24. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Cowpasture River near Head Waters, Va., July 23, 2003.

Station 02015700
Bullpasture River at Williamsville, Va.

View looking downstream at reach of Bullpasture River at Williamsville, Va.

The continuous-record streamflow-gaging station at this site is approximately 50 ft downstream from a highway bridge. The bridge likely has little backwater effect on the bankfull discharge at the station, but may create substantial backwater upstream from the bridge. The study reach was discontinued approximately 200 ft upstream of the bridge.

The bankfull channel was well defined throughout most of the reach by field indicators such as changes in bank slope and top of the bank. Several changes in slope were present in the stream banks through most of the reach, but on the right bank, the top of the bank was especially distinct in the downstream third of the reach. The banks were rocky and lightly forested with dense undergrowth. The stream channel was bordered on the right side by a flood plain, which contained some houses and yards at the time of the survey. The stream channel was bordered on the left side by a hill. The bed materials were large cobble and small boulders. Bedrock was observed in the channel bed in sections of the reach. The study reach was moderately sinuous and the gradient was mild.

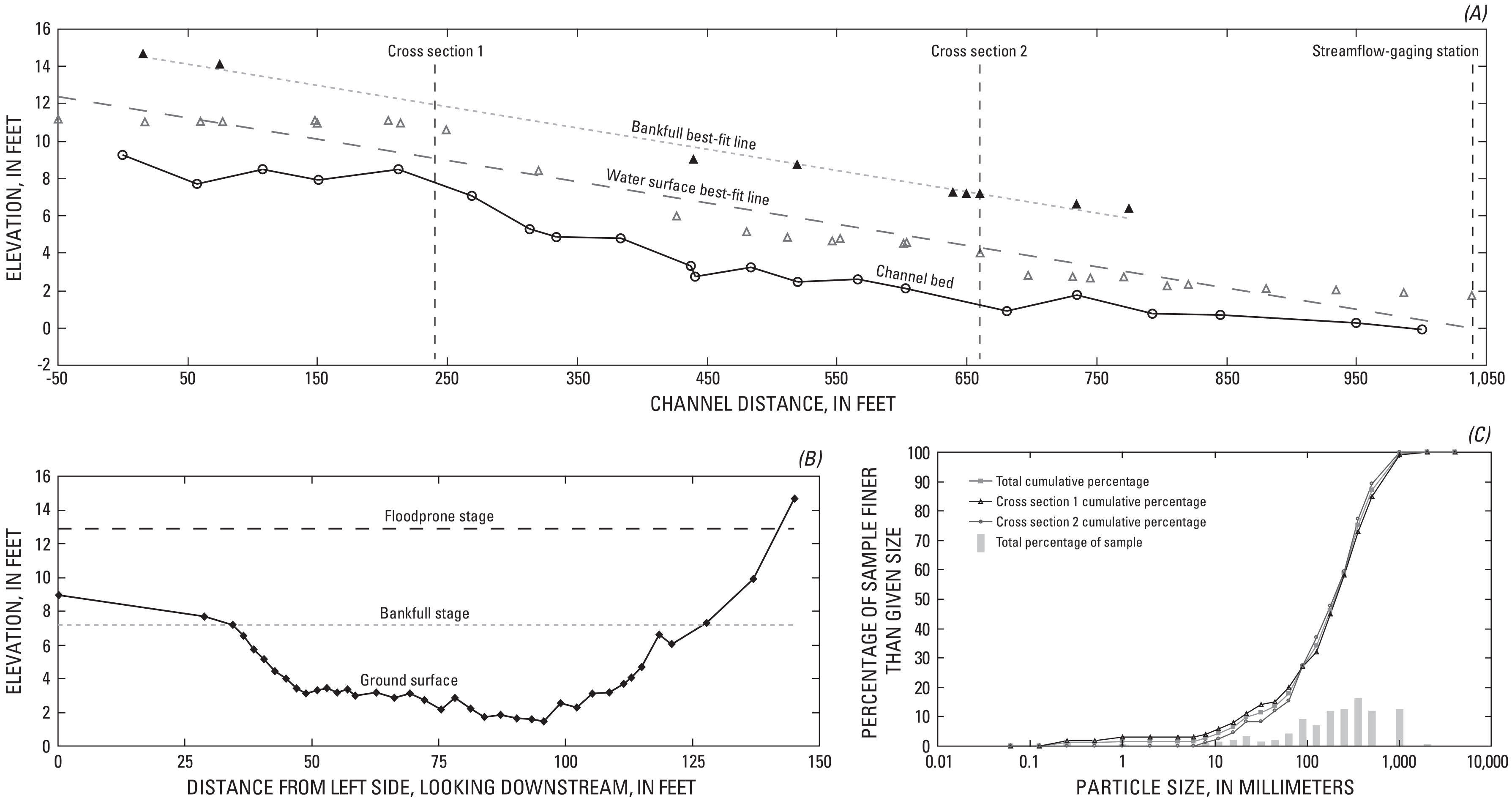

Figure A25. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Bullpasture River at Williamsville, Va., July 21, 2003.

Station 02018500
Catawba Creek near Catawba, Va.

View looking downstream at reach of Catawba Creek near Catawba, Va.

The continuous-record streamflow-gaging station is approximately 150 ft downstream from a bridge that likely has little effect on the stage-discharge relation at bankfull discharge, and about 200 ft upstream from another bridge that may create a substantial backwater at bankfull discharge. The survey reach included the first bridge, but not the second.

The bankfull channel was well defined throughout most of the reach by field indicators such as changes in bank slope, although the bankfull channel was poorly defined in the section between the two bridges. Several changes in slope were present in the stream banks through most of the reach, but a primary feature, a distinct change in slope near the top of the bank, was present in most of the reach. The banks were rocky, with numerous bedrock outcrops. The banks were forested with trees and other woody vegetation. The banks showed little erosion, except for a section of the left bank in the upstream third of the reach, which was adjacent to a highway and protected by riprap. Except for the road, the flood plains were undeveloped. The bed material at the site was exposed bedrock, gravel, and cobble. The slope of the study reach was mild and the reach was moderately sinuous.

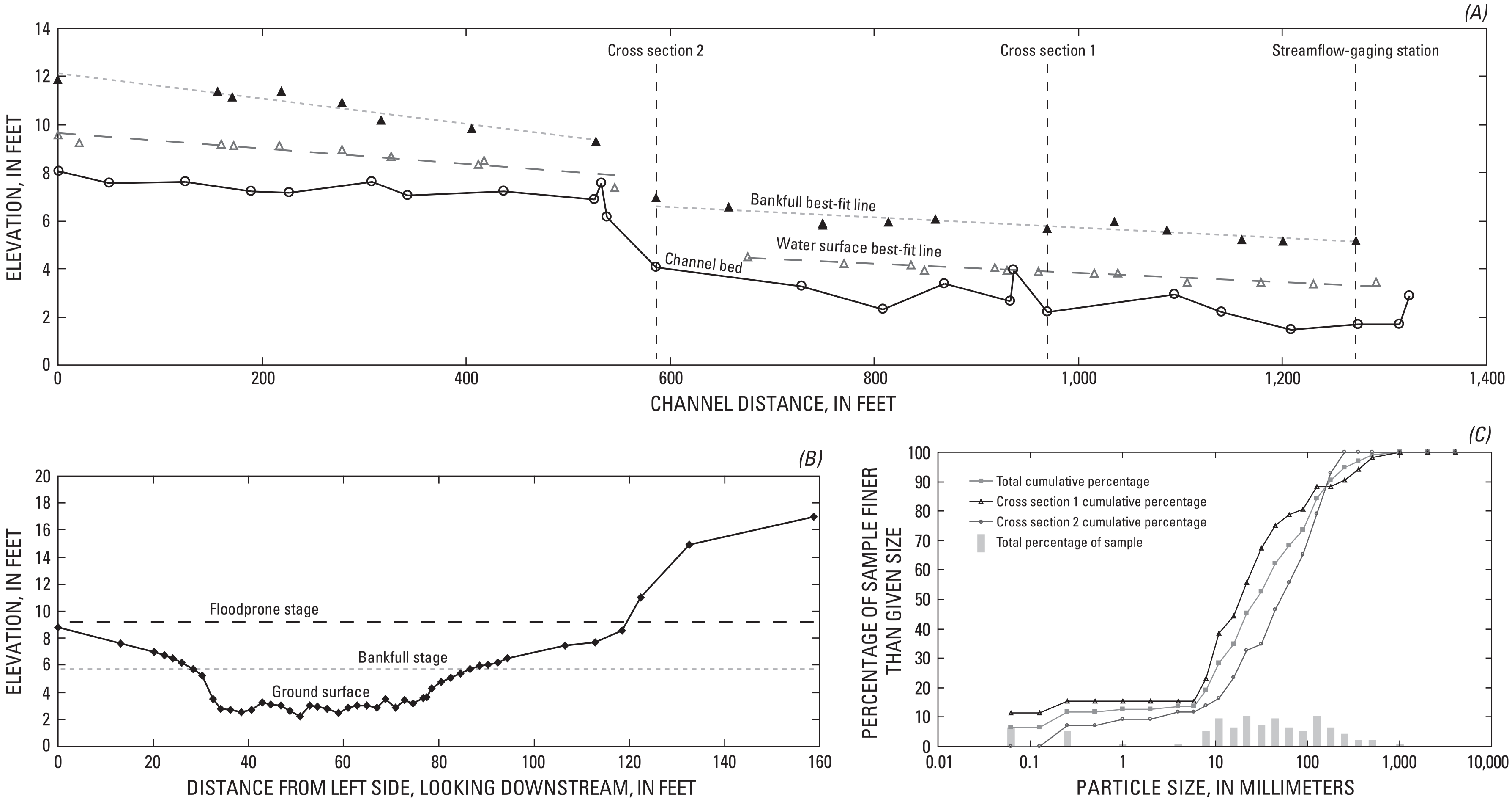

Figure A26. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Catawba Creek near Catawba, Va., August 5, 2003.

Station 02020100
Renick Run near Buchanan, VA

View looking upstream at reach of Renick Run near Buchanan, Va.

The crest-stage streamflow-gaging station at this site was attached to the upstream wingwall of a box culvert. The culvert likely has a substantial backwater effect on the stage-discharge relation at bankfull discharge. The rating for this station is theoretical. Only eight measurements have been made at the site, and all were made for discharges below the bankfull discharge.

The most common bankfull indicator at the site was the top of the bank. The channel bed was gravel and cobble and had numerous bedrock outcrops. The flood plains and banks had been cleared of all vegetation except for grass and a few scattered trees. The banks showed few signs of erosion, except for a section of cut bank on the left bank in the upstream third of the reach. The stream channel was bordered by gently sloping flood plains on both sides. The flood plain on the right side was used as a pasture at the time of the survey, and the flood plain on the left side was used for houses and yards. The study reach was fairly straight and had a moderate slope.

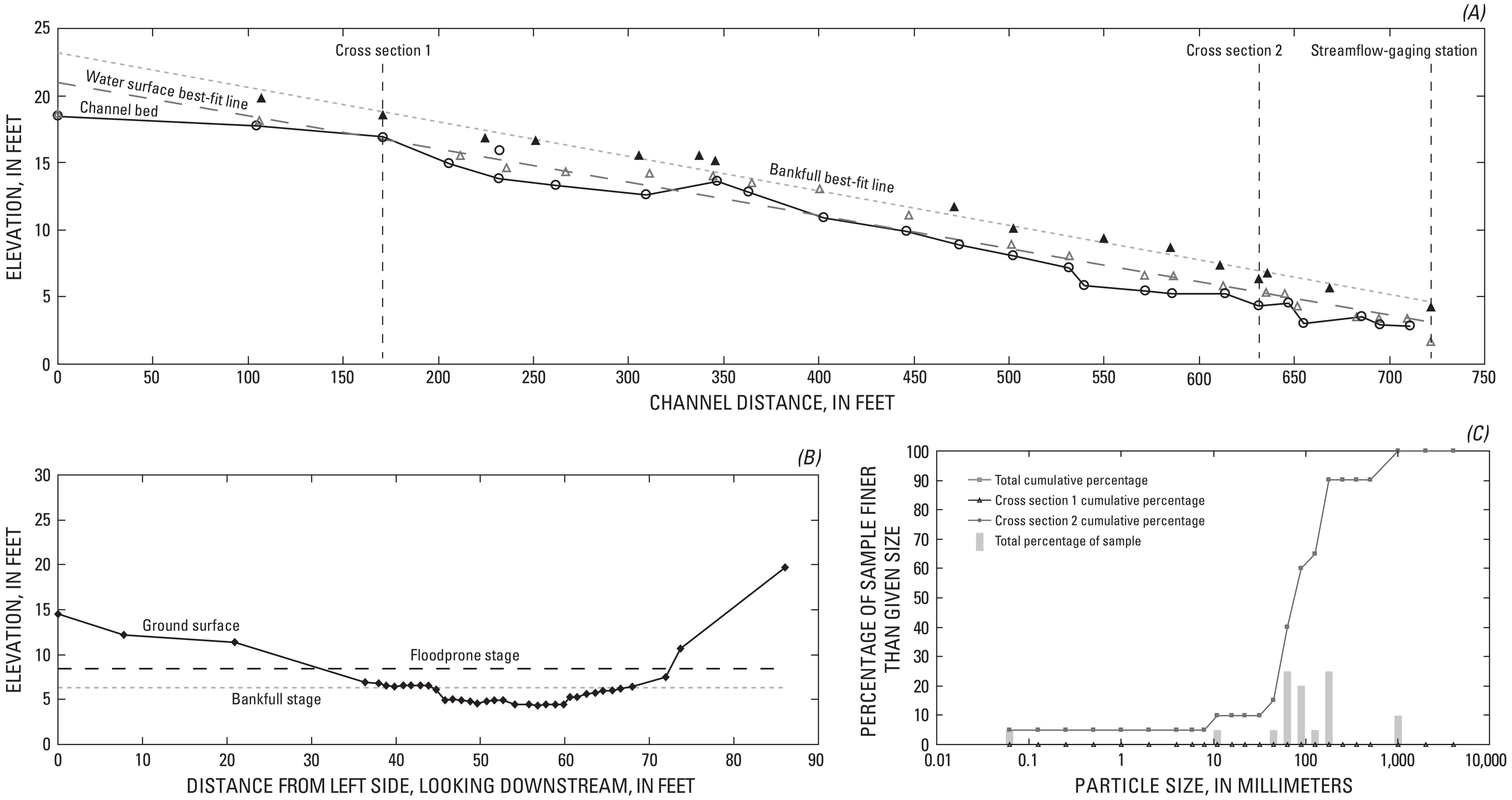

Figure A27. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Renick Run near Buchanan, Va., July 1, 2003.

Station 02053800
South Fork Roanoke River near Shawsville, Va.

View looking downstream at reach of South Fork Roanoke River near Shawsville, Va.

The streamflow-gaging station at this site is a continuous record station located at a pool approximately 95 ft downstream of a bridge on the right bank. The bridge deck is approximately 30 ft above the water surface and has two concrete piers in the channel. Minimal backwater effects may occur at bankfull discharge.

The channel was a riffle-run dominated stream with a cobble bed. The cobble seemed to be well cemented with sand and small gravel. Some sections of the bed were predominantly sand, especially in the few small pools present. No exposed bedrock was observed in the study reach. The primary bankfull indicator at this site was the top of the bank or, in the upstream sections, a stable bench feature below the top of the bank. The channel banks were vegetated with trees and grass but little small woody or herbaceous vegetation. Moderate scour was observed at some locations on the banks. The channel had a mild slope and was very straight except for a turn that was made as the stream approached and ran alongside a steep mountainside. Except for this section the flood plains were flat, cleared, and used for home sites and a church.

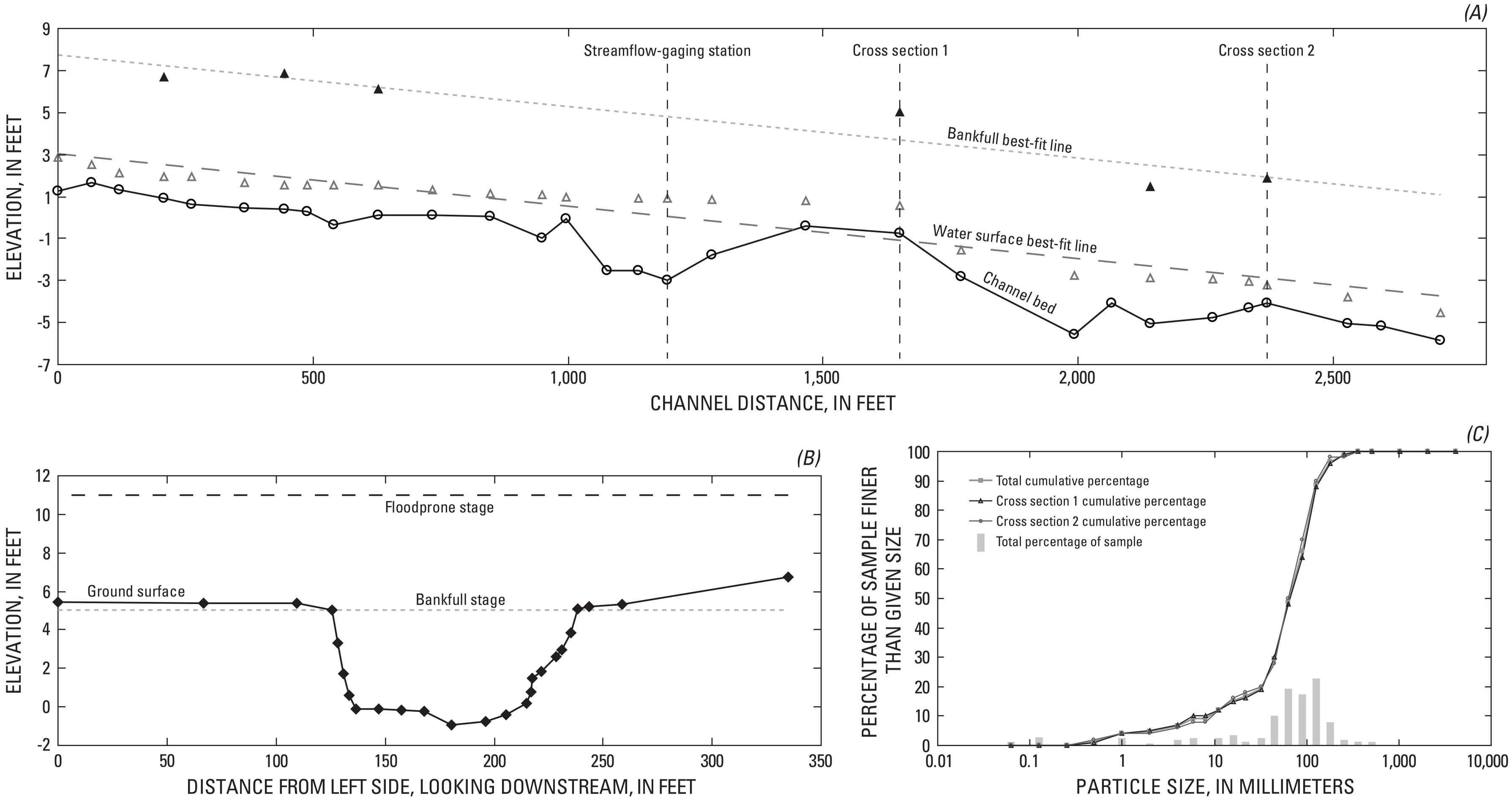

Figure A28. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of South Fork Roanoke River near Shawsville, Va., January 7, 2004.

Station 02055100
Tinker Creek near Daleville, Va.

View looking downstream at reach of Tinker Creek near Daleville, Va.

This continuous-record streamflow-gaging station is about 1,000 ft downstream from a large pipe culvert that likely had no effect on bankfull discharge in the survey reach.

The primary bankfull feature, a distinct change in slope, was present in most of the reach. The banks were rocky and well vegetated, with grasses, small woody vegetation and trees. The banks showed little erosion, except for a section of cut bank on the right bank in the middle third of the reach. Bankfull features were difficult to identify through this section. The stream channel was bordered by flood plains on both sides, which were used as a pasture at the time of the survey. The bed material was primarily gravel with significant sections of bedrock and some cobble. The channel was somewhat sinuous, narrow, and deep. The slope was mild.

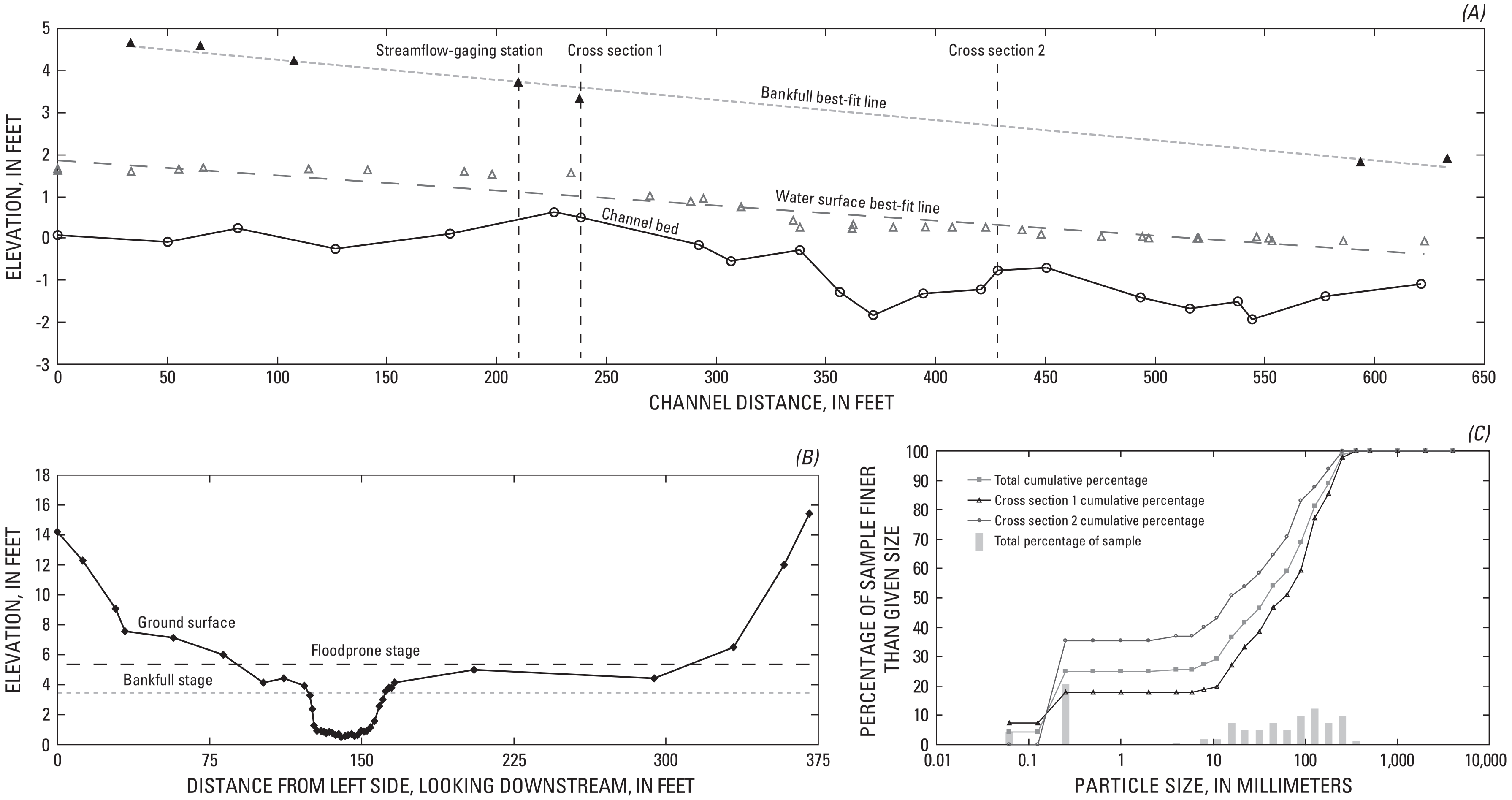

Figure A29. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Tinker Creek near Daleville, Va., August 15, 2003.

Station 03167000
Reed Creek at Grahams Forge, Va.

View looking downstream at reach of Reed Creek at Grahams Forge, Va.

This continuous-record streamflow-gaging station is located 20 ft downstream of a highway bridge. The bridge has two piers in the channel, which may cause some backwater effect at high flows though it is likely minimal.

The channel was relatively wide and shallow with many bedrock outcroppings and large boulders. There was also a lot of cobble bed material throughout the reach. The study reach was very straight and ran along a high, densely vegetated bluff on the right side. The left bank was vegetated with only grass and a few scattered trees. Very little bank erosion was observed. The gently sloping flood plain on the left side was farmland, private yards, and the site of an old, abandoned store and mill. The study reach was a riffle–run system except for a large, 200-ft-long pool that dominated the middle of the reach. The primary bankfull features identified at the site were the top of the bank or a bench below the top of the bank. The slope of the study reach was mild.

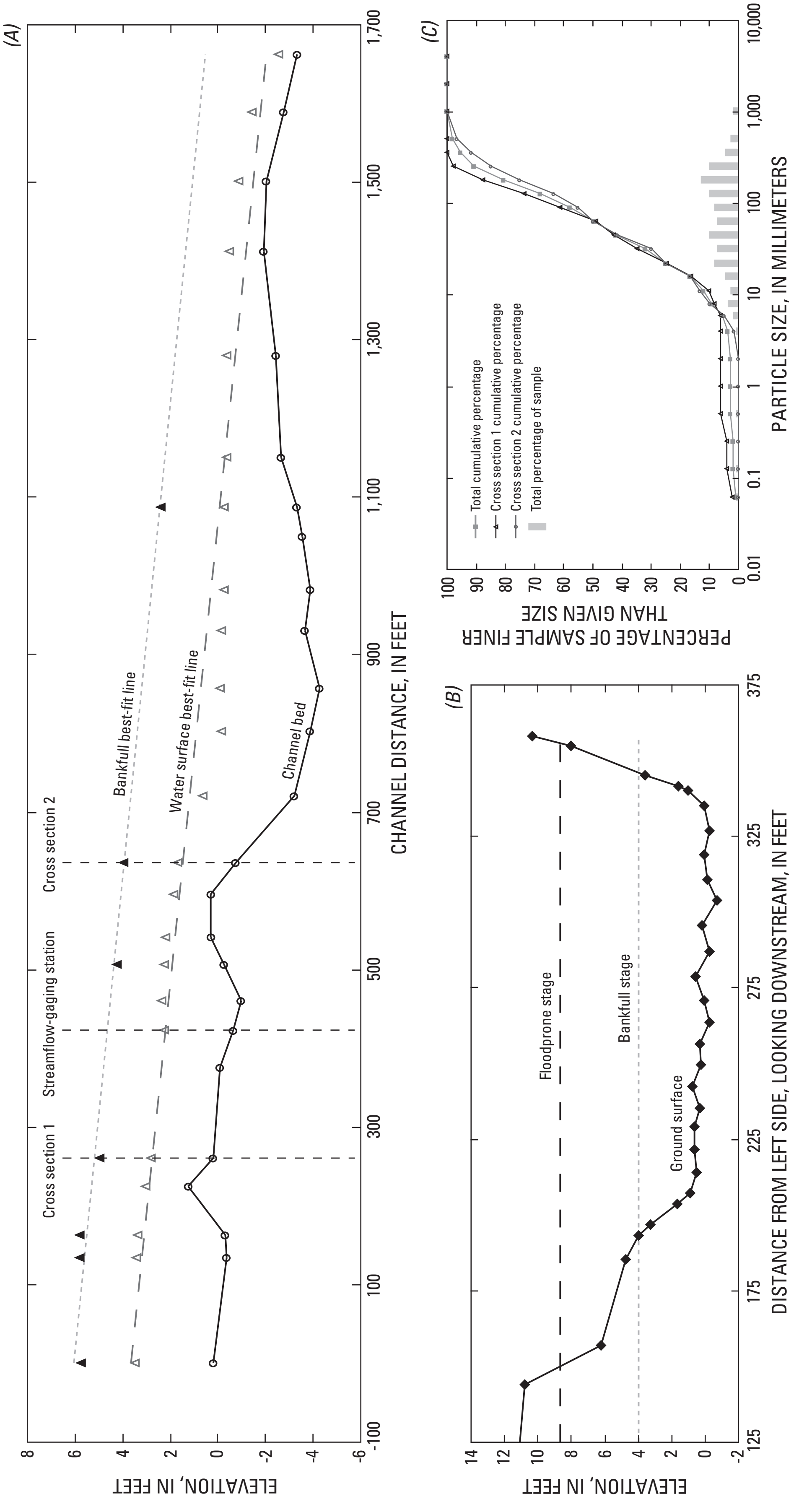

Figure A30. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Reed Creek at Grahams Forge, Va., April 19, 2004.

Station 03177710
Bluestone River at Falls Mills, Va.

View looking upstream at reach of Bluestone River at Falls Mills, Va.

The streamflow-gaging station is a continuous record station just upstream from a small bridge that likely has little backwater effect at bankfull discharge. The station at this site has been discontinued since 1997.

The stream is a meandering channel with occasional gravel point bars that runs partially adjacent to a two-lane road embankment. Approximately 400 ft upstream of the station, the stream turns away from the road and runs through a very flat farm field. Otherwise, the study reach was very straight. There is significant erosion along the banks after the turn, likely due to dairy cattle accessing the stream. The right bank of the stream upstream of the turn is filled up to the road. The bed material is mostly gravel and small cobbles on bedrock. Bedrock is exposed in some places. The primary bankfull features throughout the reach are at the top of the bank. The flood plain is very flat beyond bankfull for a long distance. The slope of the channel was mild.

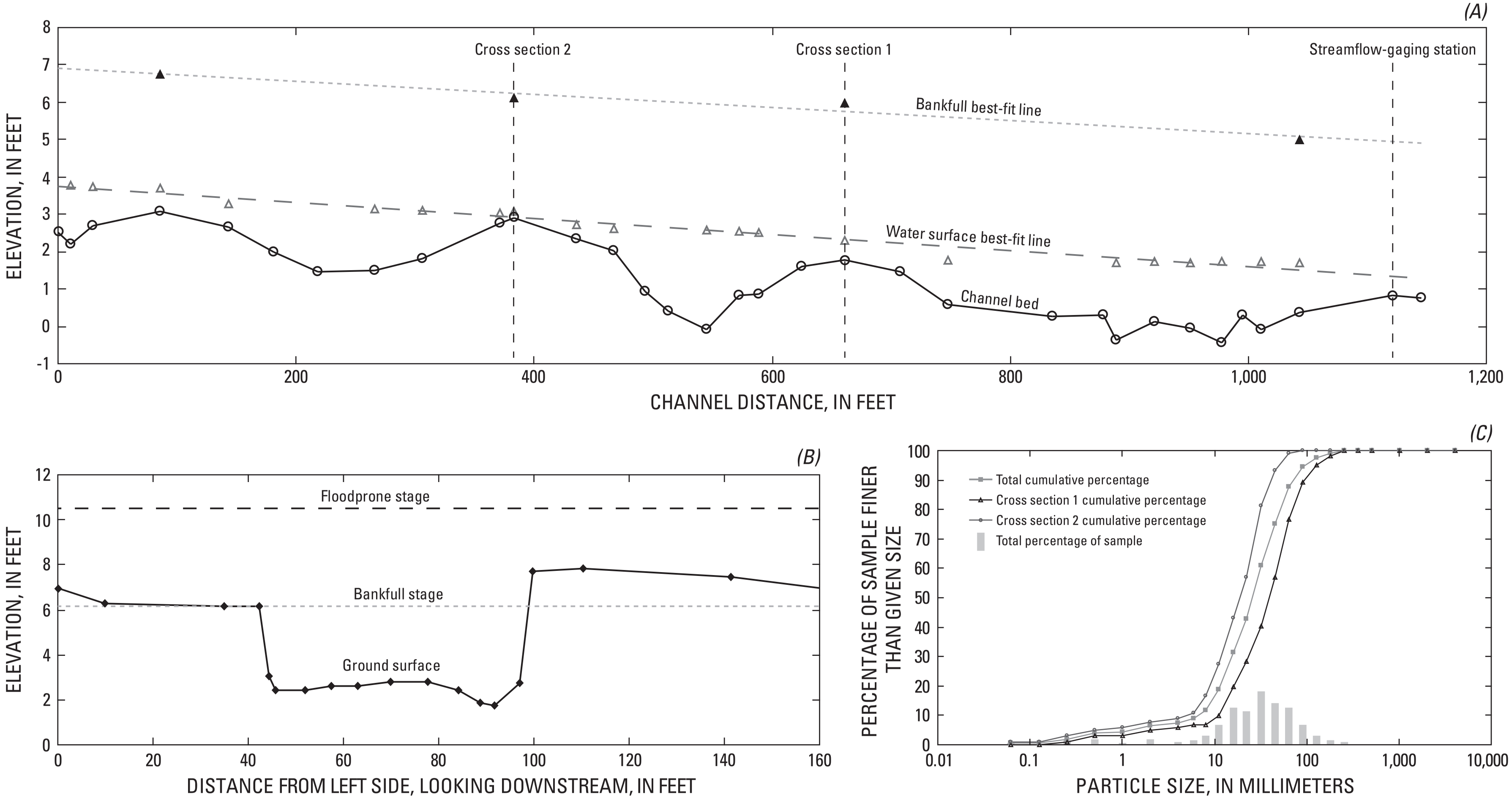

Figure A31. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Bluestone River at Falls Mills, Va., July 23, 2003.

Station 03182700
Anthony Creek near Anthony, W. Va.

View looking downstream at reach of Anthony Creek at Anthony, W. Va.

This continuous-record streamflow-gaging station was about 1 mile downstream from the nearest bridge. The station has been discontinued since 1982, and the structure is no longer present. The period when the continuous streamflow-measurement station was active, 1971-1982, was an exceptionally wet period, and Log-Pearson peakflow frequency statistics calculated for this station were exceptionally high for the region (Wiley and others, 2000). Regional frequency statistics were judged to be more representative for this station than station frequency analysis. The bankfull discharge was determined from the rating, but the frequency was from the regional regression equation.

The primary bankfull indicators at this site were the top of the bank and changes in bank slope. A primary feature, a distinct change in slope, was present in most of the reach on both banks. The banks were well vegetated with large trees and, in some sections, dense rhododendron thickets. The banks showed little erosion. The stream channel was bordered on the left side by a forested flood plain with dense rhododendron thickets for the upstream two-thirds of the reach. Downstream from this section of the reach, the left side of the channel was bordered by a steep, forested hillside that contained some very large boulders. On the right side, the upstream quarter of the stream channel was bordered by a steep, forested hill. The rest of the right side of the channel was bordered by a forested flood plain, and contained some overflow channels that probably carried a slight amount of flow at bankfull stage. The cross section for this site used for the curves was above this section. The bed material was small cobble and gravel. The study reach was relatively sinuous and the slope was mild.

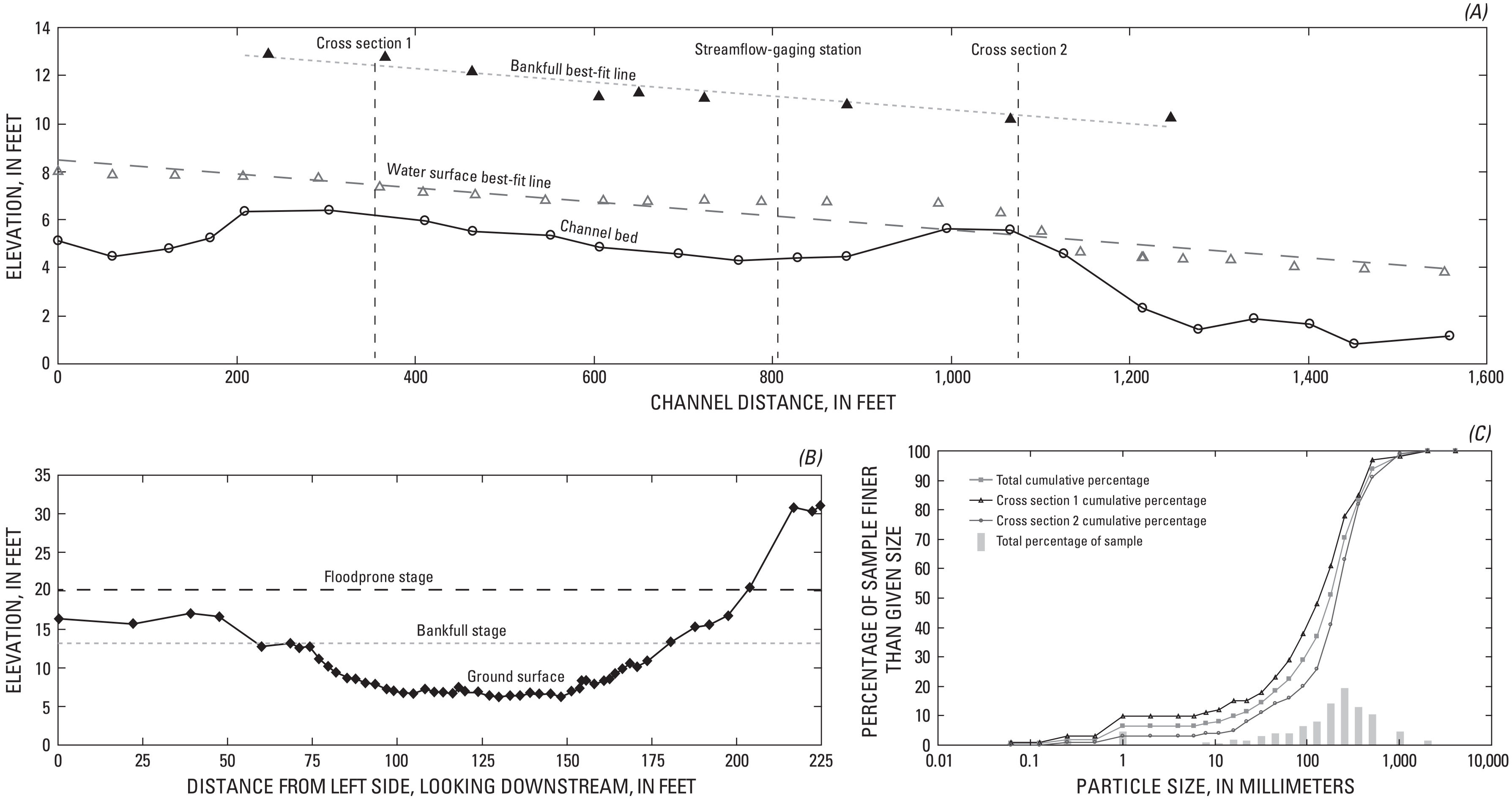

Figure A32. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Anthony Creek near Anthony, W.Va., October 9, 2003.

Station 03471500
South Fork Holston River at Riverside near Chilhowie, Va.

View looking upstream at reach of South Fork Holston River at Riverside near Chilhowie, Va.

The continuous-record streamflow-gaging station at this site is located approximately 400 ft upstream from a highway bridge. The bridge has two piers in the channel, which may cause a slight backwater effect at high flows.

The bed material in the study reach was mostly gravel and cobble over bedrock, which was exposed in many places. The bankfull channel was well defined by the top of banks. In some sections of the channel, there was a stable bench feature below the bankfull feature. The right bank of the study reach was well vegetated with trees and small woody vegetation. Very little bank erosion was observed. The flood plains on both sides were generally flat. The left flood plain was cleared for private yards and the grounds of a church. In the upstream section, the left bank was vegetated only with grass. In the downstream section the left bank was covered with small woody vegetation. The reach was very straight and had a mild slope. The reach had riffles, runs, glides, and several deep pools.

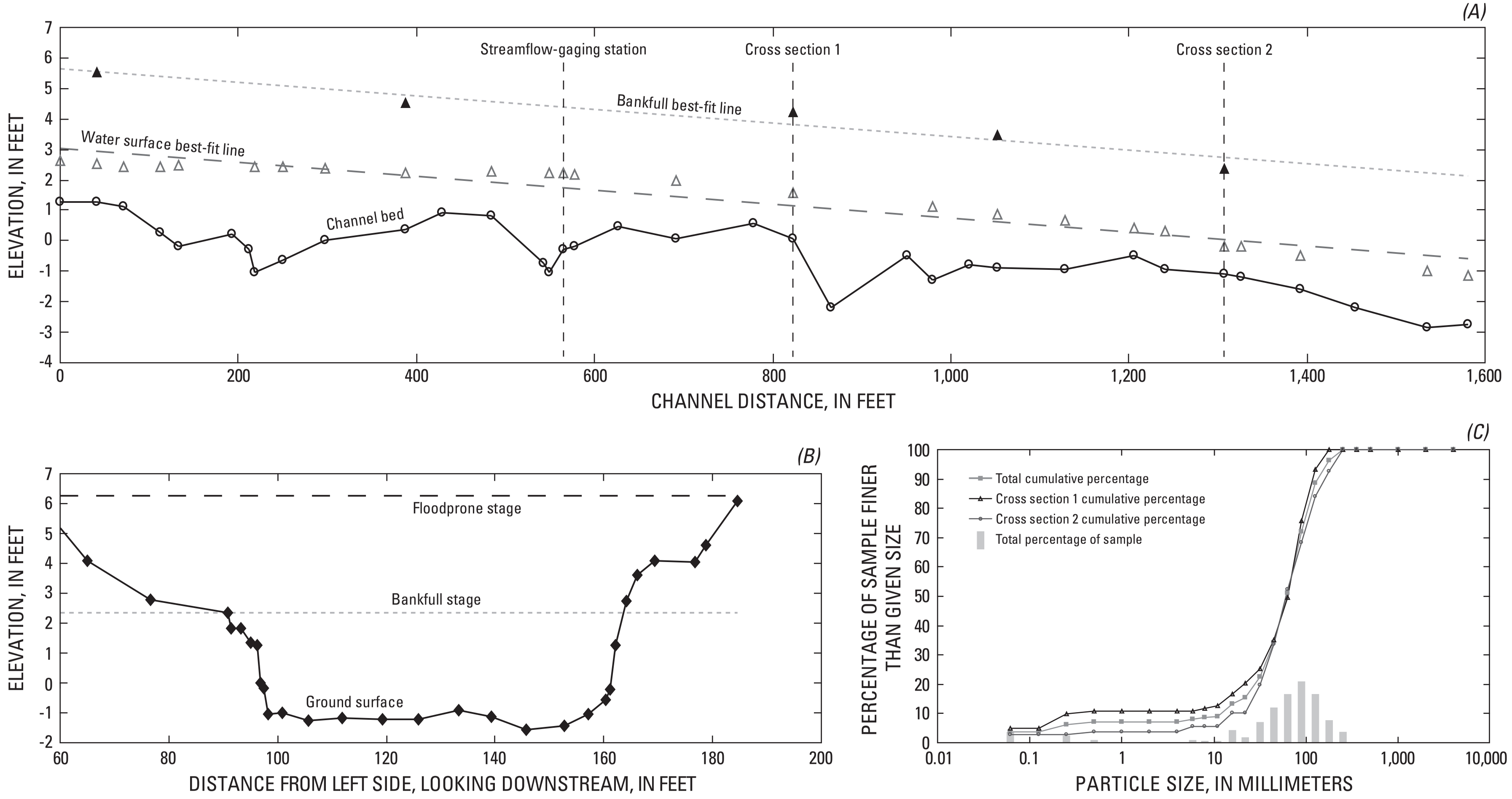

Figure A33. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of South Fork Holston River at Riverside near Chilhowie, Va., August 19, 2003.

Station 03473500
Middle Fork Holston River at Groseclose, Va.

View looking downstream at reach of Middle Fork Holston River at Groseclose, Va.

The original streamflow-gaging station at this site has been discontinued and it is now operated as a crest-stage station. The station is on the left bank immediately downstream of a large box culvert, which will cause a backwater effect at bankfull discharge. The study reach was downstream of the culvert.

The local slope at the outlet of the culvert was fairly steep but the remainder of the study reach had a much flatter gradient. The reach had long sections of pool and shorter riffles and runs. The reach was dominated by gravel bed material and there were no bedrock outcroppings observed. The channel is fairly narrow with dense woody and herbaceous vegetation on both banks. The right side of the stream runs along the bottom of a steep railroad grade for the entire length of the study reach, which is very straight. The stream was likely channelized when the railroad was constructed. The left bank appeared to be natural with a stable bankfull bench. There was also a low bench feature below bankfull throughout the reach. In the upstream section the left flood plain was quite steep; in the downstream portion the slope was more gentle but still rising high above the stream bed. Because of this and the railroad grade on the right, the stream is entrenched.

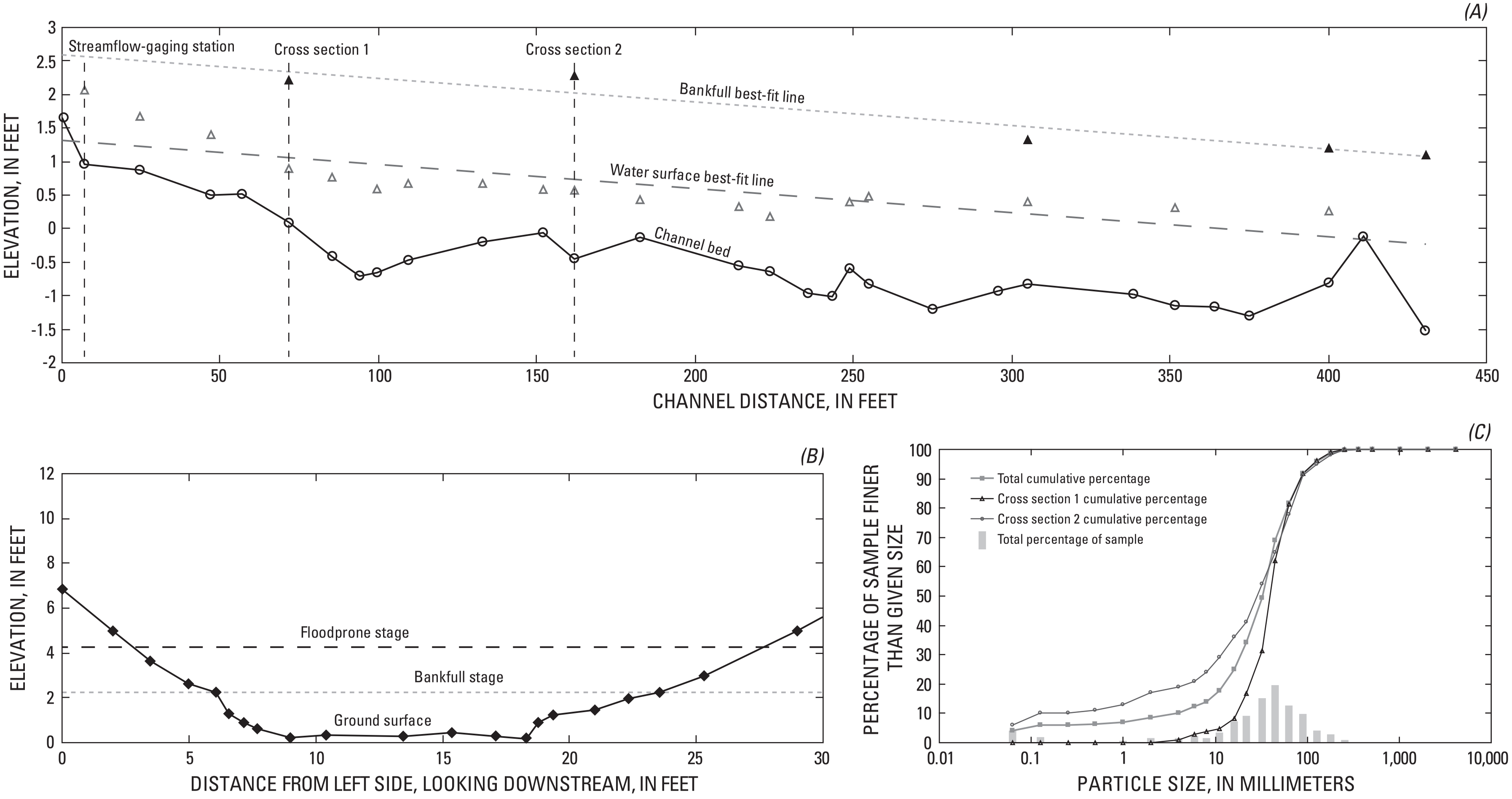

Figure A34. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Middle Fork Holston River at Groseclose, Va., July 18, 2003.

Station 03474000
Middle Fork Holston River at Seven Mile Ford, Va.

View looking downstream at reach of Middle Fork Holston River at Seven Mile Ford, Va.

The streamflow-gaging station at this site is a continuous record station that is on the right bank downstream of a bridge at the end of a long pool. The bridge has two piers in the channel and the deck is approximately 20 ft above the water surface. There may be some slight backwater effect at the bankfull discharge.

The stream had a wide, shallow channel with several significant bedrock cascades, one immediately downstream of the station. The channel had exposed bedrock throughout, which was partially covered by bed material of gravel and cobble. The study reach had deep pools, riffles/cascades, and long runs and glides. The upstream section of the study reach had wide riparian buffer on both sides. The middle section had no buffer on either side. The downstream section had a wide buffer on the right and very little buffer on the left. The primary bankfull indicator at this site was the top of the bank or, in the upstream sections, a stable bench feature below the top of the bank. Much of the upstream section from the bridge to downstream of the first cross section appears to be artificially entrenched with steep flood plains due to previous construction activities. There is a highway (I-81) on the left bank and a subdivision on the right bank. There is considerable scour through some sections of the reach, especially where the banks are near vertical due to highway fill. The study reach was wide and shallow, very straight, and had a mild slope.

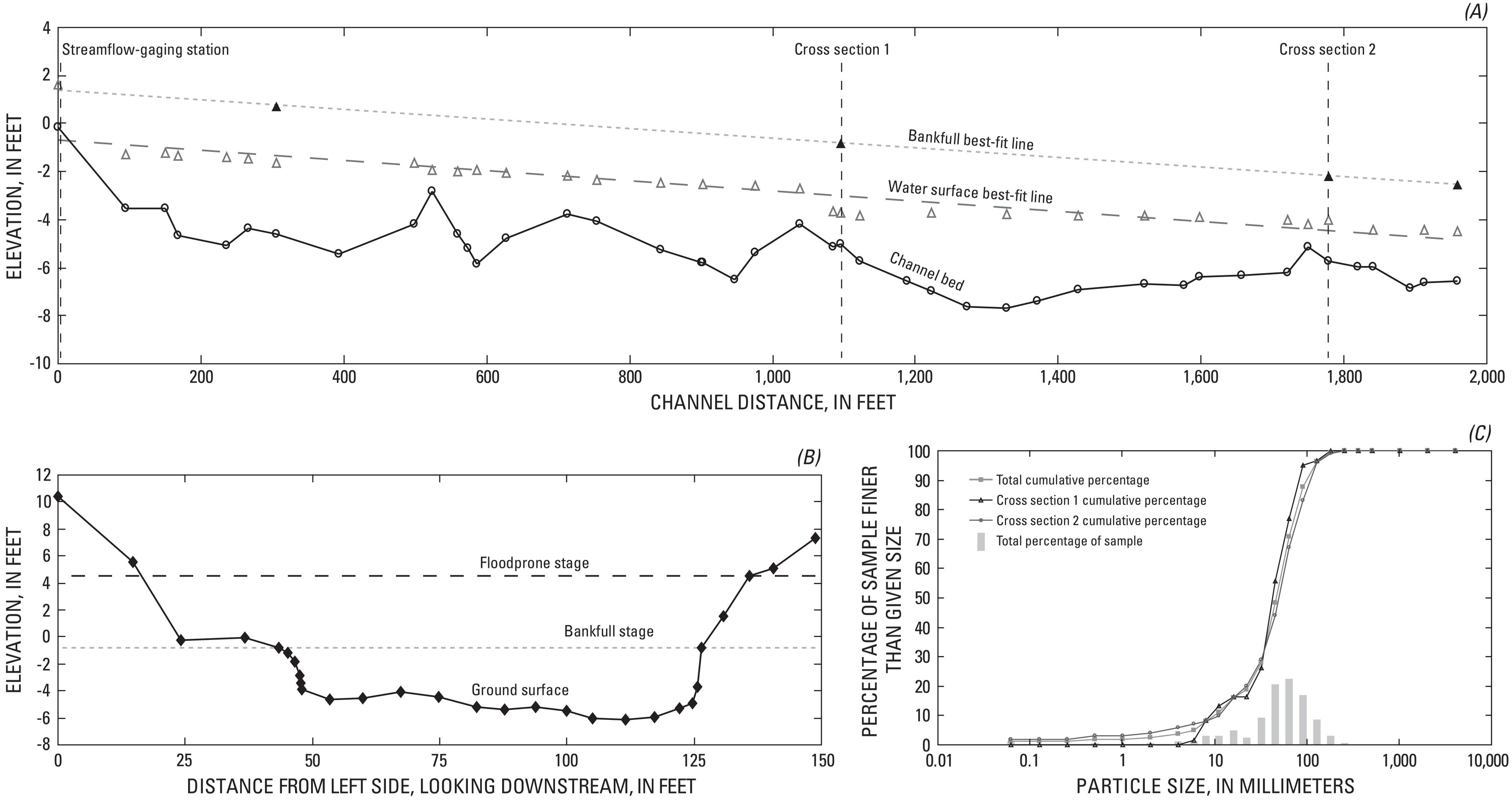

Figure A35. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of the Middle Fork Holston River near Seven Mile Ford, Va., August 6, 2003.

Station 03487800
Lick Creek near Chatham Hill, Va.

View looking downstream at reach of Lick Creek near Chatham Hill, Va.

The streamflow-gaging station at this site was once a continuous-record station but has been a crest-stage station only since 1968. It is located on a farm 270 ft upstream of a highway bridge. It is not likely that the bridge causes backwater during high flows.

The channel was wide and somewhat shallow. The bed material was mostly gravel and small cobble, and bedrock was exposed in some sections of the channel. The study reach was very straight and has a mild slope. The banks are gently sloped and appear stable. The primary bankfull feature surveyed at this site was the top of the bank or a break in slope near the top of the bank. In some places significant breaks in slope were used as bankfull features. Much of both banks were vegetated with trees and small woody vegetation. A portion of the left bank and flood plain had been completely cleared and used as farm land. Further downstream the left bank was forested. The right bank sloped up to a small road in the upstream section and was flatter and forested in the downstream section.

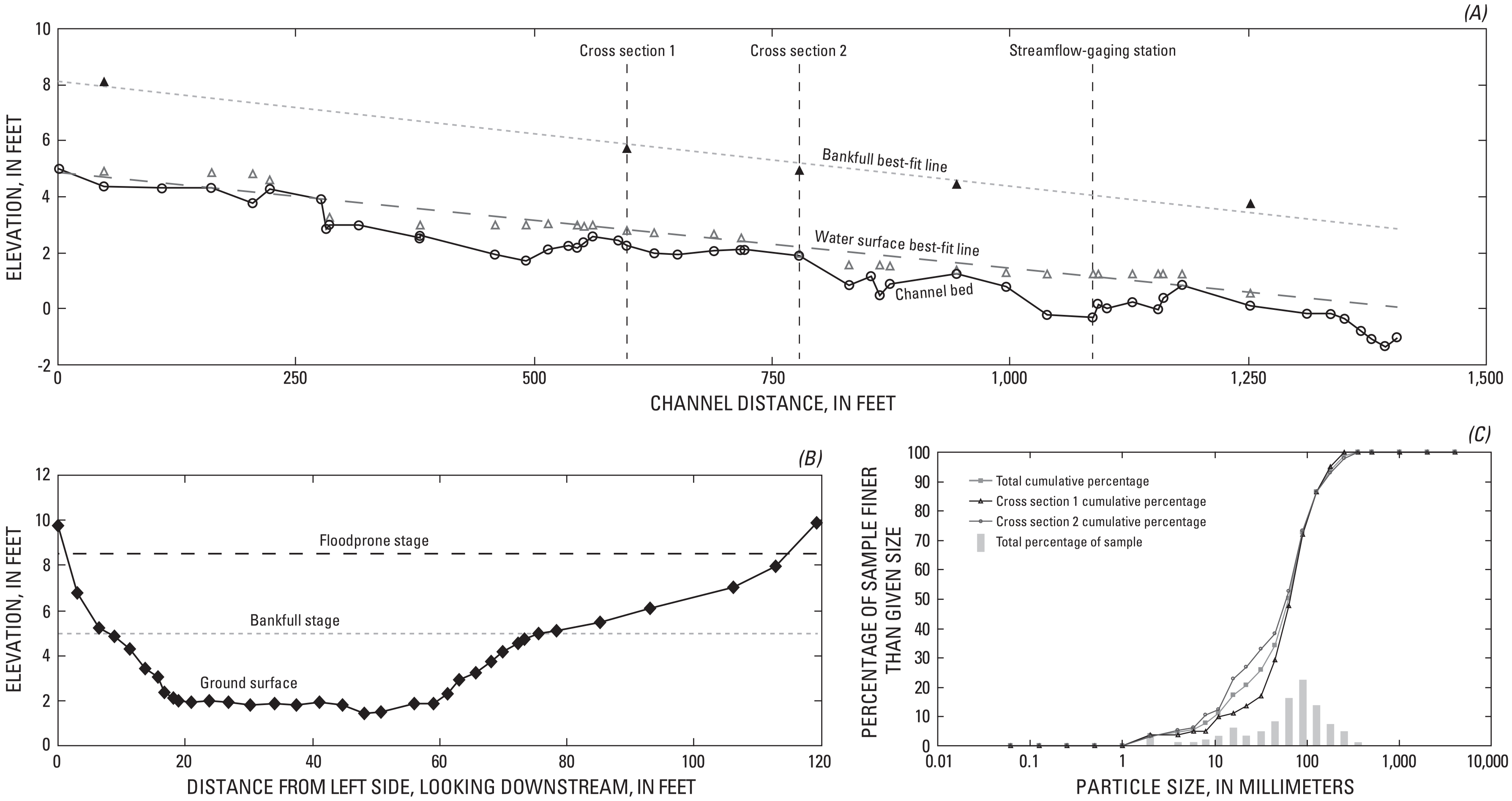

Figure A36. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Lick Creek near Chatham Hill, Va., August 6, 2003.

Station 03488000
North Fork Holston River near Saltville, Va.

View looking upstream at reach of North Fork Holston River near Saltville, Va.

The continuous-record streamflow-gaging station at this site is not in the vicinity of a bridge. There are no structures present to impede flow.

The channel was very wide and shallow and there is vegetation growing in the bed in many locations. The study reach had one of the most gentle gradients of any in the study and it was one of the most sinuous. The bed material was composed of gravel and small cobble. No exposed bedrock was observed in the study reach. The banks were vegetated sporadically with trees, small woody vegetation, and herbaceous vegetation. In many areas the flat flood plain was used for private yards and farm fields. In these locations, the banks were only grass covered. Little evidence of bank erosion was observed throughout the study reach. The primary bankfull indicator at this site was the top of the bank or a stable bench feature.

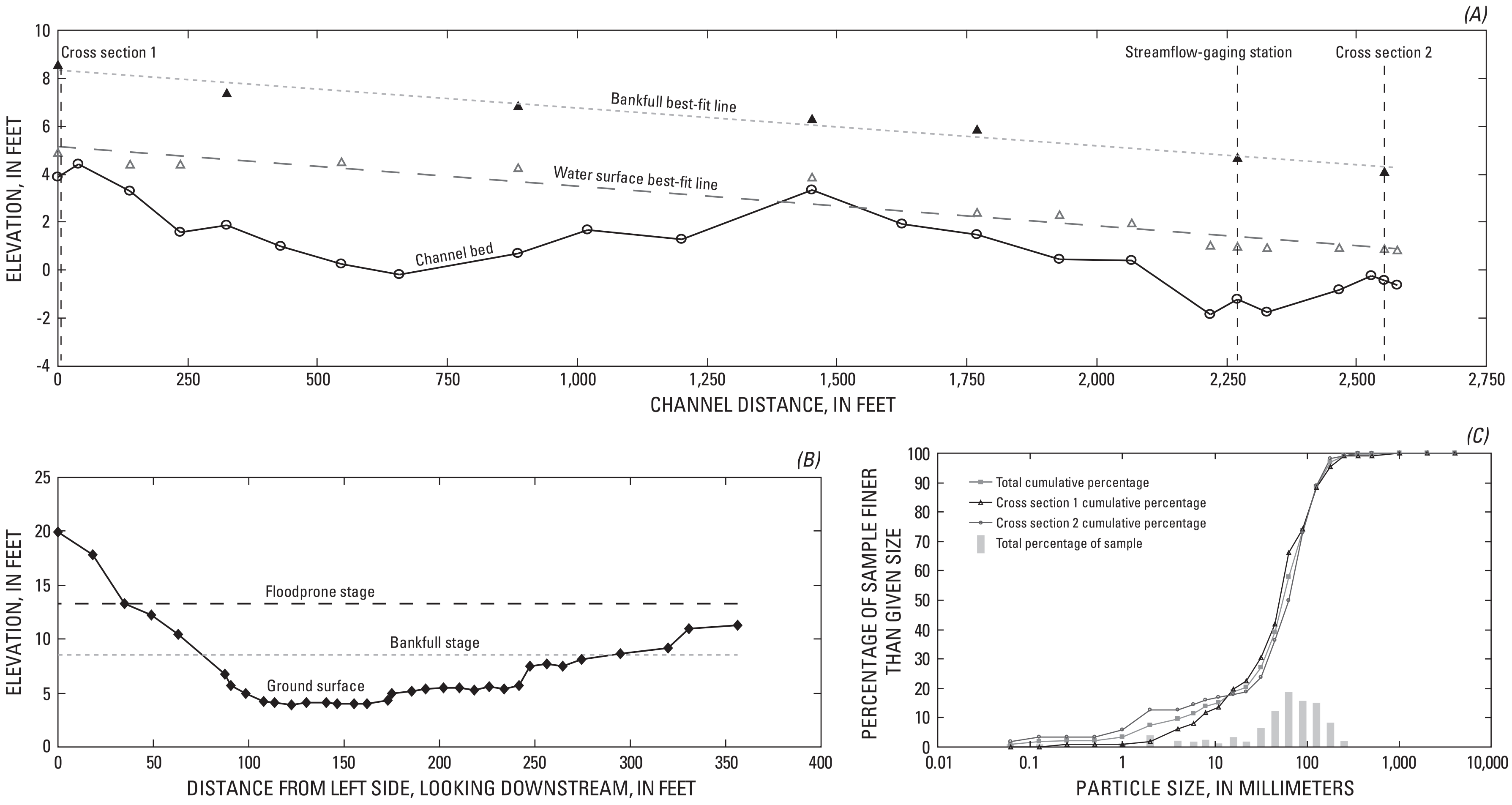

Figure A37. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of North Fork Holston River near Saltville, Va., May 19, 2004.

Station 03488450
Brumley Creek at Brumley Gap, Va.

View looking upstream at reach of Brumley Creek at Brumley Gap, Va.

This site has a crest stage streamflow-gaging station on the downstream abutment of the bridge on the right side. Few measurements have been made at the site, all for discharges well below bankfull, and the rating is theoretical. The bridge has one pier in the center of the stream which does not likely cause backwater at bankfull flows.

This is a fairly steep stream with bed material of large cobble and small boulders. The stream empties into the North Fork Holston River immediately downstream of the study site. There was a dramatic change in slope as the stream approached the much larger river. The stream is very straight for most of this length and splits into two channels both upstream and immediately downstream of the survey reach. The channel is cascading with a few scour pools and short runs. There is thick woody and herbaceous vegetation on the tops of the banks for up to 20 ft but the land is generally cleared beyond that for residential and agricultural land use. The flood plains are mostly flat or have a gentle slope. The primary bankfull indicators at the site were stable benches below the top of the bank. The benches were intermittent and relatively few bankfull features were identifiable at the site.

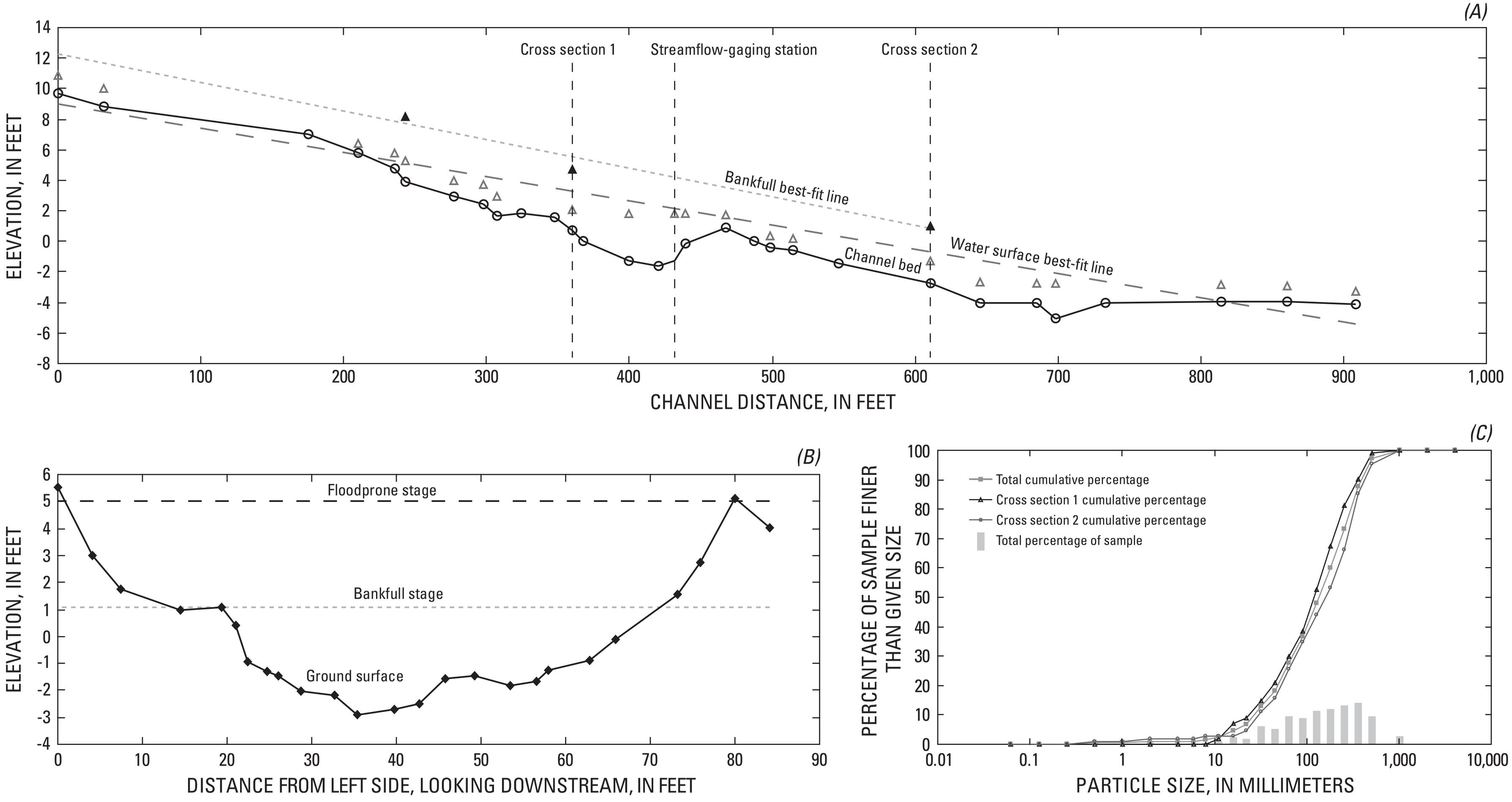

Figure A38. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Brumley Creek at Brumley Gap, Va., August 20, 2003.

Station 03489800
Cove Creek near Shelleys, Va.

View looking upstream at reach of Cove Creek near Shelleys, Va.

This site is a crest stage streamflow-gaging station attached to an upstream wingwall of a bridge. The only point on the stage discharge rating above the bankfull discharge was estimated with the contracted opening method indirect measurement. The bridge opening is narrow and the structure likely causes a backwater effect at high flows including bankfull. Although there are no piers in the channel, the bridge cuts off access to the flood plain completely.

This study reach was a very straight bedrock channel with a mild slope. The stream was relatively narrow and deep. Upstream of the bridge there were houses with maintained, sloping lawns on either side that continued down to the top of the stream banks. The downstream section was vegetated with trees and small woody and herbaceous vegetation. The bankfull flood plain was very apparent through this section and the banks were stable and vegetated. The bed material throughout the study reach was primarily bedrock. One study riffle had some gravel, the other did not. The bedrock was folded and jutted up into the flow more in some places than others, creating the riffle sections. The banks were stable and the bankfull features throughout the reach were at the top of the bank. There is a terrace on the left bank above the top of the bank.

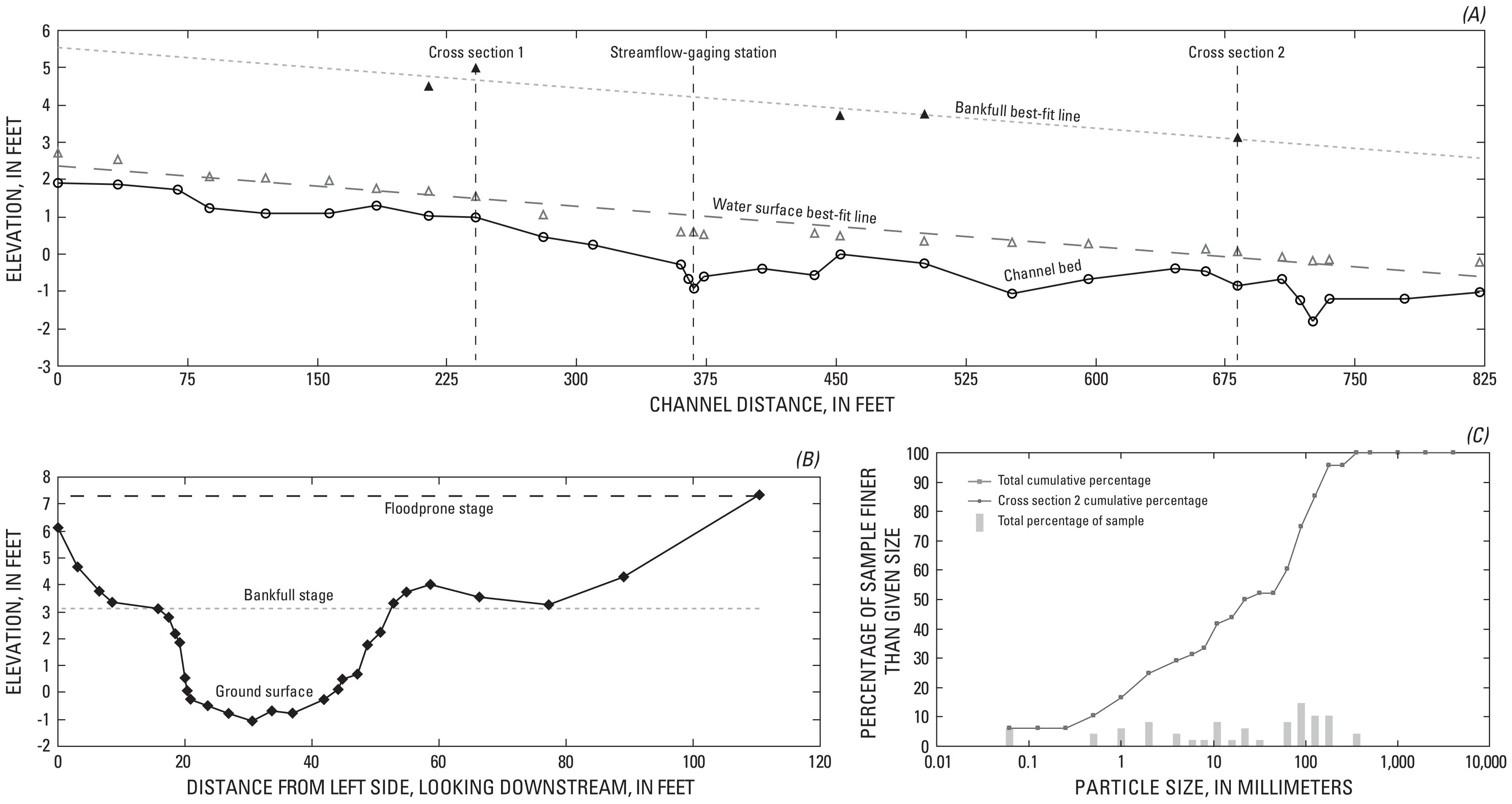

Figure A39. Longitudinal profile *(A)*, riffle cross section 2 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Cove Creek near Shelleys, Va., August 18, 2003.

Station 03523000
Big Cedar Creek near Lebanon, Va.

View looking upstream at reach of Big Cedar Creek near Lebanon, Va.

This site has a crest-stage streamflow-gaging station and the measurement record is limited. Most measurements were made during the 1950's and early 1980's. The station is located on a pier of an old bridge. The bridge deck is gone, but two abutments remain. A new highway bridge spans the channel. Neither structure seems likely to impede flow.

The study reach was fairly straight. Much of the channel was clean bedrock, especially the riffles, but some of the bedrock was covered by flat cobbles and gravel. The study reach was wide and shallow with a gentle slope. The section of stream near the station was in a fairly narrow valley which broadens downstream. Although an active flood plain existed throughout much of the site the valley walls were steep. The banks were vegetated mostly with herbaceous vegetation and some small woody
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often existed below the bankfull feature at about half of the distance between the channel bed and the bankfull stage. The banks appeared stable.

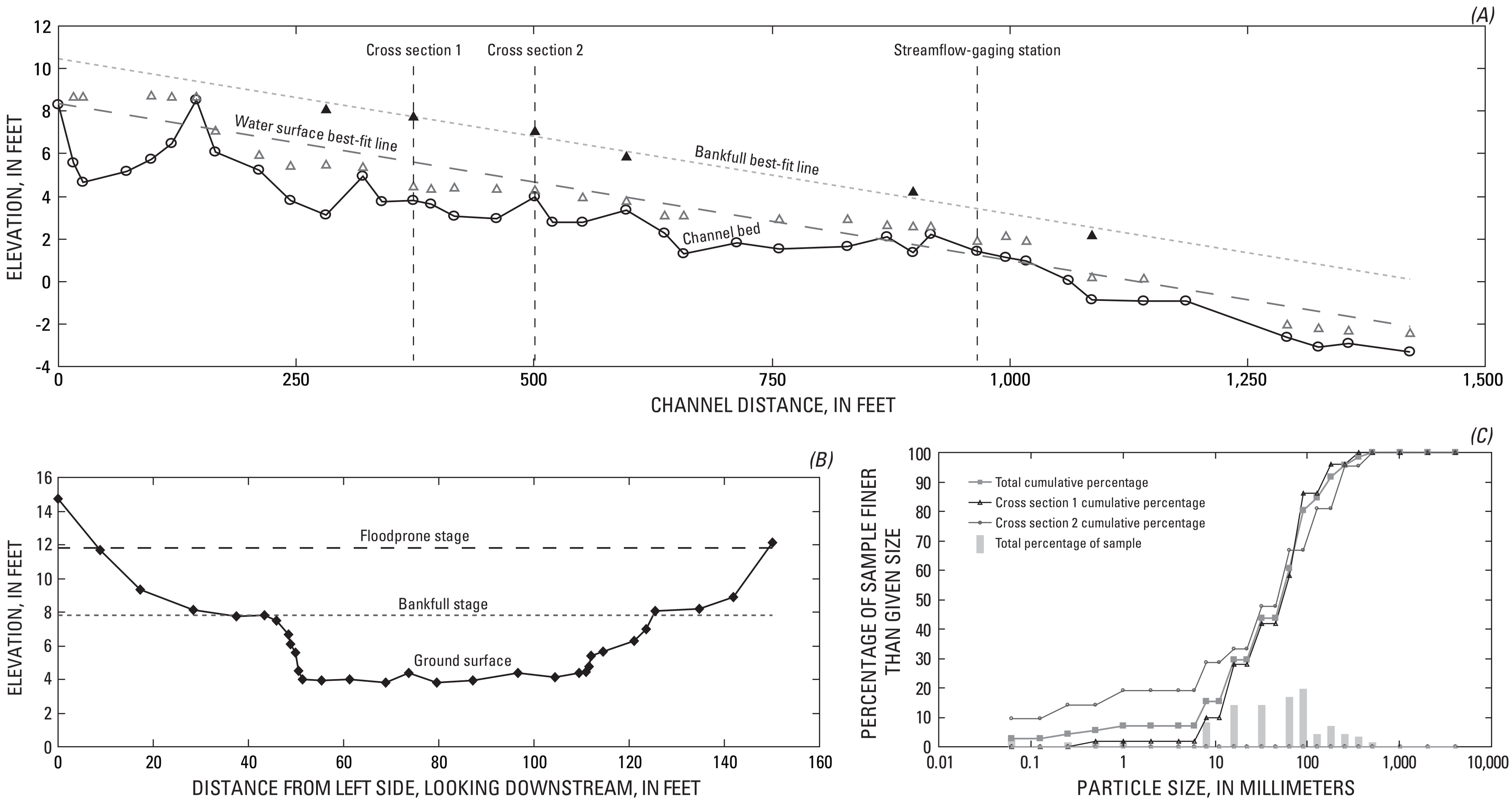

Figure A40. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Big Cedar Creek near Lebanon, Va., September 10, 2003.

Station 3475600
Cedar Creek near Meadowview, Va.

View looking upstream at reach of Cedar Creek near Meadowview, Va.

This site has a crest-stage streamflow-gaging station only. Very few measurements have been made at the site, all of which were far less than the bankfull discharge. The rating is theoretical and several measurements do not fit the rating curve well. The upstream end of the study reach is crossed by a one lane bridge over a 48-inch culvert. The culvert may restrict the high flows to some degree. There is also a culvert near the downstream end of the study reach where the crest-stage station is located, which may also restrict bankfull flows.

The study reach was a narrow, deep channel flowing over bedrock. It had no riparian buffer on either side upstream of the station and limited buffer of herbaceous vegetation on the downstream section of the study reach. The flood plain on either side was mostly flat. The stream runs next to a commercial building on the right bank and had private lawns on the left bank. The stream banks are stable throughout the study reach. Bedrock was exposed in many locations but covered through much of the reach by small to medium gravel. The study reach was very straight and has a mild slope. It has likely been channelized in the past. Far downstream of the study reach the channel becomes quite sinuous. Bankfull was determined to be the top of the bank throughout the reach.

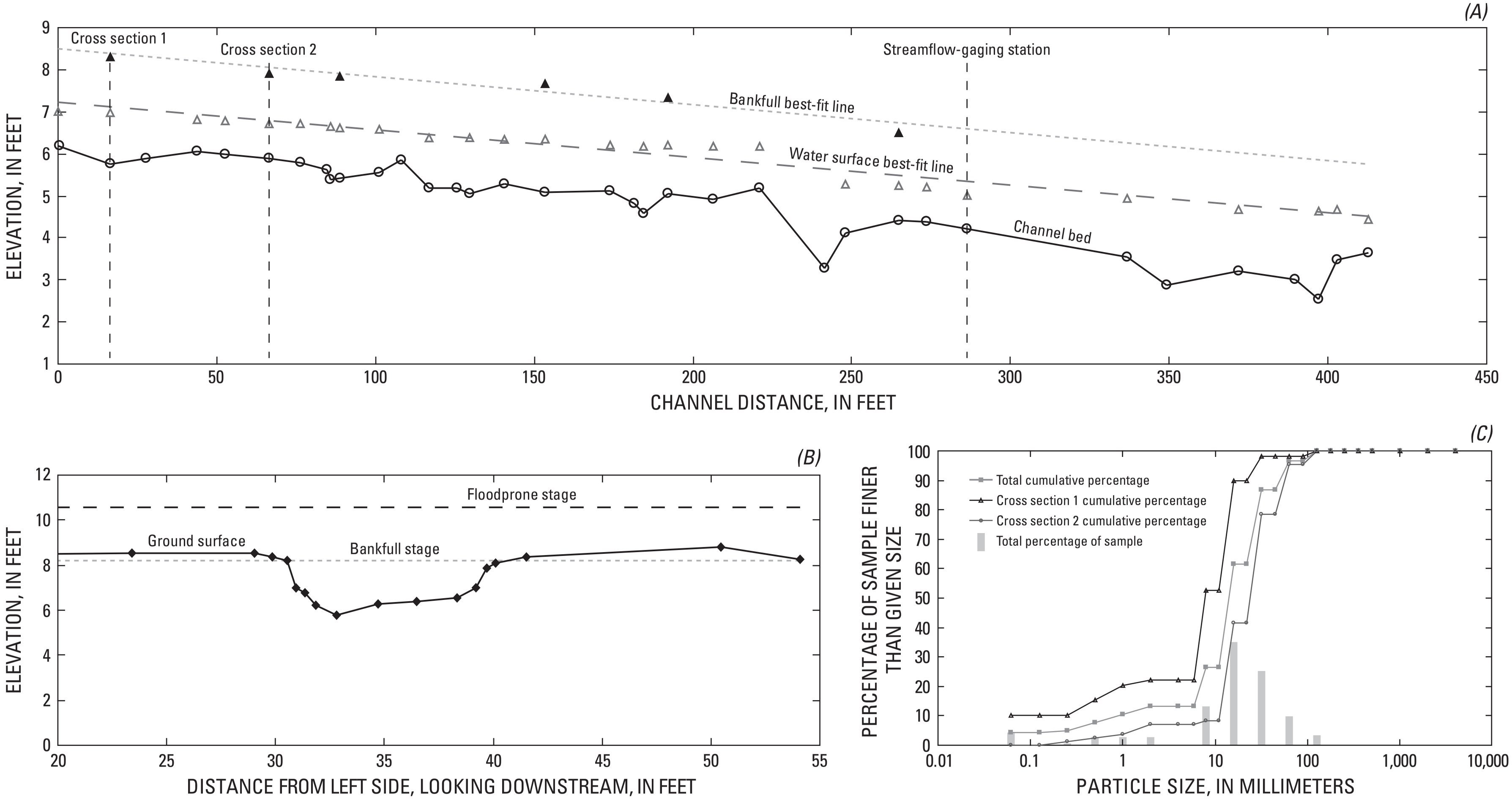

Figure A41. Longitudinal profile *(A)*, riffle cross section 1 *(B)*, and particle-size distribution of bed material *(C)*, in study reach of Cedar Creek near Meadowview, Va., September 9, 2003.