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Prepared in cooperation with the Virginia Coastal Zone Management Program and the Virginia Department of Conservation and Recreation Coastal Nonpoint Source Pollution Control Program

Bankfull Regional Curves for Streams in the Non-Urban, Non-Tidal Coastal Plain Physiographic Province, Virginia and Maryland

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

Cover. **Bush Mill Stream. View looking upstream from the bridge on State Highway 601 near Heathsville, Virginia** *(photograph taken by Jennifer L. Krstolic, U.S. Geological Survey, April 15, 2005)*.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic decimeter (dm^3)	0.03531	cubic foot (ft^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27).

Bankfull Regional Curves for Streams in the Non-Urban, Non-Tidal Coastal Plain Physiographic Province, Virginia and Maryland

By Jennifer L. Krstolic and Jeffrey J. Chaplin

Abstract

Natural-channel design involves constructing a stream channel with the dimensions, slope, and plan-view pattern that would be expected to transport water and sediment and yet maintain habitat and aesthetics consistent with unimpaired reaches. The adequate description of channel geometry in unimpaired reaches often is an important component of natural-channel design projects and can be facilitated through empirical regression relations, or regional curves, relating bankfull geometry to drainage area. One-variable, ordinary least-squares regressions relating bankfull discharge, bankfull cross-sectional area, bankfull width, and bankfull mean depth to drainage area were developed based on data collected at 20 streamflow-gaging stations in Virginia and Maryland. These regional curves can be used to estimate the bankfull discharge and bankfull channel geometry when the drainage area of a watershed is known.

Field data collected at the site for each streamflow-gaging station included one longitudinal profile of bankfull features and channel-bed slope, two riffle cross-section surveys of channel geometry, cross-section pebble counts, and one site sketch with photographs of the channel and bankfull features. The top of the bank was the bankfull feature most indicative of bankfull geometry. Field data were analyzed to determine bankfull cross-sectional area, bankfull width, bankfull mean depth, and D_{50}- and D_{84}-particle sizes for the two riffles at each site. The bankfull geometry from the 8 sites surveyed during this study represents the average of two riffle cross sections for each site, and the bankfull geometry from the 12 Maryland sites represents one cross section for each site. Regional curves developed for the 20 sites had coefficient of determination (R^2) values of 0.945, 0.890, 0.871, and 0.793 for bankfull cross-sectional area, width, mean depth, and discharge, respectively. The regional curves represent conditions for streams with defined channels and bankfull features in Virginia and Maryland with drainage areas ranging from 0.28 to 113 square miles. All sites included in the development of the regional curves were located on streams with U.S. Geological Survey streamflow-gaging stations. These curves can be used to verify bankfull features identified in the field and bankfull stage for ungaged streams in non-urban areas.

Introduction

Rebuilding physically degraded stream channels has become a key element in the management of surface-water resources throughout the Nation. Driven largely by Section 404 of the Clean Water Act, many states are required to remedy excess stream-channel adjustment that commonly results from alteration of flows or sediment supply in a watershed. Restoration of stream channels that have excessive erosion, deposition, or degraded habitat is commonly proposed and implemented by Federal, state, local, or private organizations in an effort to return the channels to more stable and biologically productive conditions. Traditional engineering practices for stream stabilization frequently rely on hardening the stream channel with rip-rap, gabions, concrete, or other countermeasures in reaches that are subjected to erosive forces. Stream restoration efforts that utilize natural-channel design techniques—with the philosophy of working in concert with stream processes rather than resisting them—have become common practice in the eastern United States and elsewhere (2007). Natural-channel design involves rebuilding a channel with the dimensions, slope, and plan-view pattern that is expected to transport water and sediment without excessive aggradation or degradation while maintaining habitat and aesthetics consistent with unimpaired reaches subjected to similar hydrologic conditions (Rosgen, 1996).

For those subscribing to this approach, the notion of a bankfull channel is the cornerstone concept. Many natural-channel designs are based on the geometry of the bankfull channel and the discharge occurring when the bankfull channel is flowing full. Although the bankfull channel is formed by a wide range of flows (Emmett, 2004), moderate flows, with recurrence intervals commonly ranging from 1 to 2 years, do more work in terms of sediment redistribution than extreme high flows, which occur less frequently (Wolman and Miller, 1960; Dunne and Leopold, 1978). For the purposes of this report, the bankfull discharge is defined as the flow that represents, or is a surrogate for, the full range of flows forming the bankfull channel.

Bankfull discharge and bankfull channel geometry are highly correlated with drainage area (Dunne and Leopold, 1978). Empirical regression relations, or regional curves, have recently been developed to estimate bankfull geometry in the Valley and Ridge Physiographic Province of Virginia (Keaton and others, 2005), the Atlantic Coastal Plain Physiographic Province (Coastal Plain) of Maryland (McCandless, 2003), the Coastal Plain of North Carolina (Doll and others, 2003), and elsewhere in the eastern United States (McCandless and Everett, 2002; Dudley, 2004; Chaplin, 2005; Sherwood and Huitger, 2005; Westergard and others, 2005). These bankfull regional curves are one-variable ordinary least-squares regressions relating bankfull discharge, bankfull cross-sectional area, bankfull width, and bankfull mean depth to drainage area in settings that are expected to have mostly homogenous hydrologic characteristics. Regression equations describing the regional curves can be used to estimate the discharge and geometry of a natural bankfull channel when drainage area of a watershed is known.

At the beginning of this study, no regional curves were available for the Coastal Plain of Virginia, and the applicability of curves developed in coastal areas of Maryland (McCandless, 2003) and North Carolina (Doll and others, 2003) in Virginia was not known. In support of stream-restoration activities, regional curves for bankfull geometry can be used to verify field identification of bankfull features in ungaged streams. As part of an ongoing effort to support stream restoration and natural-channel design endeavors in Virginia, the U.S. Geological Survey (USGS), in cooperation with the Virginia Coastal Zone Management Program and the Virginia Department of Conservation and Recreation (DCR) Coastal Nonpoint Source Pollution Control Program, began development of bankfull regional curves for use in non-urban, non-tidal coastal areas of Virginia in 2005.

Purpose and Scope

The purpose of this report is to present the data for and results of bankfull regional curve development in the non-urban, non-tidal Coastal Plain of Virginia and Maryland. Bankfull geometry was surveyed in 2005–2006, and bankfull discharge was calculated at six streamflow-gaging stations and associated stream reaches (sites) in Virginia and two sites on the Delmarva Peninsula of Maryland. Because regression relations are more robust when the sample size is large (Helsel and Hirsch, 2002), data from these 8 sites were combined with data from 12 sites previously surveyed in Maryland (McCandless, 2003) for the development of bankfull regional curves.

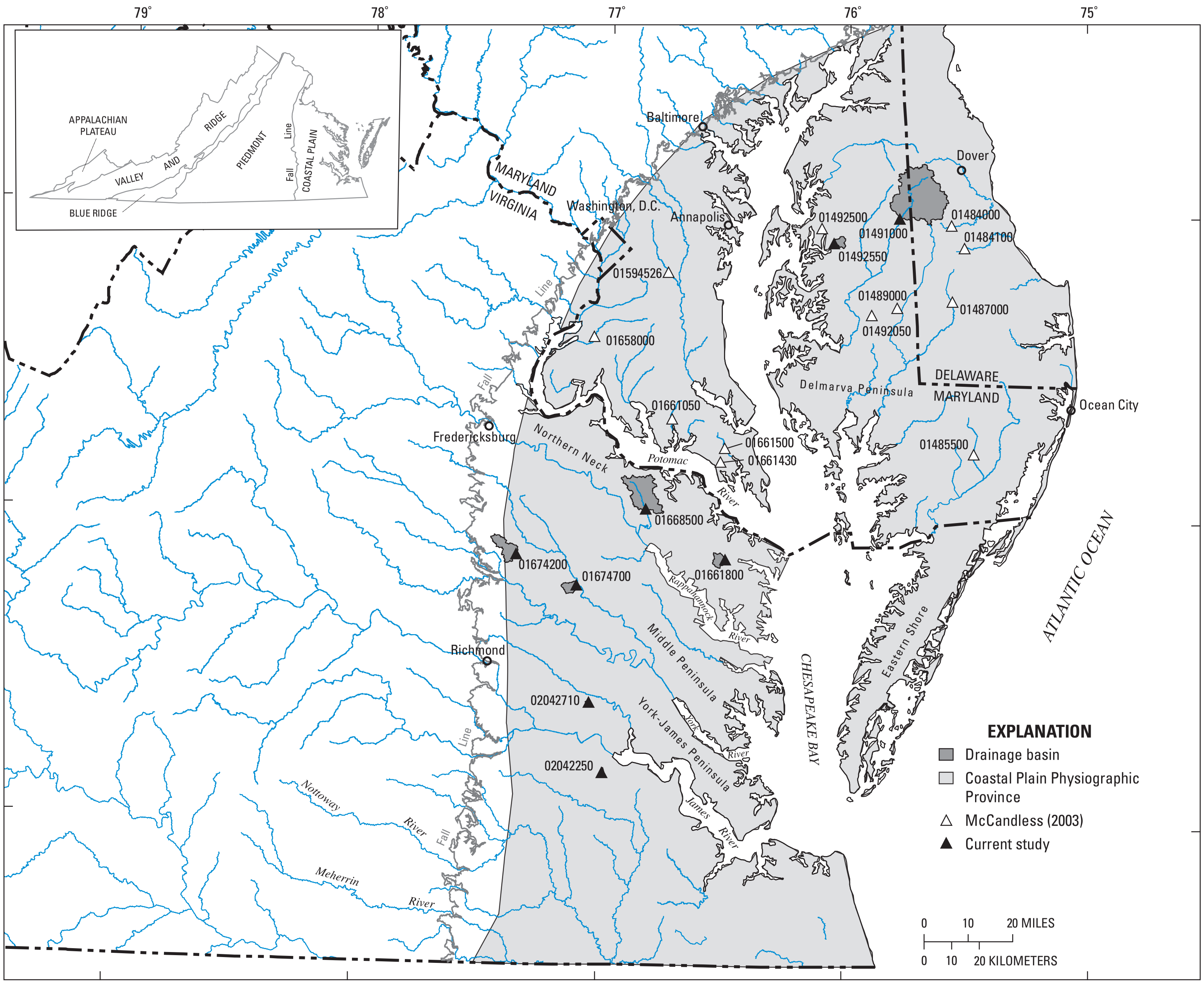
Description of Study Area

The Coastal Plain includes portions of all the states that border the Atlantic Ocean from Maine to Florida. The portion of the Coastal Plain of interest in this investigation includes parts of Virginia; Maryland; Delaware; Washington, DC; and North Carolina east of the Fall Line—the transition area between the Piedmont Physiographic Province and the Coastal Plain. The streams in the Piedmont Physiographic Province flow over resistant bedrock, which transitions into more easily eroded sediments in the Coastal Plain, producing numerous rapids, or falls at the boundary. While most of the data were collected in Virginia and Maryland (fig. 1), the potential transferability of regional curves within the Coastal Plain may prove useful to the stream restoration community. The portion of the Coastal Plain included in this investigation is an area of approximately 39,900 square miles (mi^2). Fifty Virginia counties and independent cities lie entirely or partially within the Coastal Plain, approximately 22 percent of the total land area in Virginia. Eighteen Maryland counties, 3 Delaware counties, 44 North Carolina counties, and Washington, DC, lie entirely or partially within the Coastal Plain.

According to the 2000 census (U.S. Census Bureau, 2004 a, b, c, d), approximately 13 million people live in the Coastal Plain in Delaware (4.5 million), Virginia (3.3 million), Maryland (2.5 million), North Carolina (2.4 million), and Washington, DC (0.3 million). The majority of people are concentrated in large urban areas, including the northern Virginia and western Maryland metropolitan areas near Washington, DC; the cities of Fredericksburg, Richmond, and the localities that collectively make up the Hampton Roads metropolitan area in Virginia; Baltimore, Annapolis, and Ocean City in Maryland; and Dover, Delaware. The remainder of the Coastal Plain is relatively sparsely populated, ranging from small towns to outlying non-urban areas composed of forest and agricultural land.

The climate of the region is temperate and humid, with a mean annual precipitation of approximately 43 inches (National Climate Data Center, 2005). The majority of precipitation falls during the months of May, June, July, and August (Daly, 1998).

The Coastal Plain is defined geologically by the underlying, mostly unconsolidated sediments of fluvial-deltaic and marine origin that thin toward their western limit near the Fall Line, where the Coastal Plain sediments meet the crystalline rock of the Piedmont Physiographic Province (Fenneman, 1938). In Virginia, a number of major rivers drain eastward into the Chesapeake Bay, most of which become brackish and tidal as they enter estuaries east of the Fall Line. From north to south, these rivers include, the Potomac River, Rappahannock River, York River, and James River. South of the Chesapeake Bay, the Nottoway and Meherrin Rivers flow through Virginia, into North Carolina, and into the Atlantic Ocean.



Base, state boundaries, and physiographic province boundaries from U.S. Geological Survey Digital Line Graph, 1:2,000,000, 1987
Universal Transverse Mercator 18 Projection, NAD27, Central Meridian 75°00'W
Hydrography from U.S. Environmental Protection Agency Reach File Version 1.0, 1:100,000, 1996
City locations from U.S. Census Cartographic Boundary Files, Consolidated Cities, 1:500,000, 2000
Virginia watersheds from Hayes and Wiegand (2006), 1:24,000
Maryland watersheds delineated from U.S. Geological Survey Digital Raster Graphics, 1:24,000

Figure 1. Site locations in Virginia, Maryland, and Delaware in the Coastal Plain Physiographic Province.

The topography of the Virginia Coastal Plain is characterized by rolling terrain with deeply incised stream valleys in the northwestern section and by gently rolling to level terrain with broad stream valleys in the eastern and southern sections (McFarland and Bruce, 2006). Detailed information about the underlying geology and aquifer system in Virginia is available in McFarland and Bruce (2006). Land-surface elevations decline seaward, ranging from over 300 feet (ft) above the North American Vertical Datum of 1988 (NAVD88) in the western Coastal Plain to sea level at the Atlantic coast. The mean land-surface elevation in the Coastal Plain in Virginia; Maryland; Washington, DC; and Delaware is 75.5 ft (U.S. Geological Survey, 2001). On the eastern side of the Chesapeake Bay, the land is referred to as the Eastern Shore in Virginia or the Delmarva Peninsula in Delaware and Maryland (fig. 1).

Development of Coastal Plain Bankfull Regional Curves

Six sites at streamflow-gaging stations in Virginia were surveyed, and 14 sites at streamflow-gaging stations in Maryland (surveyed by McCandless, 2003) were added to the dataset to develop regional curves for the Coastal Plain in Virginia and Maryland. Two sites from McCandless (2003) were re-surveyed during this study to verify results. Both field surveys and historical discharge data were used for bankfull identification. Detailed longitudinal and cross-sectional surveys of bankfull features at each site were used to calculate the bankfull channel geometry. The stage associated with the 1- to 2-year recurrence interval was used as a guide for field identification of bankfull features, although the true bankfull features may be higher or lower than that stage (Williams, 1978; Richards, 1982; Knighton, 1998). After surveys were completed, historical data were used to calculate the bankfull discharge for field-identified bankfull features. The bankfull cross-sectional area, bankfull width, bankfull mean depth, and bankfull discharge were regressed with drainage area by using the ordinary least squares method to construct bankfull regional curves.

Site Selection

Sites were selected by following criteria found in recent similar studies (Cinotto, 2003; McCandless, 2003; Chaplin, 2005; Keaton and others, 2005). Streams considered for this study showed few human alterations, such as channelization, dredging, or manmade bank stabilization structures. However, the existence of a streamflow-gaging station indicates some past human alteration to the stream, usually through the construction of a bridge or culvert to which the gage is attached. All streams with active or discontinued USGS streamflow-gaging stations in the Coastal Plain of Virginia were evaluated against seven selection criteria:

- At least 10 years of peak-flow data,
- Recoverable benchmarks referenced to staff gage elevations,
- Non-tidal flow conditions,
- Drainage basin area less than 250 mi^2,
- Drainage basin land use less than 20 percent urban,
- Flow regulated from less than 10 percent of the drainage area, and
- Stream reach exhibiting consistent bankfull features over a length of approximately 20 bankfull channel widths.

Six out of 51 Virginia sites met all seven selection criteria. Fifty-one streamflow-gaging stations met the peak-flow data criteria. Of the 51, 12 sites were excluded because the drainage areas were too large, and 11 sites were excluded because the land use in the basin was more than 20-percent urbanized. Twenty-five sites were visited to determine if bankfull features were identifiable. East of the Fall Line and at close proximity to the Chesapeake Bay, streams at low elevations often were tidal. Nine stream sites that were visited had flood plains filled with dense wetlands with undefined channel geometry. The primary reason they did not meet the selection criteria was the lack of consistent bankfull features. Streams in the Coastal Plain often transition between swamps with no identifiable channels and streams with identifiable channels. Streamflow-gaging stations often are installed at the short stretches where the flows are constricted by bridges or culverts. Examples include Dragon Swamp at Mascot (01669520), Seacock Creek near Ivor (02048400), and multiple sites on Cypress Swamp (02043500 and 02049700). Even though peak-flow data were available, there simply were not channel forms that met the classification criteria for this study. Other streams recently had experienced catastrophic events, such as a 200-year flood at Totopotomy Creek (01673550) that modified the channel geometry. Field observations suggest that recent hurricanes altered the geometry of many of the Coastal Plain streams making identification of bankfull features questionable.

The dearth of appropriate sites in Virginia prompted the inclusion of sites from Maryland (table 1). Fourteen sites in Maryland had previously been surveyed and were included in regional curves for the Coastal Plain of Maryland (McCandless, 2003). Although these sites meet the selection criteria set forth in this study, two were selected for duplicate surveys to compare results before the data from this study were combined with data from McCandless (2003).

Table 1. Streamflow-gaging stations used for development of regional curves for the Coastal Plain Physiographic Province in Virginia and Maryland.

[mi², square miles; ddmmss, degrees, minutes, seconds; NAD27, North American Datum of 1927; CSG, crest-stage gage; CRG, continuous-record gage]

Station name	Station number	Drainage area (mi^2)	Period of record	Station type	Latitude NAD27 (dd mm ss)	Longitude NAD27 (ddmmss)
Data from the current study						
Collins Run Tributary near Providence Forge, VA	02042710	0.28	1965–1975	CSG	372415	-770250
Bailey Branch Tributary at Spring Grove, VA	02042250	.71	1967–2004	CSG	371029	-765913
Mill Creek near Skipton, MD[a]	01492550	4.6	1966–1975	CSG	385500	-760342
Aylett Creek at Aylett, VA	01674700	6.17	1969–1995	CSG	374705	-770623
Bush Mill Stream near Heathsville, VA	01661800	6.82	1963–2005	CRG	375236	-762942
Reedy Creek near Dawn, VA	01674200	16.8	1951–2005	CSG	375255	-772135
Cat Point Creek near Montross, VA	01668500	45.6	1935–1999	CRG	380223	-764938
Choptank River near Greensboro, MD[a]	01491000	113	1948–2003	CRG	385950	-754709
Data from McCandless (2003)						
Glebe Branch at Valley Lee, MD	01661430	0.3	1968–1978	CSG	381140	-763113
Beaverdam Branch at Houston, DE	01484100	2.8	1958–2006	CRG	385420	-753047
Mill Creek near Skipton, MD	01492550	4.6	1966–1976	CSG	385500	-760342
Faulkner Branch at Federalsburg, MD	01489000	7.1	1950–1992	CRG	384244	-754734
Sallie Harris Creek near Carmichael, MD	01492500	8.1	1951–2006	CRG	385753	-760633
Gravel Run at Beulah, MD	01492050	8.4	1966–1975	CSG	384054	-755353
Murderkill River near Felton, DE	01484000	13.6	1931–1999	CRG	385833	-753403
St. Clements Creek near Clements, MD	01661050	18.5	1968–2006	CRG	381959	-764331
St. Mary's River at Great Mills, MD	01661500	24	1946–2005	CRG	381430	-763014
Nassawango Creek near Snow Hill, MD	01485500	44.9	1949–2007	CRG	381344	-752819
Mattawoman Creek near Pomonkey, MD	01658000	54.8	1949–2007	CRG	383546	-770323
Nanticoke River near Bridgeville, DE	01487000	75.4	1935–2006	CRG	384342	-753344
Western Branch at Upper Marlboro, MD	01594526	89.7	1985–2007	CRG	384851	-764456
Choptank River near Greensboro, MD	01491000	113	1948–2007	CRG	385950	-754710

[a] These streamflow-gaging stations were also surveyed by McCandless (2003) for the development of regional curves in the Maryland Coastal Plain. They were re-surveyed to establish whether the surveying techniques used in this study produced results similar to surveys conducted by McCandless (2003).

Basin Characteristics

Basin characteristics were derived to characterize basin-specific details about the land use, elevation, and precipitation regime of the sites surveyed during this investigation. Digital representations of the basin boundaries in this study were delineated for the six Virginia sites as part of an update of USGS drainage-basin areas for streamflow-gaging stations in Virginia (Hayes and Wiegand, 2006). The same methodology was followed for the two Maryland sites that were re-surveyed as part of this study. The digital basin-boundary geographic information system (GIS) layers for the eight sites surveyed during this study were used to extract basin characteristics for land use, mean elevation, and mean annual precipitation. A land-use raster dataset (30-meter (m) resolution) representing the year-2000 conditions (Goetz and others, 2004) was used to calculate the percent forest and percent wetland for each basin. The National Elevation Dataset (30-m resolution) was used to calculate mean elevation (U.S. Geological Survey, 2001). An average-annual precipitation vector dataset (4-kilometer (km) accuracy) derived from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) climate mapping system (Daly, 1998) was used to calculate mean annual precipitation for each basin.

Six sites were located on the western side of the Chesapeake Bay in Virginia, and two sites were located on the Delmarva Peninsula of Maryland. The sites range in size from 0.28 mi^2 to 113 mi^2 (table 2). The land-surface elevation

Table 2 Basin characteristics for streamflow-gaging stations surveyed during this study for development of regional curves for the Coastal Plain Physiographic Province in Virginia and Maryland.

[mi^2, square miles; ft, feet; NAVD88, North American Vertical Datum of 1988; in., inches]

Station name	Station number	Drainage area (mi^2)	Area forested[a] (percent)	Area wetlands[a] (percent)	Mean basin elevation[b] (ft NAVD88)	Mean annual precipitation (in.)	24-hour, 2-year rainfall[c] (in.)
Collins Run Tributary near Providence Forge, VA	02042710	0.28	88.9	1.7	108.2	43	3.13
Bailey Branch Tributary at Spring Grove, VA	02042250	.71	66.0	4.2	125.6	45	3.21
Mill Creek near Skipton, MD	01492550	4.6	13.6	2.0	52.0	43	3.02
Aylett Creek at Aylett, VA	01674700	6.17	75.8	1.9	124.9	43	2.96
Bush Mill Stream near Heathsville, VA	01661800	6.82	68.9	7.9	107.4	43	3.04
Reedy Creek near Dawn, VA	01674200	16.8	81.4	4.4	196.7	43	3.00
Cat Point Creek near Montross, VA	01668500	45.6	68.0	4.7	138.9	43	3.00
Choptank River near Greensboro, MD	01491000	113	50.6	5.4	57.0	43	3.00

[a] Percent forested and wetland areas from 2000 land cover dataset (Goetz and others, 2004).

[b] Mean basin elevation from U.S. Geological Survey National Elevation Dataset 30-m data (U.S. Geological Survey, 2001).

[c] Bonnin and others (2004).

in the Coastal Plain in Virginia; Maryland; Washington, DC; and Delaware ranges from 11.5 ft to 252 ft, with a mean elevation of 75.5 ft (U.S. Geological Survey, 2001). The mean elevation for each basin ranged from 52.0 ft to 196.7 ft above NAVD88. Seventy-five percent of mean elevations for each basin were higher than the mean elevation of the Coastal Plain in the study area. The minimum elevation for each basin ranged from 11.5 ft to 94.5 ft above NAVD88. Two sites had minimum elevations that were higher than the mean elevation of the Coastal Plain. All sites were non-tidal and higher on the landscape than many streams in the Coastal Plain. The sites all exhibit fairly well-defined cross-sectional geometry, while many low-lying coastal water courses, whether tidal or not, do not exhibit these characteristics. Mean annual precipitation at the sites was about 43 inches (in.), except for Bailey Branch Tributary near Spring Grove, Virginia, which had a mean annual precipitation of about 45 in. (table 2).

Basin land use was dominated by forest, with all but one basin having more than 50-percent forested land (table 2). Mill Creek has 13.6-percent forested land and 80-percent agricultural land. An average of 4 percent of each basin land use was wetland as classified in Goetz and others (2004). The National Wetlands Inventory reported an average of 6 percent of each basin land use as wetland (U.S. Fish and Wildlife Service, 1979). The predominance of wetlands in the flood plain may not be accurately represented by the numbers presented in table 2 because field observations indicated a high percentage of the active flood plain consisted of herbaceous and forested wetlands, which appeared to be closely tied to the stream and shallow ground-water system (fig. 2).

Field Data Collection

Field data were collected between May 2005 and October 2006 for the purpose of computing bankfull geometry and discharge. Because these computations are based on the relative elevation of the bankfull channel, data collection

Figure 2. A flood plain wetland at the Cat Point Creek study site in Virginia. View from the left bank of the cross section toward the water edge near large trees.

was focused on identification and surveying of bankfull features. Before surveying, the field team walked a distance of at least 20 times the estimated bankfull width upstream or downstream from the streamflow-gaging station to identify potential morphological features representing bankfull stage. These bankfull features typically included:

- the top of the bank (fig. 3), or
- a prominent break in slope at an elevation lower than the top of the bank, or
- the elevation of depositional features, such as a bench feature on the bank (fig. 4).

At most sites in this study, the top of the bank represented the top of the bankfull channel. The active flood plain often decreased in elevation as it sloped away from the active channel into flood plain wetlands. This indicated that sediment has been repeatedly deposited as the stage exceeded bankfull and energy dissipated on the flood plain. Breaks in slope at an elevation lower than the top of the bank and point bars (fig. 4) were the next most common features that indicated the bankfull channel. In Bailey Branch Tributary and Collins Run Tributary (table 1), the channel was slightly incised but appeared to be building a new bankfull channel with identifiable benches. The higher features in these basins were terraces, with lower bankfull features defining the bankfull channel. These two sites are the only sites located south of the James River; they have the smallest drainage areas in Virginia and the steepest slopes. They were included in the dataset partly because they represent channel forms that were not present in more northern parts of the study area. The consistency of these benches throughout the surveyed sites indicates that the streams met the selection criteria for inclusion in the study.

Figure 3. Bankfull features representing the top of the bank at Mill Creek in Maryland. Survey rod base is at the top of the bankfull feature.

Figure 4. Bankfull bench or point bar along the right bank of Cat Point Creek in Virginia. Flow is from right to left.

Surveys of the Bankfull Channel

At each site, a longitudinal profile of the study reach and two cross-section surveys at selected riffles within the reach were completed following procedures described by Harrelson and others (1994), Leopold (1994), and Rosgen (1996). By definition, streams that have bed material in the size range of 2 millimeters (mm) to 256 mm develop the characteristic riffle-pool sequences (Knighton, 1998) that are common in the streams in other physiographic provinces in Virginia and Maryland. The streams in the Coastal Plain observed during this study had varied bed material, usually dominated by sand (0.125 mm to 2 mm). Often the bed material was heterogeneous, with gravel as large as 90 mm in size. It has been noted that concentrations of coarse particles analogous to riffles and spaced at five to seven times the channel width can be found in sand-bed streams (Leopold and others, 1966). Throughout the field surveys, streams were evaluated under the premise that pool-riffle sequences could be present. In the sand-bed streams, the shallowing of the thalweg and coarsening of the bed material were used to indicate the location of a riffle. This methodology was used to keep the selection criteria consistent for all streams.

The longitudinal profile consisted of an elevation profile of bankfull indicators, thalweg, and current water surface along the study reach, which extended at least 20 bankfull widths. The study reach also included the location of the streamflow-gaging station. If more than one possible bankfull feature was consistent throughout the reach, all features were surveyed but only one was ultimately selected as the bankfull feature. At stations along the longitudinal profile where bankfull features were not well defined, only water surface and thalweg were surveyed. Cross-section surveys were completed at two riffles within the study reach for computation of bankfull area, width, mean depth, and discharge. The elevation of the bankfull feature selected at each cross section was graphically compared to the longitudinal elevation profile of the bankfull channel to ensure that the two were similar.

The longitudinal profile of the bankfull channel and cross sections were surveyed using a laser level and a 2–3 person field crew. All surveys were referenced to a previously established datum at each streamflow-gaging station. Laser levels provide vertical elevation information but do not provide horizontal coordinates. For the longitudinal profile, horizontal stationing was determined with a measuring tape placed along one edge of the stream. For the cross sections, a tape was secured on the left bank and strung across to the right bank for stationing. The average of the channel geometry parameters from the two cross-section surveys was used in the regression analysis to develop regional curves.

Pebble Counts

Pebble counts were conducted at the two riffle cross sections, following a modified Wolman (1954) methodology to document the particle-size distributions. Pebbles were selected by extending a finger into the water without looking and picking up the first particle touched (first blind touch). Particles were collected within the bankfull channel at regular intervals from bankfull to bankfull, including some bank particles, until a count of 100 was reached. The intermediate diameter (Wolman, 1954) of particles larger than 2 mm was measured with a ruler to the nearest millimeter. Particles smaller than 2 mm were compared with a sand gauge card for size classification. The diameter of each particle was recorded and grouped by sieve-size classes (comparable to using a square sieve to sort the material) based on the Wentworth scale (Leopold and others, 2000; Bunte and Abt, 2001). The sieve-size class for a particle of 15 mm would be represented as 16 mm, indicating that the particle is smaller than 16 mm but larger than 11 mm. The diameter of the median particle (D_{50}) (Leopold and others, 1964) was calculated by ranking all records for particle sizes and selecting the 50th percentile. The particle size that is two standard deviations higher is the D_{84} or the particle size that is larger than 84 percent of the sample (Leopold and others, 1964). The data from both cross sections were combined to determine the D_{50} and D_{84} representative of riffles within the reach.

Bankfull Discharge

For this study, bankfull discharge is defined as the flow that represents, or is a surrogate for, the range of flows that form the bankfull channel (Emmett, 2004). Even though larger flows may move appreciably more sediment during a given event, the bankfull discharge is expected to move the most sediment in a stream over time, thereby maintaining the flood plain, building point bars and meanders, and shaping the channel (Dunne and Leopold, 1978). This characterization of bankfull discharge has also been referred to as effective discharge—the discharge that transports the largest fraction of annual-sediment yield over a period of years (Andrews, 1980). Even though the similarity of these terms is debatable (Pickup and Warner, 1975), many have concluded that the bankfull discharge reasonably represents the effective discharge (Wolman and Miller, 1960; Andrews, 1980; Rosgen, 1996) and is an adequate surrogate for the range of flows that form a channel in streams that do not have very resistant boundaries (Knighton, 1998).

The recurrence frequency for bankfull discharge has also been a source of debate. Some investigators have suggested there is no common recurrence frequency (Williams, 1978), but the majority have indicated bankfull discharge can be expected over a relatively narrow range of recurrence intervals. For example, Rosgen (1996) indicates bankfull discharge occurs approximately every 1 to 2 years, and Wolman and Miller (1960) define the recurrence frequency even more narrowly as approximately every 1.5 years. Data-collection methods developed in the mid-1990s for natural-channel design assumed that bankfull discharge has a recurrence frequency of less than 2 years (Harrelson and others, 1994). More recently, bankfull discharge was assumed to have a recurrence frequency of 1 to 3 years for regional curve development in New York (Powell and others, 2004; Westergard and others, 2005) and 1 to 2 years for regional curve development in Pennsylvania (White, 2001; Cinotto, 2003; Chaplin, 2005) and parts of Maryland, Virginia, and West Virginia (Keaton and others, 2005). The assumptions for this study generally are consistent with previous work of similar nature. The recurrence frequency of bankfull discharge was expected to be between 1 to 2 years, but bankfull features corresponding to discharges outside of this range were considered.

Procedures described by Harrelson and others (1994), Rosgen (1996), and Powell and others (2004) were followed for identification of the bankfull channel and subsequent determination of bankfull discharge. These procedures are consistent with those used by Keaton and others (2005) in the Valley and Ridge Physiographic Province of Virginia. Long-term streamflow and cross-sectional geometry data stored by the USGS in the Automated Data Processing System (ADAPS; U.S. Geological Survey, 2003) were used in combination with bankfull indicators identified in the field to define the bankfull channel at each site.

After the bankfull channel was defined along the reach including the streamflow-gaging station, the water-surface elevation (stage) that would occur in the bankfull channel and a relation between stage and discharge (rating) were used to select the discharge that corresponded to the elevation of the bankfull channel at the streamflow-gaging station. The recurrence frequency of the bankfull discharge was then determined by comparing the bankfull discharge to a frequency distribution of annual peak discharges fit to a Pearson Type III frequency distribution (Hydrology Subcommittee of the Interagency Advisory Committee on Water Data, 1982).

Comparison Surveys of Maryland Sites

Two sites were selected for duplicate surveys to establish whether the surveying techniques used in this study produced results similar to surveys conducted for the Maryland Coastal Plain regional curves (McCandless, 2003). One site with a large drainage area, Choptank River near Greensboro, MD (113 mi^2), and one site with a small drainage area, Mill Creek near Skipton, MD (4.6 mi^2), were selected for duplicate surveys to compare channel geometry at both ends of the range of drainage areas. The duplicate surveys were conducted to ensure that the variability observed was not due to differing survey techniques. The methods described in this report were used to survey both Maryland sites. Cross sections were selected on the basis of field personnel judgment and not necessarily at the exact same location as McCandless (2003). The resulting channel geometry measurements indicate that the surveying techniques used in this study produced similar results (table 3).

Bankfull width and mean depth can be highly variable, but their product, cross-sectional area, tends to be a more consistent characteristic. For Choptank River, the largest site included in this investigation, there was a 0.2-percent difference in cross-sectional area between the McCandless (2003) survey and that conducted in this study (table 3). For Mill Creek there was a 12.2-percent difference in the cross-sectional area between the McCandless (2003) survey and that conducted in this study (table 3). Streams with large basins tend to have less variability in cross-sectional channel geometry than streams with small basins, so it was not surprising that the difference between Mill Creek surveys was larger. Bankfull width and mean depth measurements were more variable than cross-sectional area for the duplicate surveys. For the Choptank River, the bankfull width differed by 19.2 percent, and mean depth differed by 16.6 percent. For Mill Creek, the bankfull width differed by 26.3 percent, and mean depth by 18.8 percent. The McCandless (2003) cross section locations for Mill Creek appear to be 400 ft downstream from those surveyed for this study, and there were some wetland drainages in between the cross sections, which may account for the differences in width and depth. In addition to the duplicate field surveys, an analysis of covariance test between the McCandless (2003) data and that of this study showed no significant difference in the slope or intercepts for either regression. The test and results are described in the section comparing the Coastal Plain Regressions for Maryland, North Carolina, and Virginia. The McCandless (2003) data and the six sites surveyed during this study were combined into one dataset for the development of one set of regional curves for the Coastal Plain in Virginia and Maryland.

Table 3. Duplicate-survey results from stream bankfull channel geometry surveys at two streamflow-gaging stations in Maryland.

[USGS, U.S. Geological Survey; na, not applicable]

	McCandless (2003)	USGS (This study)	Percent difference
Choptank River near Greensboro, Maryland (01491000)			
Bankfull area, in square feet	383.0	382.5	0.2
Bankfull width, in feet	97.2	115.9	-19.2
Bankfull mean depth, in feet	3.9	3.3	16.6
Width-to-depth ratio	24.7	35.5	-43.9
Rosgen stream type[a]	C5c	C	na
Mill Creek near Skipton, Maryland (01492550)			
Bankfull area, in square feet	27.1	23.8	12.2
Bankfull width, in feet	26.8	19.8	26.3
Bankfull mean depth, in feet	1.0	1.2	-18.8
Width-to-depth ratio	26.5	16.2	38.9
Rosgen stream type[a]	C5	C	na

[a] From Rosgen (1996).

Analysis of Bankfull Channel Data

Bankfull features from the longitudinal profile surveys that were relatively consistent throughout the reach, nearly parallel to the water-surface slope, and were located at a reasonable elevation based on the 1- to 2-year recurrence interval range were used to define the bankfull channel throughout the reach. Only bankfull features that met these criteria were retained in the final longitudinal profile plots (appendix 1). Bankfull elevations from the two cross-section surveys were plotted with the longitudinal profiles and served as an additional check that bankfull was appropriately defined.

The longitudinal profiles and cross-section bankfull elevations were used to select the bankfull stage at the streamflow-gaging station. A trend line through the longitudinal profile bankfull features was extended through the location of the streamflow-gaging station. The elevation where the trend line crossed the location of the streamflow-gaging station represents bankfull stage. Bankfull discharge (table 4) was determined by comparing this bankfull stage to ratings available for each site. The ratings relate stage to discharge over a range of hydrologic conditions, including bankfull discharge.

Table 4. Bankfull channel geometry data collected for this study in streams in the Coastal Plain Physiographic Province in Virginia and Maryland.

[Values in the table represent the average of two cross sections for each site. mi^2, square miles; ft^2, square feet; ft, feet; ft^3/s, cubic feet per second; mm, millimeters; >, greater than; <, less than]

Station name	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)	D50[a] (mm)	D84[b] (mm)	Width: depth ratio	Entrenchment ratio	Channel slope (ft/ft)	Rosgen stream type[c]
Collins Run Tributary near Providence Forge, VA	02042710	0.28	6.2	7.7	0.8	19.5	1.5	20.2	2	8	9.8	2.7	0.0049	E
Bailey Branch Tributary at Spring Grove, VA	02042250	.71	13.4	10.3	1.3	48.0	2.1	30.0	11	32	7.6	2.7	.0039	E
Mill Creek near Skipton, MD	01492550	4.6	23.8	19.8	1.2	30.1	1.0	90.6	.5	2	16.2	> 4.6*	.0017	C
Aylett Creek at Aylett, VA	01674700	6.17	30.8	16.6	1.9	170.0	1.3	198.4	4	8	8.9	> 6.3*	.0015	E
Bush Mill Stream near Heathsville, VA	01661800	6.82	58.3	23.3	2.5	49.8	< 1 year	127.0	.5	2	9.3	> 4.2*	.0025	E
Reedy Creek near Dawn, VA	01674200	16.8	50.5	25.9	2.0	116.0	1.1	144.3	.25	2	13.3	> 4.5*	.0038	C
Cat Point Creek near Montross, VA	01668500	45.6	97.0	31.3	3.1	109.6	< 1 year	476.4	1	2	10.4	> 10.2*	.0025	E
Choptank River near Greensboro, MD	01491000	113	382.5	115.9	3.3	636.6	1.1	1450.0	11	23	35.5	> 2.2*	.0002	C

[a] Particle size larger than 50 percent of cross section streambed material, or median particle size; value represents the sieve size a particle would not pass through.

[b] Particle size larger than 84 percent of cross section streambed material.

[c] From Rosgen (1996). This classification system is not applicable for all Coastal Plain streams. Numerical designation for particle size was not assigned because pebble counts were only conducted at riffles.

* The flood-prone elevation was not surveyed because the flood-plain elevation was lower than two times bankfull elevation for more than 60 feet in either direction from the channel.

The recurrence interval (table 4) of each bankfull discharge was determined from a frequency distribution of annual peak discharges following methods described by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (1982). All but two sites had recurrence intervals between 1 and 2 years. Cat Point Creek, VA, and Bush Mill Stream, VA, had recurrence intervals less than 1 year. Both sites are in the Northern Neck, have sand-bed channels, and have high percentages of wetlands in the basin. Only one site had a recurrence interval greater than 1.5 years. Coastal Plain basins may have large percentages of wetland storage, which may contribute to low bankfull-discharge recurrence intervals. The slope of the reach from one riffle thalweg elevation to a downstream riffle thalweg elevation was calculated for each site (table 4; Leopold and others, 1964).

Two cross-section profiles for each site were plotted showing the water-surface elevation at the time of the survey and the bankfull stage (appendix 1). Bankfull cross-sectional area, bankfull width, and bankfull mean depth for each riffle were determined from field data, along with the D_{50}- and D_{84}-particle size for the two riffles combined (table 4; appendix 1). Additional ratios were calculated from the cross-section geometry data (table 4): width-to-depth ratio (bankfull width divided by mean depth) and entrenchment ratio (flood-prone width divided by bankfull width). The flood-prone width represents the elevation on the flood plain that equals the elevation of two times the deepest point of the bankfull cross section (Rosgen, 1996). The entrenchment ratio provides a reference to how steep and wide the flood plain is relative to the bankfull width. The width-to-depth ratio and entrenchment ratio values in table 4 were calculated as the average of the two cross sections for each site.

Comparison of Coastal Plain Regressions for Maryland, North Carolina, and Virginia Stations

More than 15 sets of regional curves have been developed for physiographic provinces in the Eastern United States (Natural Resources Conservation Service, 2007). Dunne and Leopold (1978) found consistent patterns in channel geometry within this portion of the United States. The availability of data for the Coastal Plain in Virginia and the two adjacent states of Maryland and North Carolina provides an opportunity to examine regional patterns within one physiographic province. There are three questions to consider:

- Are the datasets from Virginia, Maryland, and North Carolina significantly different from each other?
- Are the site-selection criteria and survey methodologies similar for each state?
- Could the datasets be combined to create one set of Coastal Plain regional curves that explain more variability than the regional curves for any one state?

The first question was addressed through statistical examination of the slopes and intercepts of channel geometry regressions for each state. Individual regressions for Virginia (n = 6), Maryland (n = 14; McCandless, 2003), and North Carolina stations (n = 16; Doll and others, 2003) were plotted together for comparison (figs. 5, 6, 7, and 8). An analysis of covariance (ANCOVA) was performed to determine if there were significant differences in slopes or intercepts between the regressions plotted in figures 5–8. Within the statistical package, MATLAB (The MathWorks, Inc., 2006), the ‘aoctool’ function was used to perform the ANCOVA and calculate the simple linear regressions for three groups—Virginia, Maryland, and North Carolina. A multiple comparison procedure was used to compare regressions of each group (Virginia and Maryland, Maryland and North Carolina, North Carolina and Virginia) and to determine whether pairs of slopes or intercepts were significantly different based on a specified alpha level (alpha = 0.05).

The compare procedure subtracts the Virginia slope from the Maryland slope to examine the overlap in the slopes of each pair of regressions. The same is done for paired regression intercepts. The range of overlap is described by a 95-percent confidence interval for the difference in values (The MathWorks, Inc., 2006). If the confidence interval includes zero, there is enough overlap in the slope or intercept values of the two regressions that they cannot be considered significantly different (The MathWorks, Inc., 2006).

The slopes and intercepts for each regression model were paired with those of another state, with all combinations examined as part of the ANCOVA procedure. The results of this analysis indicated no differences in the slopes or intercepts for the regressions of drainage area and bankfull cross-sectional area, bankfull width, or bankfull mean depth at the 95-percent significance level (all confidence intervals contained zero). However, the results of the analysis of the regressions of drainage area and bankfull discharge indicated a significant difference in the slopes of Virginia and Maryland, and Virginia and North Carolina. In the Maryland Coastal Plain regional curves study, the bankfull discharge was significantly higher for sites on the west side of the Chesapeake Bay than on the east side (McCandless, 2003). This was attributed to differences in channel slope in the basins studied. To test whether western sites (which commonly have steeper slopes (McCandless, 2003)) would show a similar distribution, the Virginia regression was compared with a regression of only Maryland western sites, but the results still showed a significant difference between the slopes of the regressions. By including only western sites from the Maryland dataset, the regression contained four sites with large drainage areas and only one site with a small drainage area, increasing the potential that the site with a small drainage area could disproportionately influence the regression slope. The Virginia regression contained six sites with mid-range drainage areas.

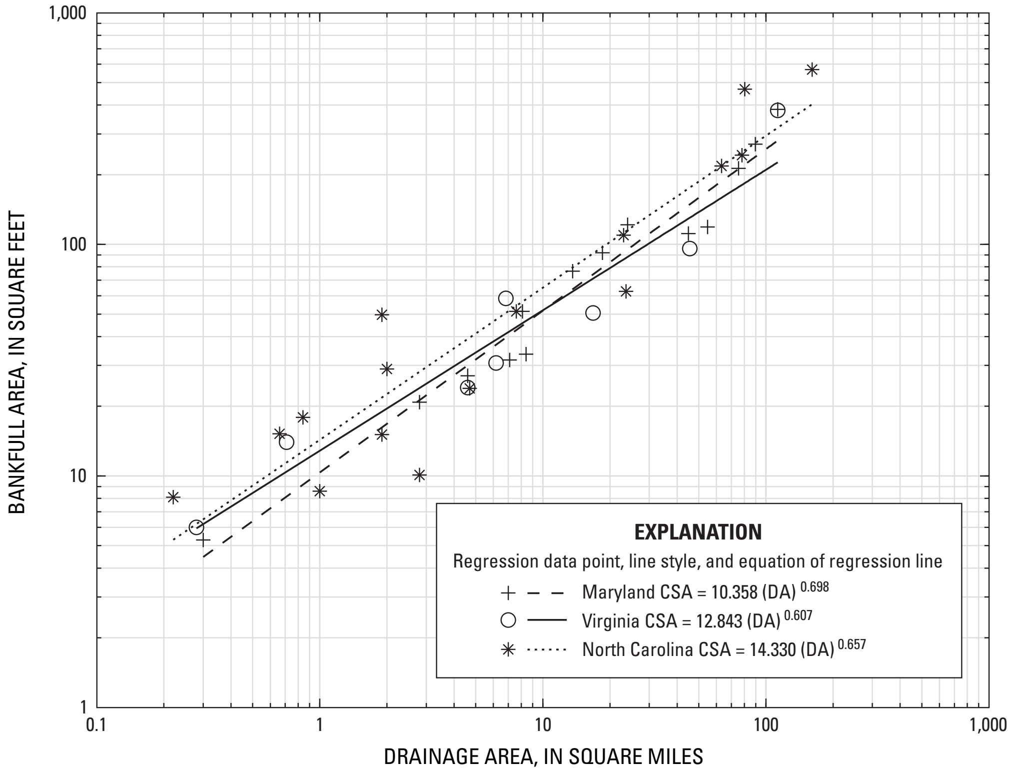


Figure 5. Log-log plot of three regressions of bankfull cross-sectional area (CSA) and drainage area (DA) for streams in the Coastal Plain Physiographic Province in Maryland, Virginia, and North Carolina.

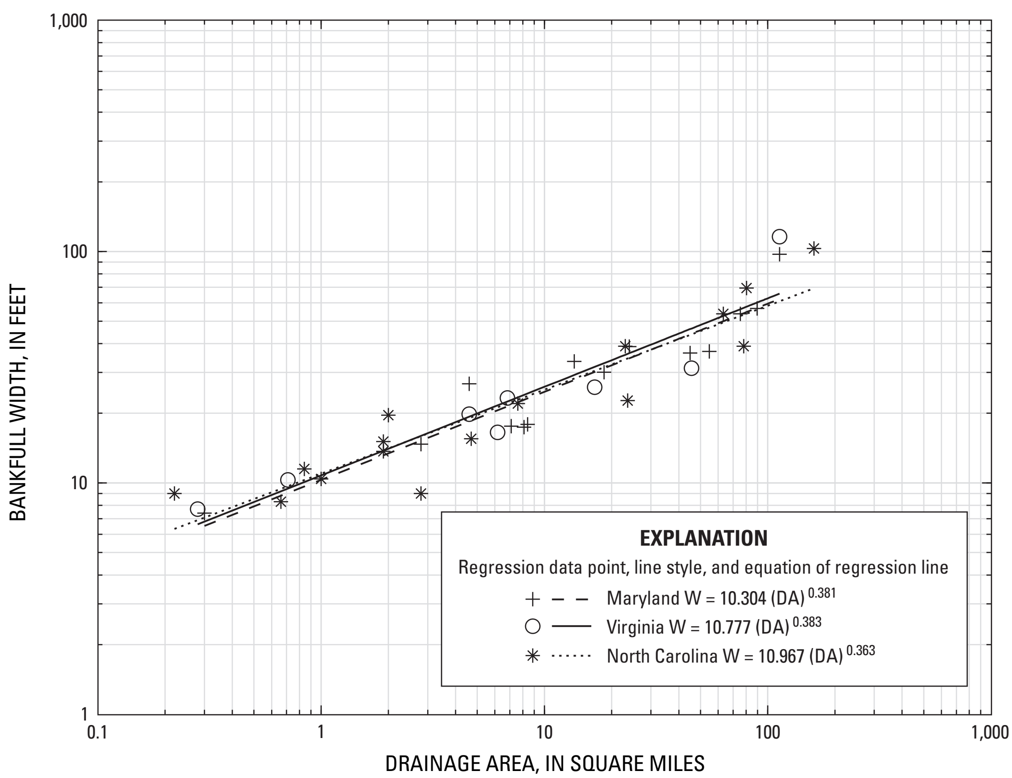


Figure 6. Log-log plot of three regressions of bankfull width (W) and drainage area (DA) for streams in the Coastal Plain Physiographic Province in Maryland, Virginia, and North Carolina.

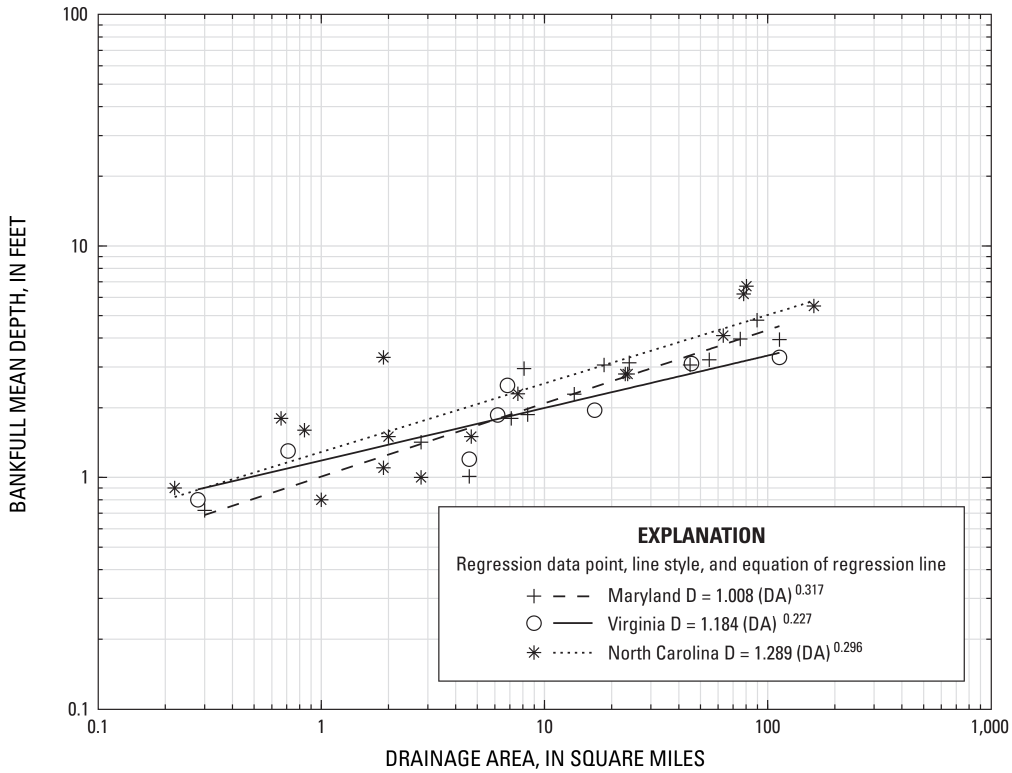


Figure 7. Log-log plot of three regressions of bankfull mean depth (D) and drainage area (DA) for streams in the Coastal Plain Physiographic Province in Maryland, Virginia, and North Carolina.

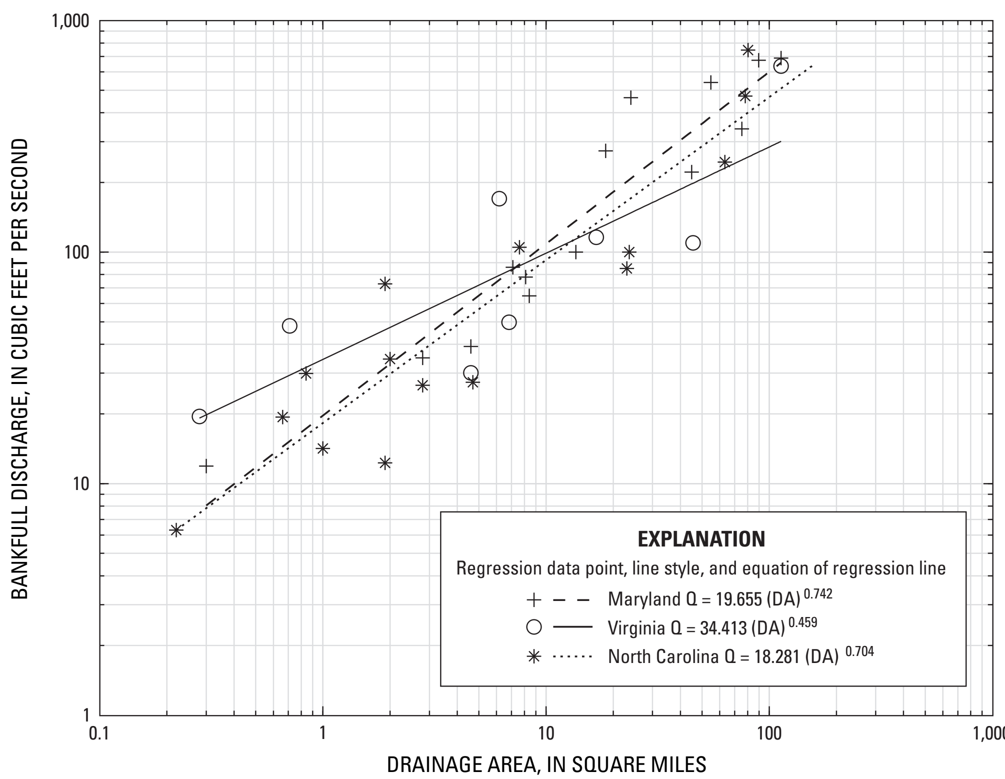


Figure 8. Log-log plot of three regressions of estimated bankfull discharge (Q) and drainage area (DA) for streams in the Coastal Plain Physiographic Province in Maryland, Virginia, and North Carolina.

The site-selection criteria and the survey methodologies were evaluated for Maryland and North Carolina studies. The Maryland data (McCandless, 2003; table 5) represent channel geometry from published surveys of sites where USGS streamflow-gaging stations are located. The site-selection process for inclusion in the Maryland regional curves was similar to that of this study. Survey results published in McCandless (2003) were verified during this investigation with two duplicate surveys (table 3). The North Carolina data (Doll and others, 2003) represent channel geometry from an on-line draft report and include nine reference reaches that are not located at USGS streamflow-gaging stations. Only seven of the North Carolina sites surveyed were located at USGS streamflow-gaging stations. While reference sites are useful in stream restoration design, they lack the historical data to verify the discharge relation and recurrence interval that a long period of record at a USGS streamflow-gaging station affords. North Carolina survey results were not verified through duplicate surveys during this investigation because this was outside the scope of work. The North Carolina cross-section surveys were conducted at both riffles and runs, whereas the Virginia and Maryland cross-section surveys were conducted only at riffles.

The source of variability in bankfull geometries is an important consideration in the decision to include or omit data. Variability due to natural channel-forming processes can largely be explained by drainage area (Leopold, 1994; Rosgen, 1996). However, variability resulting from different site-selection criteria or methods cannot be explained by drainage area and may lead to spurious relations. The similarity of the site-selection criteria for this study and McCandless (2003), along with relatively good agreement between duplicate surveys, supports the combination of these two datasets into one composite dataset. Because survey results presented in Doll and others (2003) were not verified through duplicate surveys and some sites were not at USGS streamflow-gaging stations, further study would be necessary to support inclusion of the North Carolina data. For this study, only the data collected at the 20 sites in Maryland and Virginia were considered for regional curve development.

The third question was addressed by comparing the regression statistics for sites surveyed for this study and a combined dataset of sites surveyed for this study and sites surveyed by McCandless (2003). The regression statistics for regional curves developed with data from this study (n = 8) compared with regional curves developed with the combined data from both studies (n = 20) indicate that the regression was strengthened with the addition of McCandless (2003) data. The amount of variability in bankfull geometry or discharge that is explained by drainage area is measured with the coefficient of determination (R^2). With the addition of McCandless (2003) data to the regression, the R^2 statistic for cross-sectional area increased from 0.925 to 0.945, indicating that drainage area explains 2 percent more of the variability. It is expected that the residual standard error (SE) would decrease as the predictive power of a regression increases.

Table 5. Bankfull channel geometry data collected by McCandless (2003) in streams in the Coastal Plain Physiographic Province in Maryland and Delaware.

[mi^2, square miles; ft^2, square feet; ft, feet; ft^3/s, cubic feet per second; mm, millimeters]

Station name	Station number	Drainage area (mi^2)	Cross-sectional area[a] (ft^2)	Width (ft)	Mean depth (ft)	Estimated discharge (ft^3/s)	Recurrence interval (years)	Rosgen stream type[b]
Glebe Branch at Valley Lee, MD	01661430	0.3	5.3	7.4	0.7	11.9	1.1	C4
Beaverdam Branch at Houston, DE	01484100	2.8	20.9	14.7	1.4	35.0	1.4	E5
Mill Creek near Skipton, MD	01492550	4.6	27.1	26.8	1.0	39.1	1.1	C5
Faulkner Branch at Federalsburg, MD	01489000	7.1	31.6	17.6	1.8	85.9	1.2	E5
Sallie Harris Creek near Carmichael, MD	01492500	8.1	51.3	17.4	3.0	78.0	1.1	E5
Gravel Run at Beulah, MD	01492050	8.4	33.5	17.9	1.9	64.7	1.4	E5
Murderkill River near Felton, DE	01484000	13.6	76.7	33.5	2.3	100.0	1.1	C5c-
St. Clements Creek near Clements, MD	01661050	18.5	92.1	30.1	3.1	273.4	1.2	E5
St. Mary's River at Great Mills, MD	01661500	24	121.4	38.8	3.1	464.9	1.2	C4
Nassawango Creek near Snow Hill, MD	01485500	44.9	111.4	36.4	3.1	221.6	1.1	E5
Mattawoman Creek near Pomonkey, MD	01658000	54.8	119.1	37.0	3.2	540.0	1.2	C4
Nanticoke River near Bridgeville, DE	01487000	75.4	213.0	53.8	4.0	340.7	1.2	C5c-
Western Branch at Upper Marlboro, MD	01594526	89.7	271.0	56.7	4.8	673.2	1.0	C5c-
Choptank River near Greensboro, MD	01491000	113	383.0	97.2	3.9	689.3	1.1	C5c-

[a] Values updated to represent the product of width and depth, and rounded to one decimal place.

[b] From Rosgen (1996).

With the addition of the McCandless (2003) data, the SE for cross-sectional area decreased from 0.372 to 0.279. Prediction intervals around the regression of the combined dataset were 33 percent narrower than prediction intervals around the regression of data from this study alone. Increases in R^2 statistic and the decreases in SE were of similar magnitude for bankfull width, mean depth, and estimated bankfull discharge as those presented for cross-sectional area. These evaluations support the combination of sites surveyed for this study and sites surveyed by McCandless (2003; n = 20) into a composite dataset for the creation of one set of regional curves for the Coastal Plain.

Coastal Plain Regional Curves

Simple linear regression techniques were used to develop regional curves for the Coastal Plain in Virginia and Maryland from two sources of data: (1) channel geometry data from 8 sites that were surveyed for this study in the Coastal Plain of Virginia and the Delmarva Peninsula of Maryland (table 4), and (2) the remaining 12 sites surveyed by McCandless (2003) that were not duplicated in this study (table 5) for a total of 20 sites in the regression analysis. MATLAB version 7.3.0.267 (R2006b) software (The MathWorks, Inc., 2006) was used for the statistical analyses and graphics.

The response variables—bankfull cross-sectional area, bankfull width, and bankfull mean depth and estimated bankfull discharge for all 20 sites (tables 4 and 5)—were regressed against the explanatory variable—drainage area—to show the relation between drainage area and each of the variables. The relation between drainage area and each response variable was described by fitting a power function with a best-fit line through the data points for each parameter using the least-squares method. The power functions were plotted on a log-log scale. The resulting power functions commonly have the form: $y = a(DA)^b$. For the purpose of computing diagnostic statistics, the power functions were transformed to a log-linear form:

$$\ln(y) = \ln(a) + (b * \ln(DA)) \tag{1}$$

where

- ln = natural log, base e,
- y = bankfull response variable,
- DA = drainage area,
- a = the intercept of the regression line, and
- b = a coefficient of the regression line representing the slope of the regression line.

The power functions that relate bankfull cross-sectional area, width, mean depth, and estimated bankfull discharge to drainage area representing the Coastal Plain of Virginia and Maryland are illustrated in figures 9, 10, 11, and 12. Table 6 gives the equations and diagnostic statistics for each regression. These regional curves also show the 95-percent prediction intervals for individual estimates of the response variable. Prediction intervals represent 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, 2002, p. 242–245; Keaton and others 2005).

Regional curves (and other regression relations) are only estimates of the true relation between bankfull response variables and drainage area because they are generated from a sample of sites that is intended to represent the population. The applicability of regional curves depends on how well the sample of sites represents the population, adherence to the assumptions of the underlying regression model, the fit of the

Table 6. Equations and diagnostic statistics for regional curves relating drainage area to bankfull discharge and bankfull channel geometry for streams in the Coastal Plain Physiographic Province in Virginia and Maryland.

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

Equation	R^2	Residual standard error (natural log base e)	Residual standard error (percent)[a]	n	p-value for regression slope[b]	F-statistic	F-statistic p-value[c]	p-value for Lillietest[d]
$CSA = 11.9899*(DA)^{0.63803}$	0.945	0.279	28.6	20	<0.0001	306.39	< 0.0001	0.137
$W = 10.4459*(DA)^{0.36543}$	.890	.232	23.1	20	< .0001	145.93	< .0001	.386
$D = 1.145*(DA)^{0.27345}$	.871	.190	18.1	20	< .0001	121.80	< .0001	.116
$Q = 28.3076*(DA)^{0.59834}$	.793	.552	59.3	20	< .0001	68.87	< .0001	.307

[a] Conversion from residual standard error natural log to percent, following Tasker (1978).

[b] p-value less than 0.05 means that the slope of the regression is different than zero.

[c] p-value of the F-statistic presented although assumption of log-normal distribution is not met.

[d] Lillietest (The MathWorks Inc., 2006) performs a Lillilifors test of the default null hypothesis that the sample in vector x comes from a distribution in the normal family, against the alternative that it does not come from a normal distribution. A p-value of greater than 0.05 indicates that the regression residuals are normally distributed.

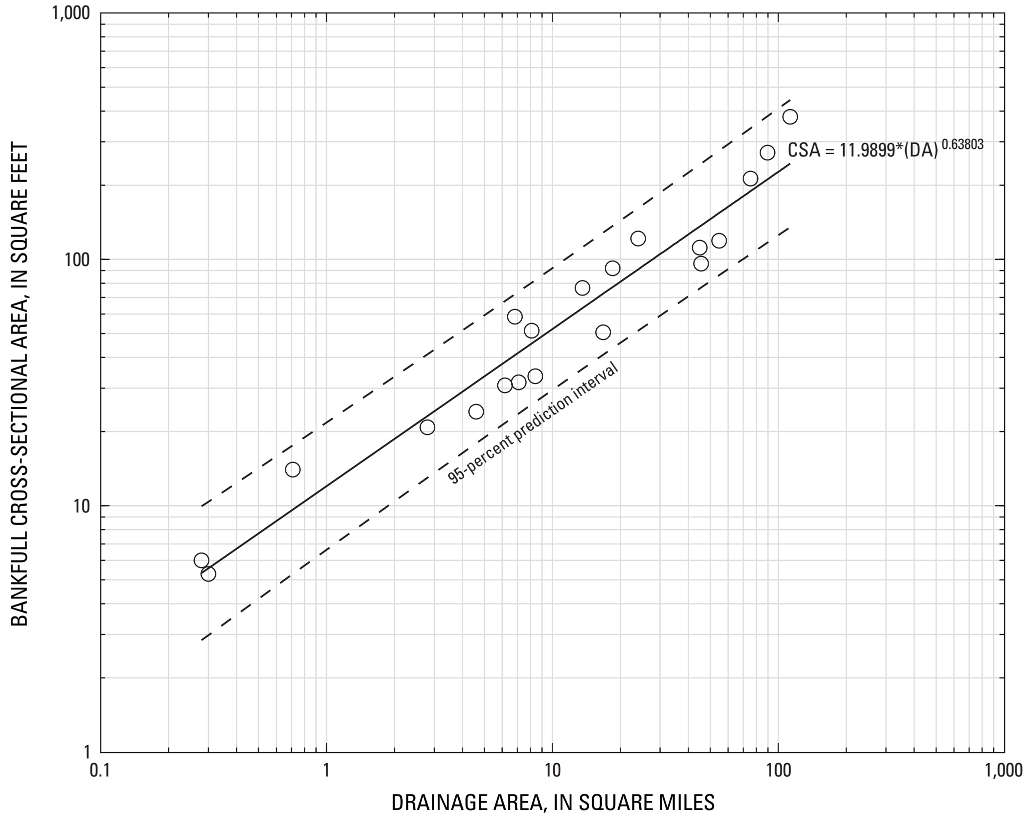


Figure 9. Regional curve relating bankfull cross-sectional area (CSA) to drainage area (DA) for streams in the non-urban, non-tidal Coastal Plain Physiographic Province of Virginia and Maryland.

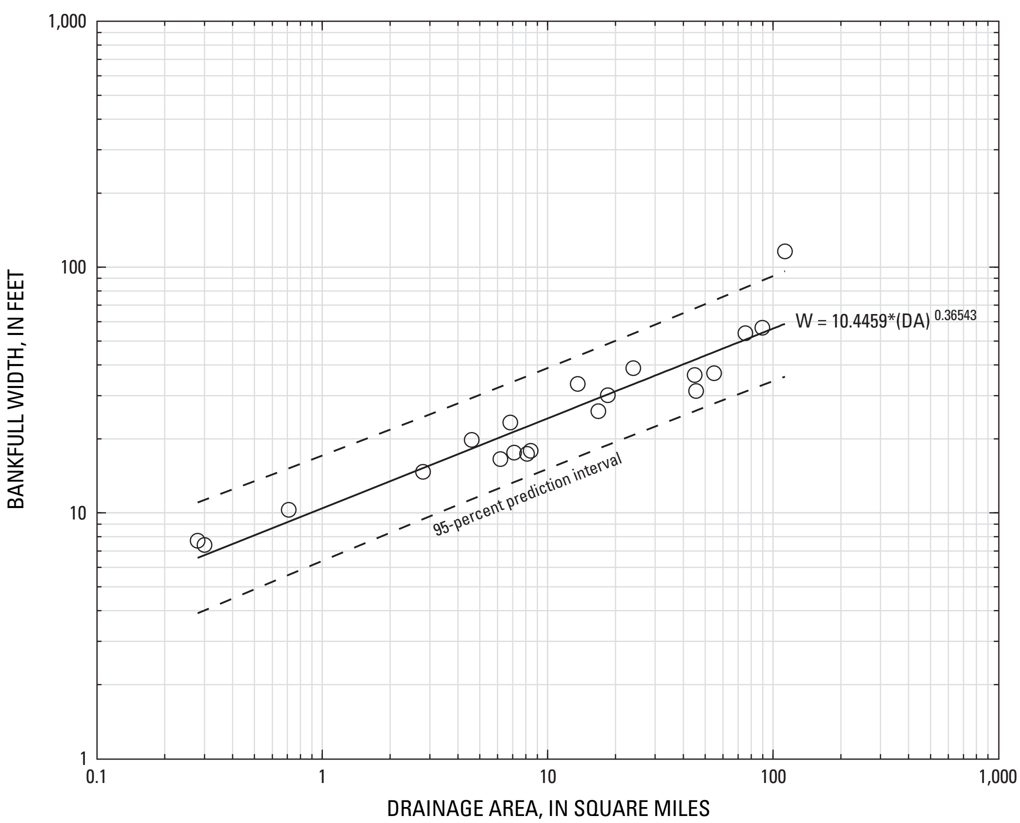


Figure 10. Regional curve relating bankfull width (W) to drainage area (DA) for streams in the non-urban, non-tidal Coastal Plain Physiographic Province of Virginia and Maryland.

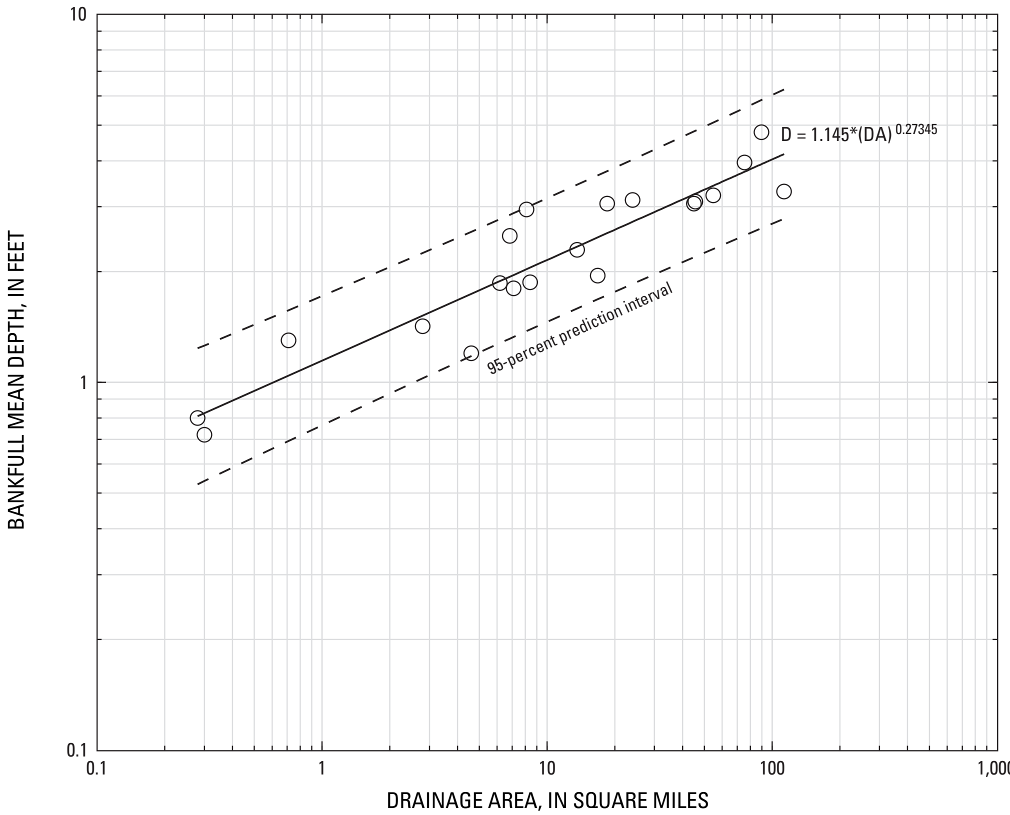


Figure 11. Regional curve relating bankfull mean depth (D) to drainage area (DA) for streams in the non-urban, non-tidal Coastal Plain Physiographic Province of Virginia and Maryland.

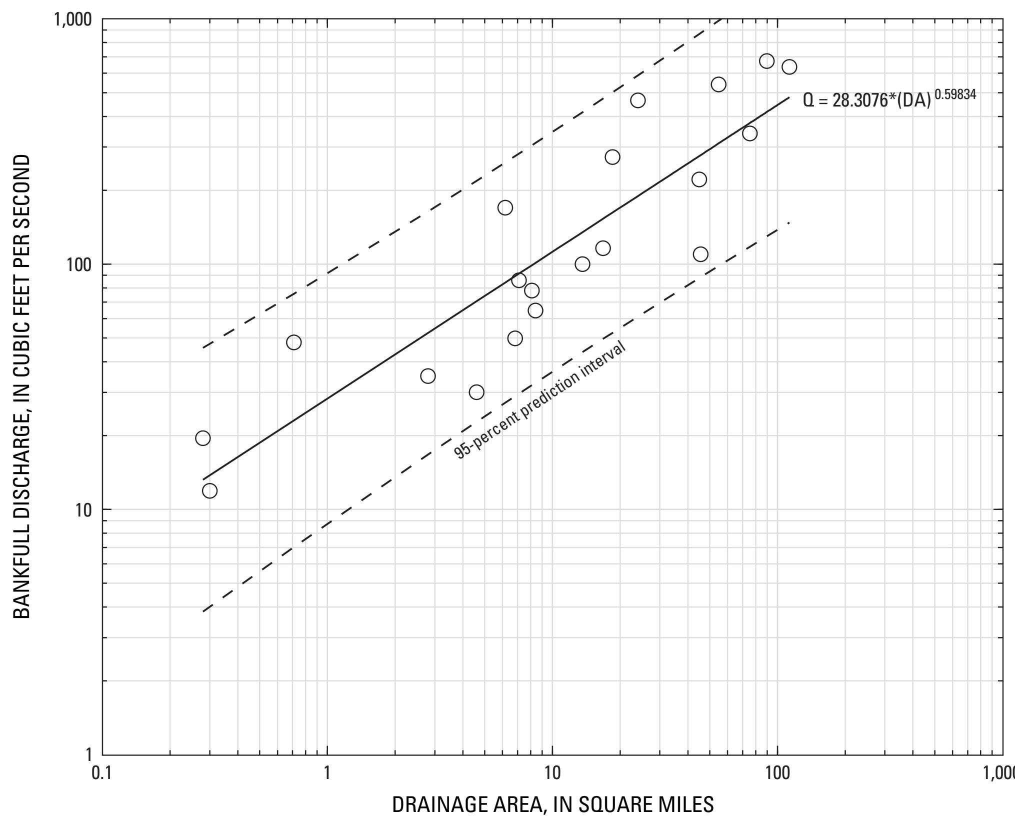


Figure 12. Regional curve relating estimated bankfull discharge (Q) to drainage area (DA) for streams in the non-urban, non-tidal Coastal Plain Physiographic Province of Virginia and Maryland.

curve used to develop it, influence of any given data point, and the confidence in the relation over the range of represented drainage areas. The applicability of regional curves developed here was evaluated on the basis of selected statistical diagnostics that measure the significance of the slope (indicated by p-values), the distribution of residuals, influence of each streamflow-gaging station (given by statistical measures of Cook's distance and two leverage statistics: h_i and standardized residual), and the amount of variability explained by drainage area (given by R^2). For this study the slope of each regional curve was considered significantly different from zero if the p-value (probability that a difference occurs by chance) was less than 0.05.

The regressions developed have slopes that are significantly different from zero (p-values are less than 0.0001; table 6) with residuals that upon visual inspection appear to be normally distributed and to vary randomly with drainage area (figs. 13, 14, 15, and 16). Higher R^2 values suggest that a greater portion of the variability is explained but are not necessarily indicative of a better regression relation. The R^2 value indicates that 94.5 percent of the variability in bankfull cross-sectional area is explained by drainage area, with 89.0 percent, 87.1 percent, and 79.3 percent of the variability explained by drainage area for bankfull width, mean depth, and bankfull discharge, respectively (table 6). The relatively high R^2 value for cross-sectional area indicates that it has the strongest relation to drainage area of the parameters measured. Lower R^2 values for bankfull width and mean depth indicate the greater variability in the geometries measured.

Width and depth may vary considerably from site to site due to differences in local morphology; however, they generally vary in opposite directions. Their product—cross-sectional area—tends to be a more consistent characteristic and to maintain a higher correlation with drainage area. The lower R^2 values for estimated bankfull discharge may reflect the time period for which streamflow data were available and the age of the rating tables for the streamflow-gaging stations. The variance in bankfull discharge also may be related to basin characteristics and geographic location.

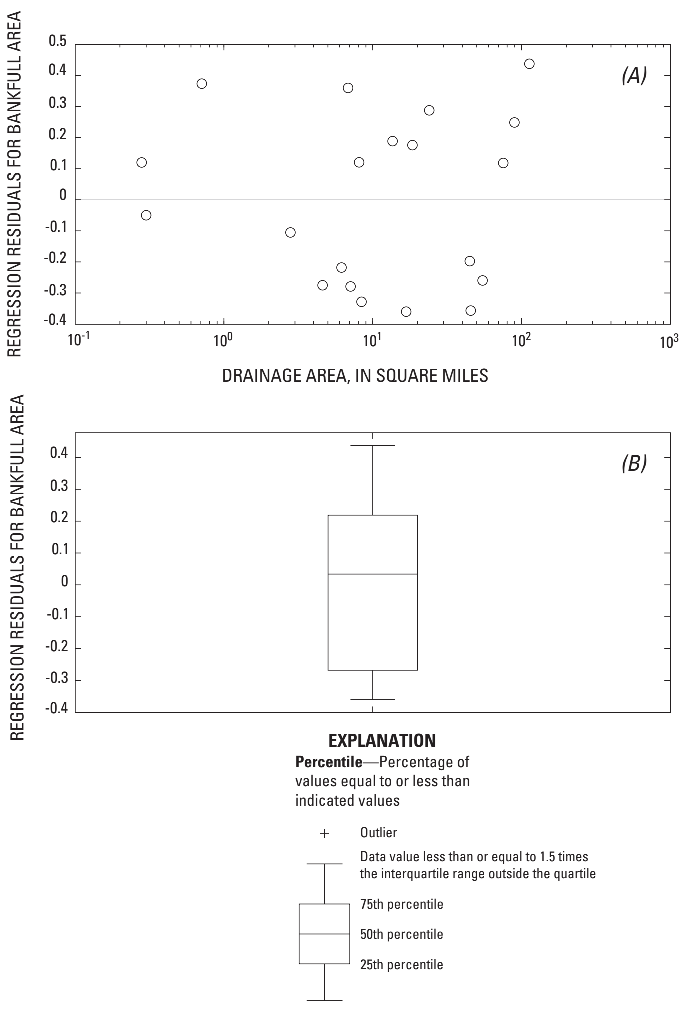


Figure 13. (A) Regression residuals for regional curves relating drainage area to bankfull cross-sectional area (for data, see fig. 9) and (B) box plot of the distribution of residuals for bankfull cross-sectional area.

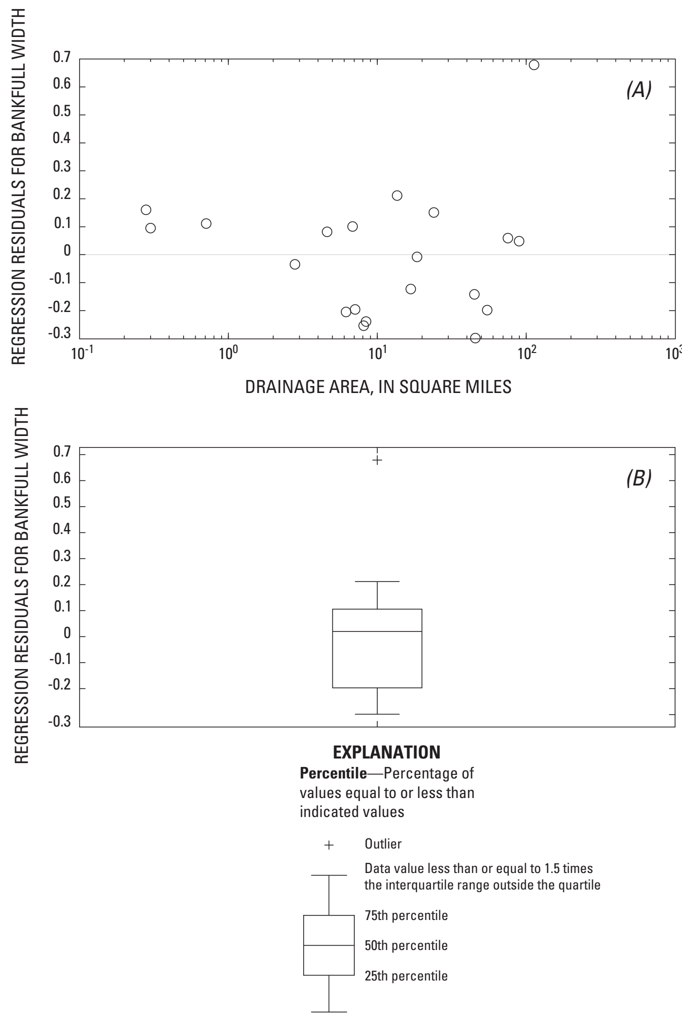


Figure 14. (A) Regression residuals for regional curves relating drainage area to bankfull width (for data, see fig. 10) and (B) box plot of the distribution of residuals for bankfull width.

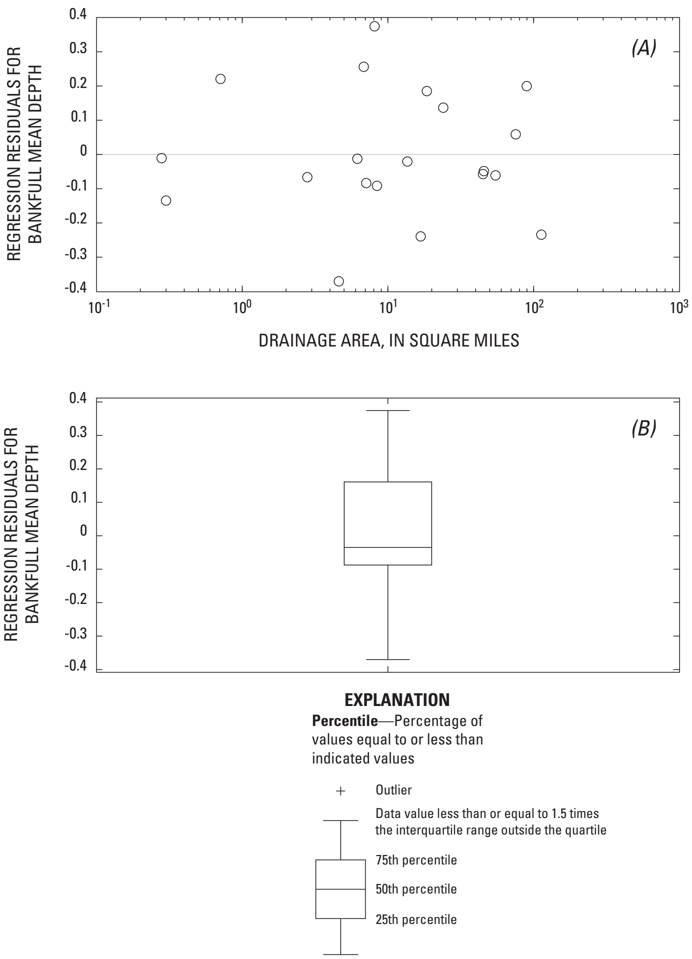


Figure 15. (A) Regression residuals for regional curves relating drainage area to bankfull mean depth (for data, see fig. 11) and (B) box plot of the distribution of residuals for bankfull mean depth.

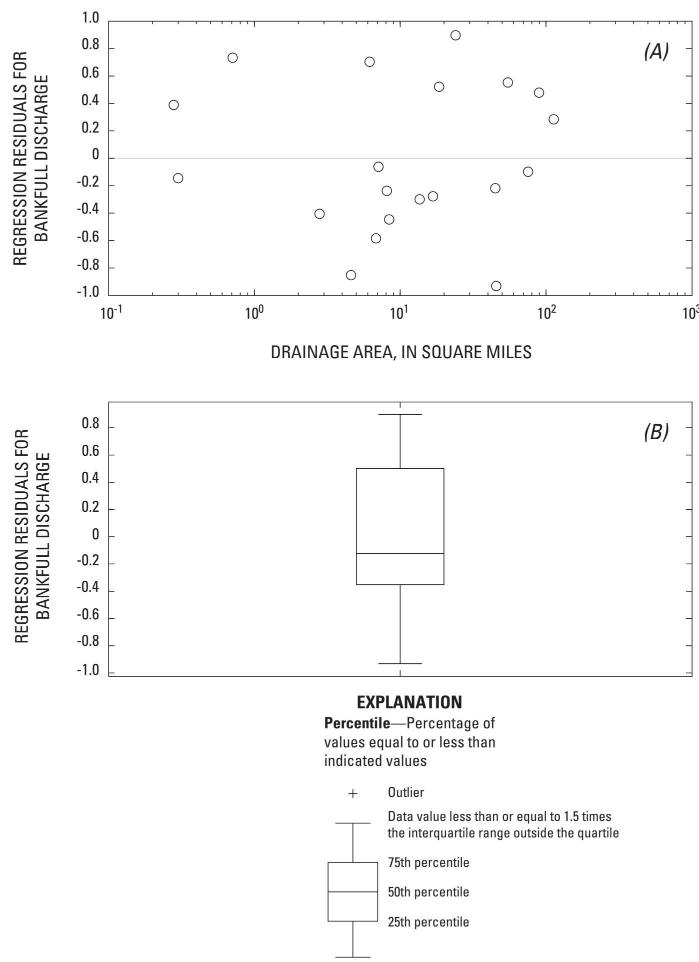


Figure 16. (A) Regression residuals for regional curves relating drainage area to estimated bankfull discharge (for data, see fig. 12) and (B) box plot of the distribution of residuals for estimated bankfull discharge.

Each regression was evaluated closely to determine if any points represented outliers. The residuals were visually inspected to see if there was non-constant variance (heteroscedascity) as the explanatory variable increased (figs. 13–16). Box plots of the residuals showed their approximate normality with only one outlier for bankfull width. A lillietest (The MathWorks Inc., 2006), a version of Lillilifors test, was performed to test the normality of the residuals. All p-values were greater than 0.05, indicating that the regression residuals are normally distributed.

The Choptank River, MD, was an outlier for bankfull width, but it was not an outlier for any other parameter. The measured width was more that twice the width of any other site measured, which may be why it does not fit with the other values in the regression. Measures of h_i (leverage in the x-direction), standardized residual (leverage in the y-direction), and Cook's Distance statistic for all regressions were within the expected limits, indicating no individual streamflow-gaging station had excessive influential effects on the regressions.

Limitations

The bankfull regional curves presented in this report are applicable to the identification of bankfull geometry and discharge in non-tidal, non-urban streams of the Coastal Plain Physiographic Province. Factors, such as land use, stream gradient, stream type, mean elevation, and drainage area, should be considered when assessing the applicability of the Coastal Plain bankfull regional curves. The streams of the Coastal Plain often transition between swamps with no defined channel geometry to areas of slightly higher gradient with defined channel geometry. The predominance of flood plain wetlands and the extremely low gradients of the flood plains may prove to be important considerations in stream restoration projects.

Streams included in this study had well-defined bankfull channel geometries that could be surveyed. Because of the site-selection requirements, many streams were excluded from the dataset. The streams that were included in this study are single-channel, low-gradient, meandering, riffle/pool streams with channel slopes less than 0.005. The valleys that contain the streams are broad, with wide floodplains and some terraces. Based on the Rosgen (1994) classification of natural rivers, the stream types represented by the regional curves developed in this study could be classified as 55-percent stream type E and 45-percent stream type C. No other stream types were included in the investigation. While the regional curves represent both types of streams together, the applicability of the curves for identifying bankfull features on other types of channels has not been tested. Seventy-five percent of mean elevations for each basin were higher than the mean elevation of the Coastal Plain. The mean basin elevation is an additional consideration as to the applicability of these regional curves.

Fifty percent of the stage-discharge ratings for streamflow-gaging stations were at least 25 years old. The recurrence intervals presented in this report are based on short-record discharge datasets. Many of the datasets contain only 10 years of peak-flow data, and can contain one peak that could represent an outlier. For this reason, the recurrence intervals calculated from the peak-flow dataset may be slightly lower than would be expected if a longer-record dataset were available.

The streams surveyed were in close proximity to a USGS streamflow-gaging station, which often was mounted on a bridge or culvert. Because of manmade features within the study reaches, the streams do not represent ‘reference reach conditions’. No assessment of habitat health was conducted, and no statements were made regarding habitat conditions. The regional curves provide an estimate of bankfull geometry and serve as tools for field identification of bankfull features. They can be used in stream assessments of ungaged streams as a guide for identifying the expected natural-channel geometry in those streams. The regional curves are believed to be accurate within the prediction intervals for the range of drainage areas studied. Outside this range it is uncertain how far the regression relations may be extended with accuracy.

Summary

The U.S. Geological Survey (USGS), in cooperation with the Virginia Coastal Zone Management Program and the Virginia Department of Conservation and Recreation Coastal Nonpoint Source Pollution Control Program, developed bankfull regional curves for streams in non-urban, non-tidal coastal areas of Virginia in 2005. These regional curves are one-variable, ordinary least-squares regressions relating bankfull discharge, bankfull cross-sectional area, bankfull width, and bankfull mean depth to drainage area in settings that are expected to have homogenous runoff characteristics. Equations describing the regional curves can be used to estimate the discharge and geometry of the bankfull channel when the drainage area of the watershed is known.

Bankfull geometry and discharge data were collected at six streamflow-gaging stations and associated stream reaches (sites) in Virginia and two sites on the Delmarva Peninsula of Maryland. Data from these 8 sites were combined with data from 12 sites in Maryland for the development of regional curves. All sites represent drainages that feed into the Chesapeake Bay. Drainage areas for the 20 sites range from 0.28 mi^2 to 113 mi^2.

Field-data collection included one longitudinal profile of bankfull features and channel slope, two cross-section surveys of channel geometry, one pebble count at each cross section, and one site sketch with photographs of the bankfull channel for each site. Field data were analyzed to determine bankfull area, bankfull width, bankfull mean depth, and D_{50}- and D_{84}-particle size for two riffles at each site.

Two sites were selected for duplicate surveys to establish whether the surveying techniques used in this study (2005–2006) produced similar results to the surveys (in 2003) for the regional curves of the Coastal Plain in Maryland. The comparisons of the duplicate surveys indicated that the Maryland regional curve data were similar to those collected in this study. The similarity of data allowed the creation of a composite dataset and the development of one set of bankfull regional curves for the Coastal Plain in Virginia and Maryland.

Simple linear regression techniques were used to develop regional curves for the Coastal Plain representing Virginia and Maryland from two sources of data: (1) channel geometry data from 8 stations that were surveyed for this study in the Coastal Plain of Virginia and the Delmarva Peninsula of Maryland, and (2) data from 12 stations in Maryland that were not duplicated in this study for a total of 20 sites in the regression analysis. Bankfull cross-sectional area, bankfull width, bankfull mean depth, and estimated bankfull discharge—the response variables—were regressed against drainage area—the explanatory variable—to show the relation between drainage area and each response variable. The relatively high R^2 value (0.945) for cross-sectional area indicates that it had the strongest linear relation to drainage area of the parameters measured. The R^2 values for the other geometry parameters indicate that 89.0 percent, 87.1 percent, and 79.3 percent of the variability in each regional curve was explained by drainage area for bankfull width, mean depth, and bankfull discharge, respectively.

The regional curves provide an estimate of bankfull geometry and serve as tools for field identification of bankfull features. They can be used in stream assessments of ungaged streams as a guide for identifying the expected natural-channel geometry in those streams. The regional curves are believed to be accurate within the prediction intervals for the range of drainage areas studied. Outside this range it is uncertain how far the regression relations may be extended with accuracy. The bankfull regional curves developed are applicable to non-urban streams in the non-tidal Coastal Plain areas of Virginia and Maryland.

Acknowledgments

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Appendix 1—Streamflow-Gaging Station Numbers, Site Descriptions and Photographs, Longitudinal Profiles, Riffle Cross Sections, and Bed Material Particle-Size Distributions of Cross Sections

Station 01674700
Aylett Creek at Aylett, VA

View looking upstream at reach of Aylett Creek at Aylett, VA

The study reach for Aylett Creek was 920 ft long and included gages located at stations 258 and 338. The reach is bisected by a divided four-lane bridge. The west-bound lanes, on the upstream side of the reach, pass over a bridge, which has a scour hole underneath. Between the east- and west-bound lanes there is an area of deposition with a point bar on the left bank that almost cuts off flow to the left-most box of a 3-box culvert. The east-bound lanes pass over the 3-box culvert. The upstream and downstream crest-stage partial-record streamflow-gaging stations (CSG) were mounted on the bridge abutment for the east-bound lanes. Thirty feet downstream from the culvert there is a large scour hole 5 ft deep. There were large sand deposits along the banks at an elevation higher than bankfull for at least 200 ft below the culvert. They may be from recent hurricanes (Hurricane Gaston 2004) which brought intense rainfall to this area. It is likely that swift flows through the culvert and some straightening during the bridge construction influence the straight section of stream for 150 ft below the culvert. After 150 ft the stream became more sinuous. The cross sections were located toward the end of the reach in a part of the channel that was relatively unaffected by the culvert. Approximately 1,500 ft below the end of the reach, the channel becomes divided and flows into a swamp.

The reach was narrow with deep pools (4 ft). Pools and runs dominated the reach, with riffles identifiable by particle size and depth. The slope was gradual with a few slight jumps making it somewhat difficult to identify riffles. The bed material was sand and small gravel with sand dominant except in the riffles. Coarse woody debris created short backwater areas and increased roughness in the channel. Often the woody debris was a contributor to pool formation.

Bankfull features along this reach were located at the top of the bank. The banks were stable with little erosion. The banks were stabilized by large small and trees with some grass. The active floodplain was covered with a mix of young trees, understory herbaceous plants, vines, and some manicured grass. The left bank was a residential area with a forested buffer of 50 to 300 ft along the reach. The right bank was forested.

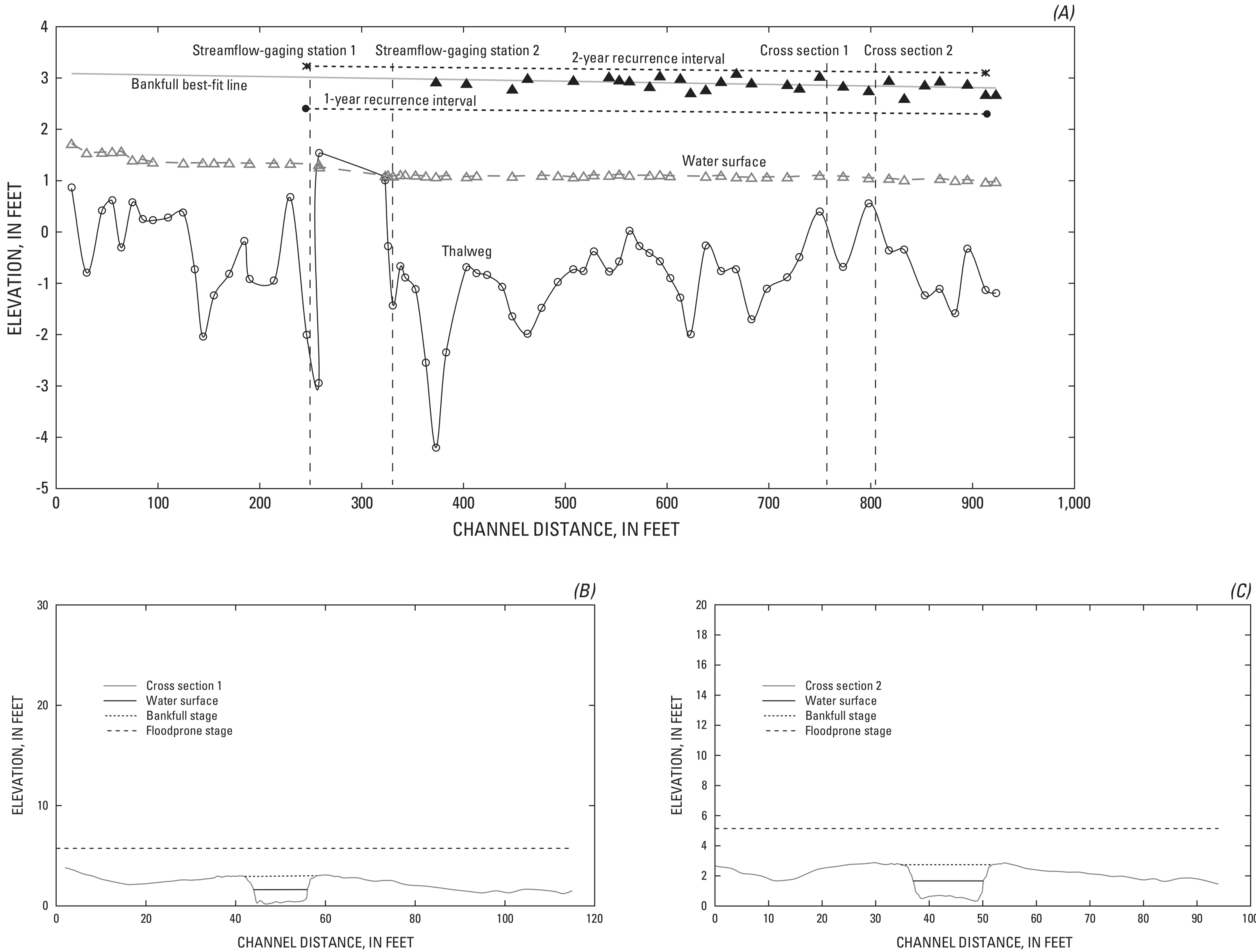
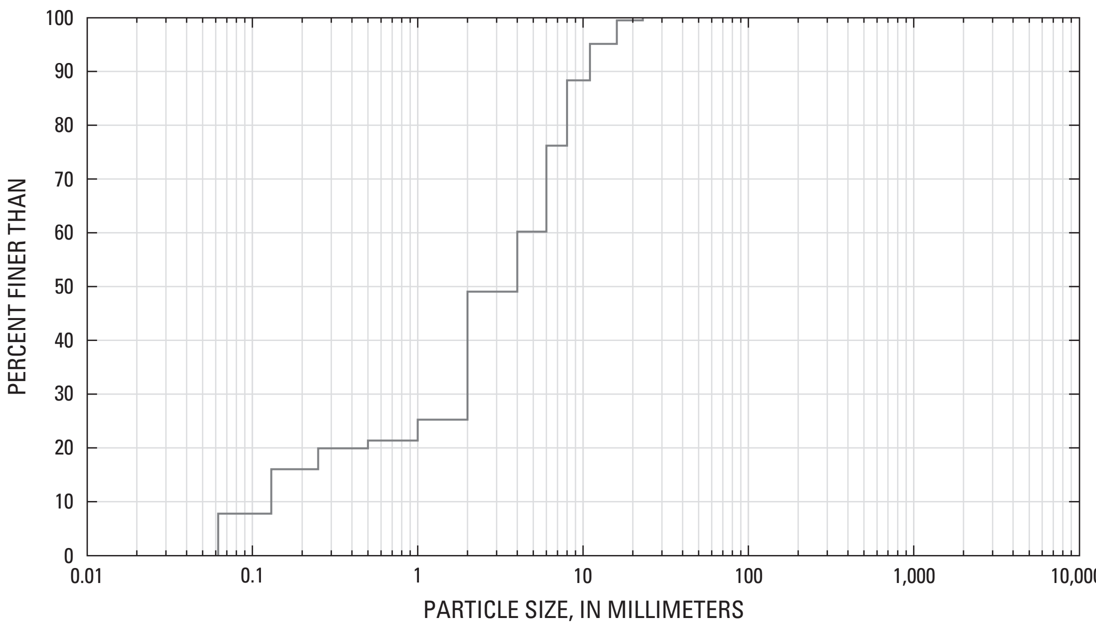


Figure A1. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Aylett Creek at Aylett, VA, May 24, 2005.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
7.77	41.26	50.97	0.00	0.00	0.00	0.25	4.00	8.00

Total count = 206

Figure A2. Particle-size distribution of bed material in the study reach of Aylett Creek at Aylett, VA, May 24, 2005.

Station 02042250
Bailey Branch Tributary at Spring Grove, VA

View looking upstream at reach of Bailey Branch Tributary at Spring Grove, VA

The study reach at Bailey Branch Tributary was 300 ft long, ending at the location of the upstream crest-stage partial-record streamflow-gaging station (CSG). For the next 58 ft, the creek passes through a 2-box culvert which likely has some backwater affect at bankfull stage. At two locations (station 150 and 290) along the reach there were springs that contribute to the flow. The stream was more sinuous at the top of the reach with two major bends up to station 120 and then was relatively straight until the culvert where it turns to the right to pass under the road.

The stream was narrow and shallow with few depths deeper than 1 ft during the time of survey. Throughout the reach the channel maintained a riffle-run-pool sequence. Slopes at riffles within this reach were visible during the survey, making this site slightly different than most of the other sites in this study. The bed material was dominated by gravel and sand with gravel present in the runs as well as riffles. A little cobble was present in the riffles. Much coarse woody debris was embedded in the channel. The floodplain slope was roughly 14 percent on the left bank of cross section 1, which is a much greater slope than other sites in this study. The valley shape and channel slope give this site the appearance of a Piedmont stream, but it is in the Coastal Plain.

Bankfull features in this reach were low benches on the inside of a slightly entrenched channel. Two sets of bankfull features were surveyed here, the benches and top of the bank, but the top of the bank represents a 5-year flood or higher. The river may be forming new bank features within a previously used channel. The low-banks seem to fit with a 1-year event. The stream banks were heavily vegetated with herbaceous plants such as ferns, jewelweed, vines, grasses, and moss. Watercress was growing across at least half of the channel width at the two spring locations. The active floodplain contained mature deciduous trees, such as tulip, beech, maple, and sycamore, with a developing under-story of shrubs including privet and multiflora rose for 50 ft on either side of the channel.

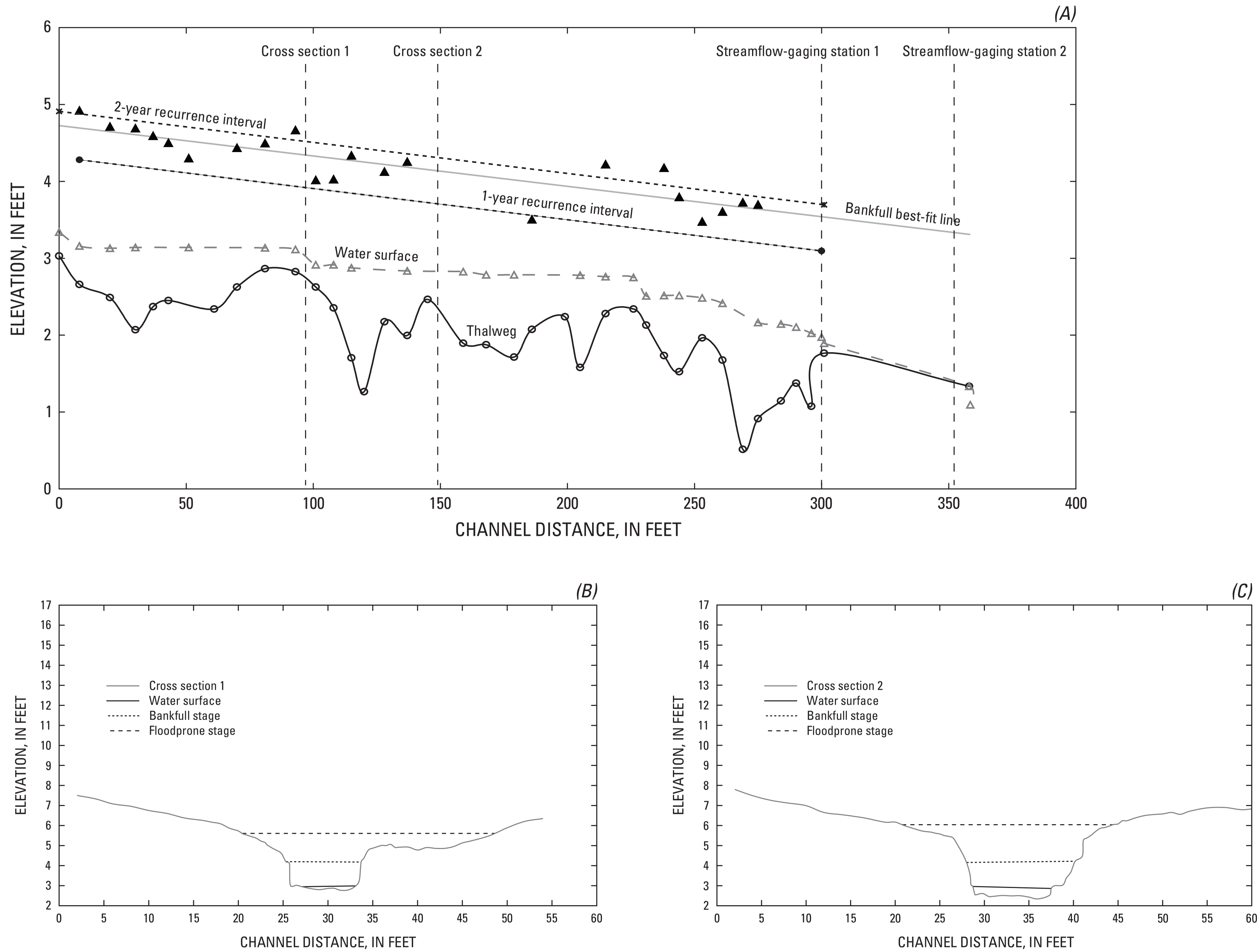
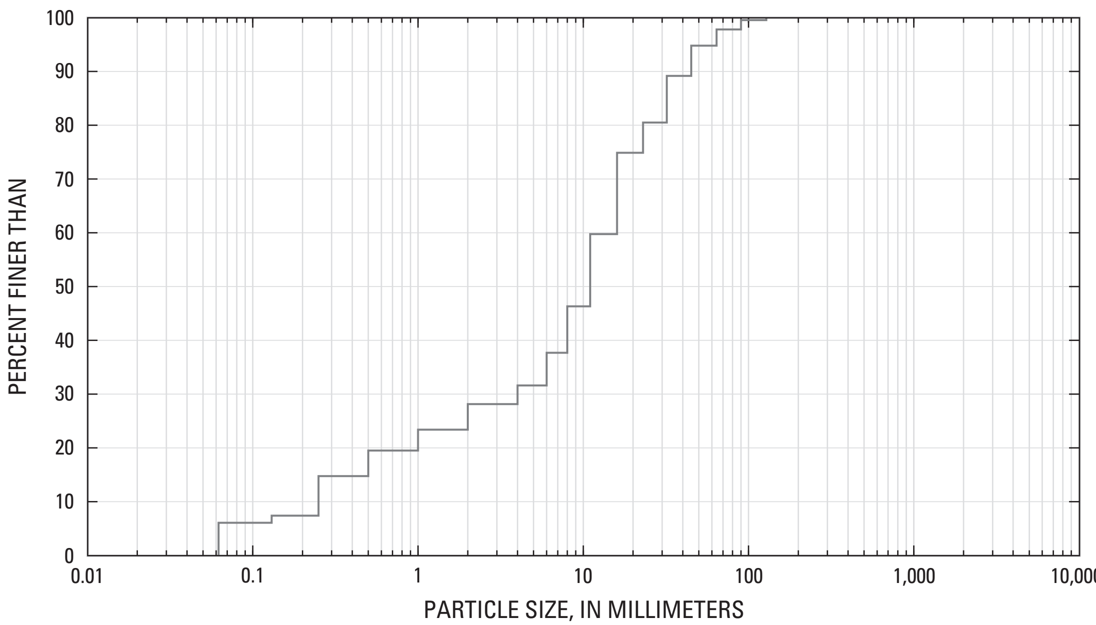


Figure A3. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Bailey Branch Tributary at Spring Grove, VA, May 26, 2005.



Composite material

Size classification, in percent						Percent finer, in millimeters		
SiltClay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
6.06	22.08	69.70	2.16	0.00	0.00	0.50	11.00	32.00

Total count = 231

Figure A4. Particle-size distribution of bed material in the study reach of Bailey Branch Tributary at Spring Grove, VA, May 26, 2005.

Station 01661800
Bush Mill Stream near Heathsville, VA

View looking downstream at reach of Bush Mill Stream near Heathsville, VA

The study reach at Bush Mill Stream was 530 ft long, ending at the location of the continuous-record streamflow-gaging station (CRG) just upstream from a 2-lane bridge with a 4-box culvert. There seems to be little backwater affect from the bridge at bankfull stage. An old railroad- or road-grade crosses the stream near station 300. This raised elevation of 10 ft above bankfull does not appear to affect the stream, but bankfull features in that section could not be identified. Cross section 1 was located at station 104. At station 270, a small tributary enters on the right bank and many of the bankfull features were lower in this part of the reach than upstream. Overland flow from the small tributary probably contributes to bank erosion in this section, making the bankfull features lower. After the tributary, Bush Mill Stream takes a turn to the left and flows straight to the CRG from station 300 to 530. Cross section 2 was in this section at station 428. Station 270 appears to be a dividing point between a narrow, sinuous channel with slightly higher bankfull features and a wide, straight channel, which may have been altered when the road was constructed.

The channel was run-pool dominated with riffles identifiable by particle size and depth. The slope was gradual with a few slight jumps making it somewhat difficult to identify riffles. The bed material was almost entirely sand with a minor amount of gravel present in the riffles. Coarse woody debris and fallen trees added to the roughness within the channel and created small backwater areas.

Bankfull features selected in this reach represent the top of the bank. The break in slope was surveyed but considered too low. Banks were heavily vegetated with herbaceous vegetation, saplings, and some large trees including maple, oak, sycamore, and holly. Many of the bends in the river occurred at large, mature trees, which appeared to be stabilizing the banks. In the upper section of the reach there were undercut banks, but erosion was not common along the reach. The active floodplain was forested with mostly young trees, few mature trees, and green briar (smilax), and was heavily vegetated with grass.

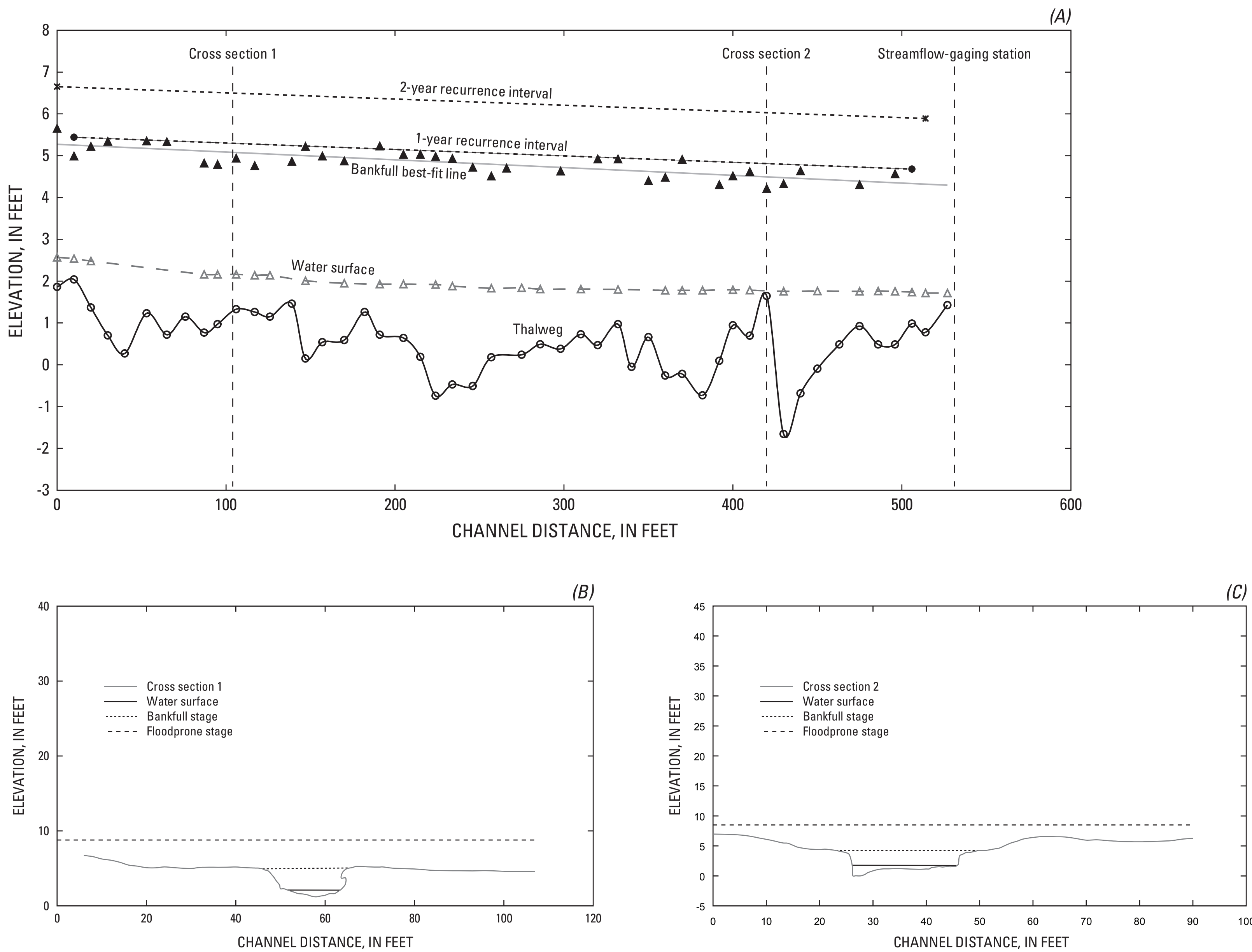
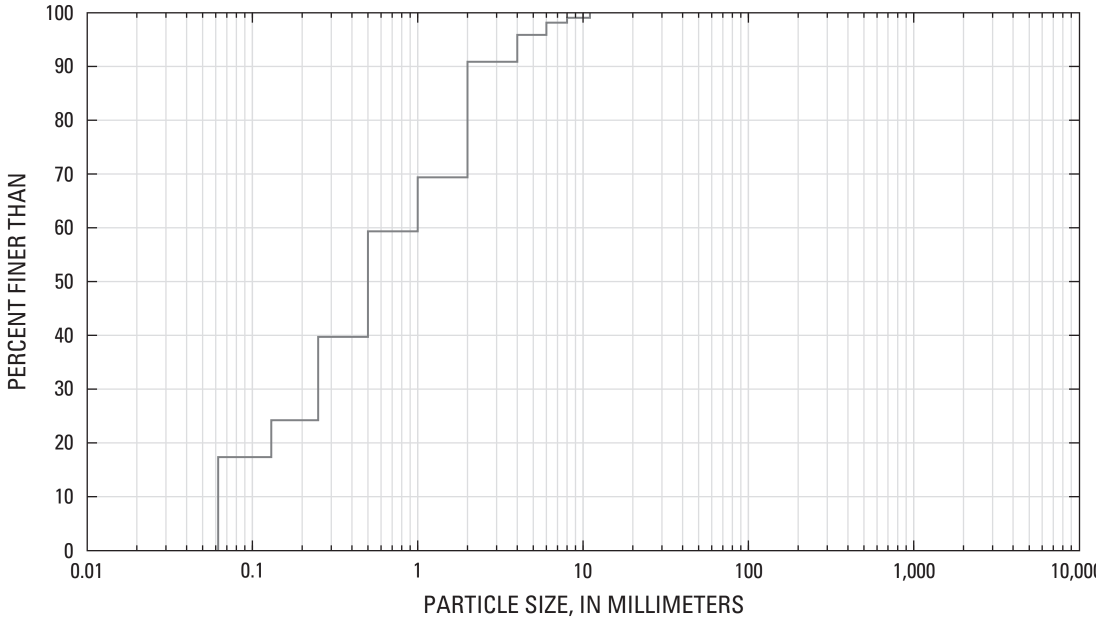


Figure A5. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Bush Mill Stream near Heathsville, VA, May 19, 2005.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
17.35	73.52	9.13	0.00	0.00	0.00	0.06	0.50	2.00

Total count = 219

Figure A6. Particle-size distribution of bed material in the study reach of Bush Mill Stream near Heathsville, VA, May 19, 2005.

Station 01668500
Cat Point Creek near Montross, VA

View looking upstream at reach at Cat Point Creek near Montross, VA

The study reach at Cat Point Creek was 935 ft long, ending 85 ft downstream from the location of the continuous-record streamflow-gaging station (CRG) at the upstream end of a 2-lane bridge. There had been disturbance in the vicinity of the gage prior to its discontinuation. The location of the gage was close to an old road-grade, with wooden bridge pylons still present in the channel. A small tributary that enters on the right bank had washed out the land around the gage and caused the gage to fall into the river. At the mouth of the small tributary there was a scour hole with a mid-channel sand bar between the gage and the bridge downstream. The upstream 800 ft of reach were relatively unaffected by anthropogenic forces. There was a natural sinuosity throughout the reach.

The creek was wide with deep holes that were undetectable because the water was murky brown with little light penetration, likely because of tannins in the water. The channel was run-pool dominated with riffles only identifiable by particle size and depth. The slope was gradual with a few slight jumps making it somewhat difficult to identify riffles. The bed material was almost entirely sand with a minor amount of very small gravel present in some riffles. Coarse woody debris added to the roughness within the channel and often seemed to contribute to riffle formation.

The bankfull features were predominantly the top of the bank, although many low point bars, or benches, were forming. These were surveyed, but considered too low and inconsistent. The top of the bank was the highest feature for at least 100 ft away from the channel in either direction. The banks were heavily vegetated with herbaceous cover, shrubs, small saplings, and some large deciduous trees. There was a buffer of trees and shrubs for at least 10 ft on either side of the creek, including maple, birch, beech, and ironwood trees. The active floodplain on the right bank was forested; however, the left bank was an emergent wetland with arrow-head, pond lily, hibiscus, grass, and sedges with some birch trees. There was standing water in rivulets throughout the floodplain, but much of the land surface was dry during the survey.

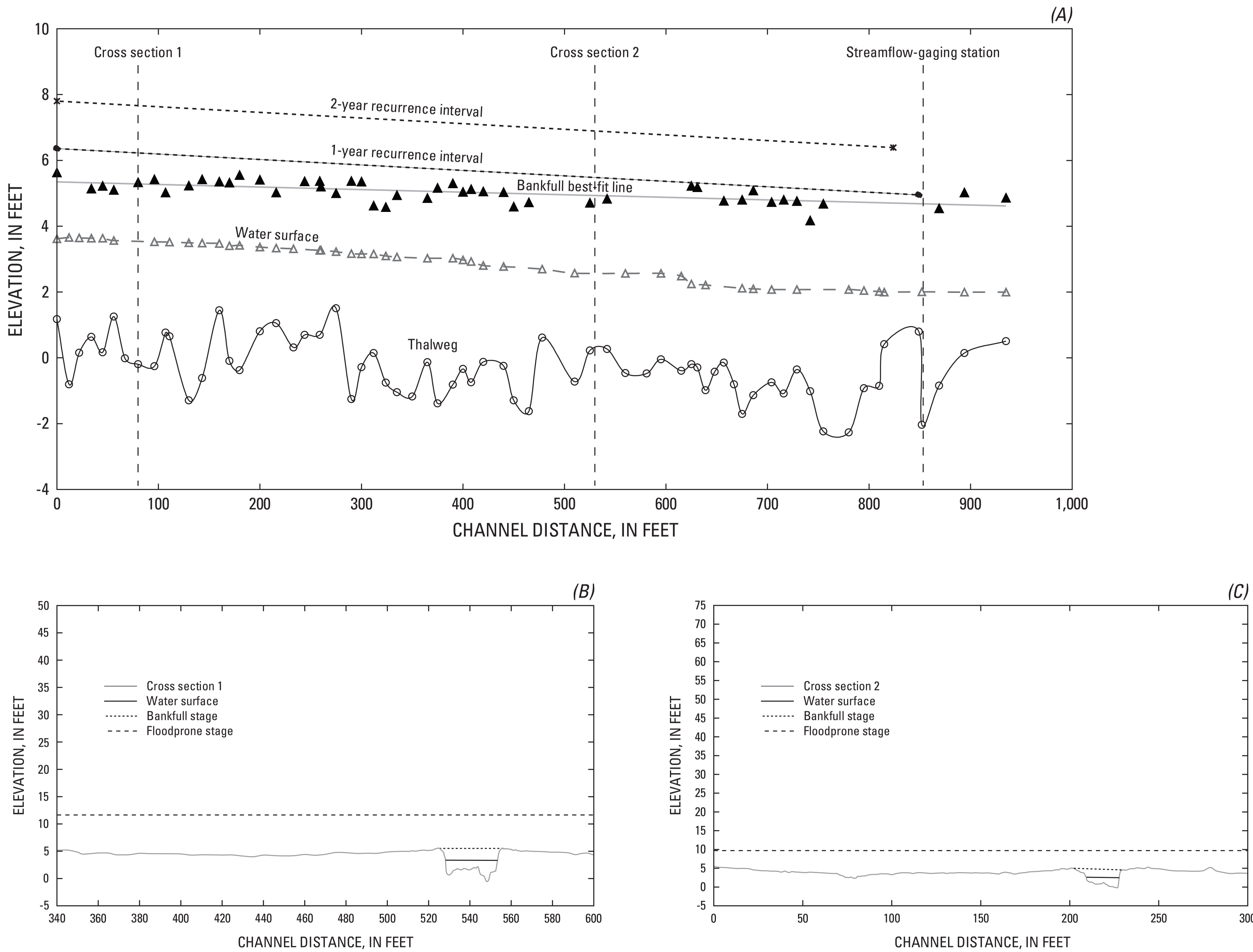
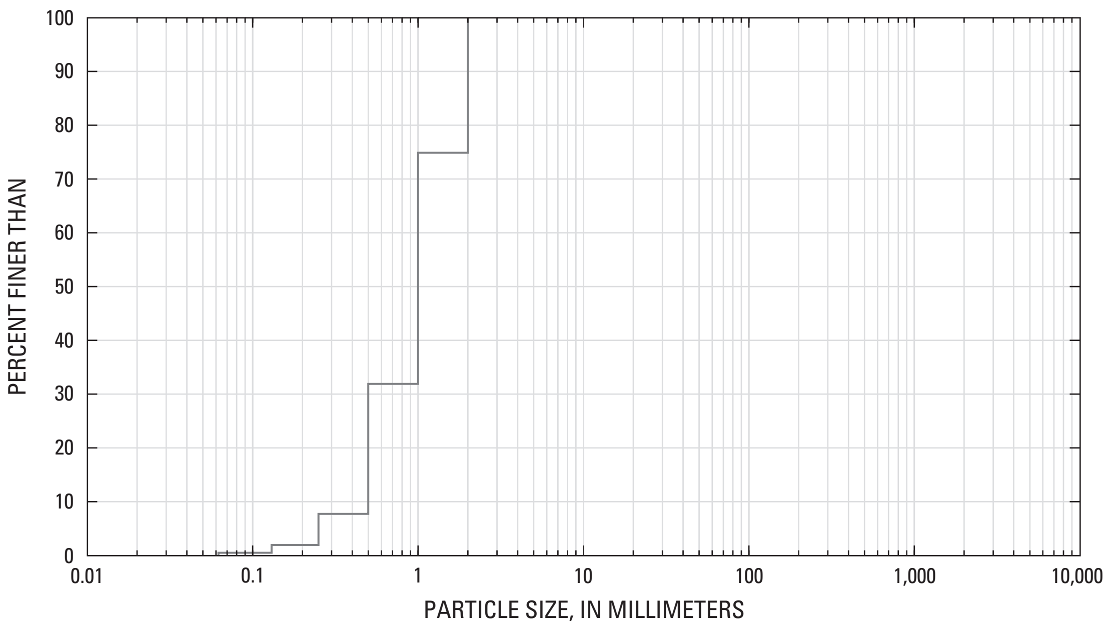


Figure A7. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in study reach of Cat Point Creek near Montross, VA, May 17, 2005. The water-surface elevation (WSL) rose 0.24 ft during the longitudinal profile survey. The difference in WSL between station 615 and 625 is not due to a dam, but rather the difference in WSL from rainfall.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
0.48	99.52	0.00	0.00	0.00	0.00	0.50	1.00	2.00

Total count = 207

Figure A8. Particle-size distribution of bed material in the study reach of Cat Point Creek near Montross, VA, May 17, 2005.

Station 01491000
Choptank River near Greensboro, MD

View looking upstream at reach of Choptank River near Greensboro, MD

View of weir and streamflow-gaging station on the left bank at reach of Choptank River near Greensboro, MD

The study reach at Choptank River was 1,300 ft long, ending downstream of the continuous-record streamflow-gaging station (CRG) and weir, which were located at station 1135. The weir had a significant affect on the water-surface profile through the study reach. The weir may have contributed to a back water effect throughout the reach. Upstream from the weir was an old roadbed with a depression wetland on the left bank. Downstream from the weir there was a deep scour pool. This site had the largest drainage area available for the study and also served as a comparison stream with McCandless (2003).

The stream was wide with consistent widths and depths. The bed material was a mixture of gravel and sand, with small gravel dominating in the riffles. The large amount of coarse woody debris in the form of mature tree trunks and limbs influenced sediment deposition patterns and scour.

Bankfull features in the reach were represented by the top of the bank, although lower features were surveyed. There were breaks in slopes that were considered too low.

The vegetation on the banks was made of herbaceous plants, briars (smilax), small saplings, shrubs, and mature trees. The banks contained cut banks and scour holes around the coarse woody debris. The active floodplain was forested wetland with deciduous trees, such as box elder, maple, oak, and birch.

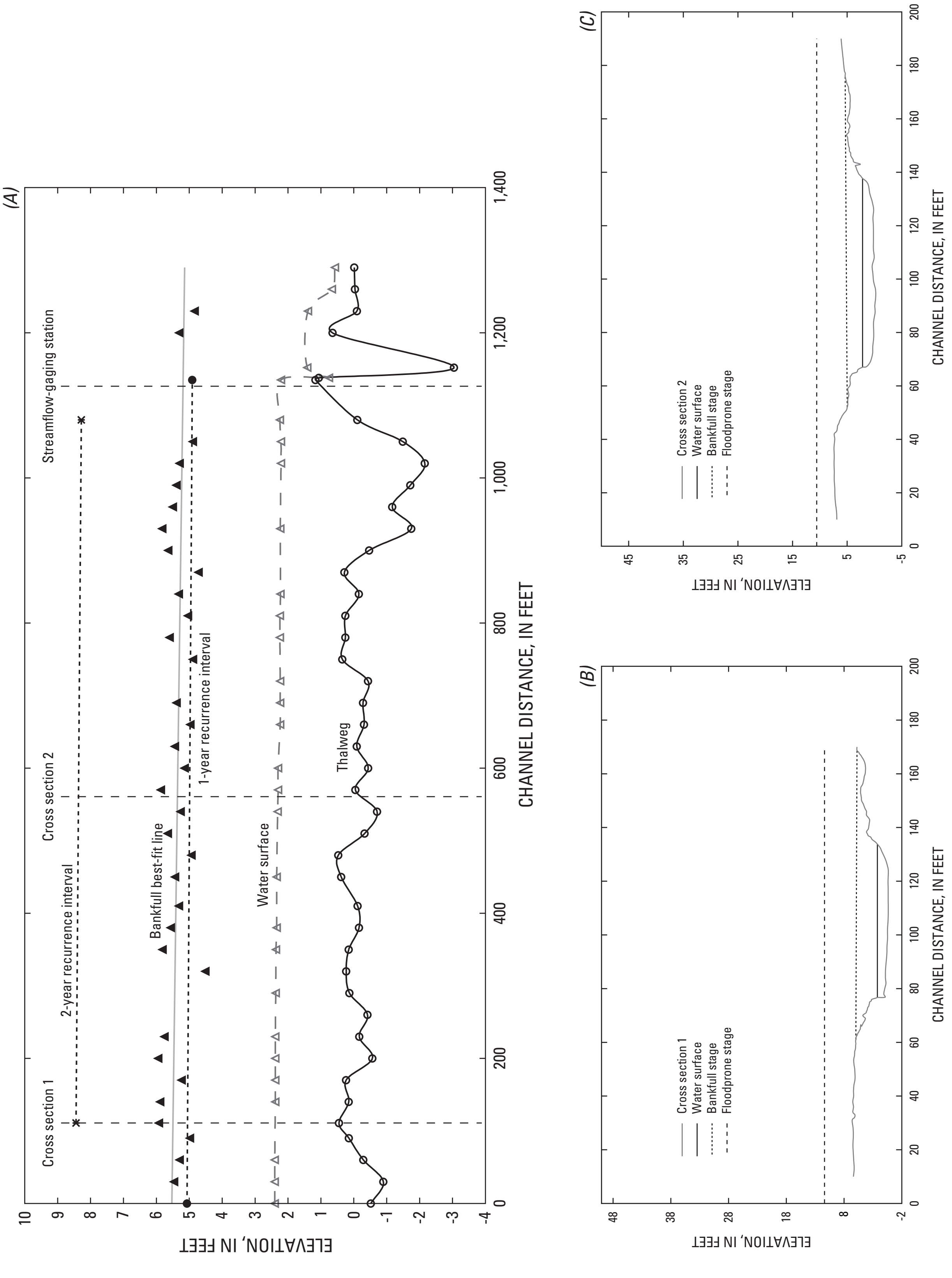
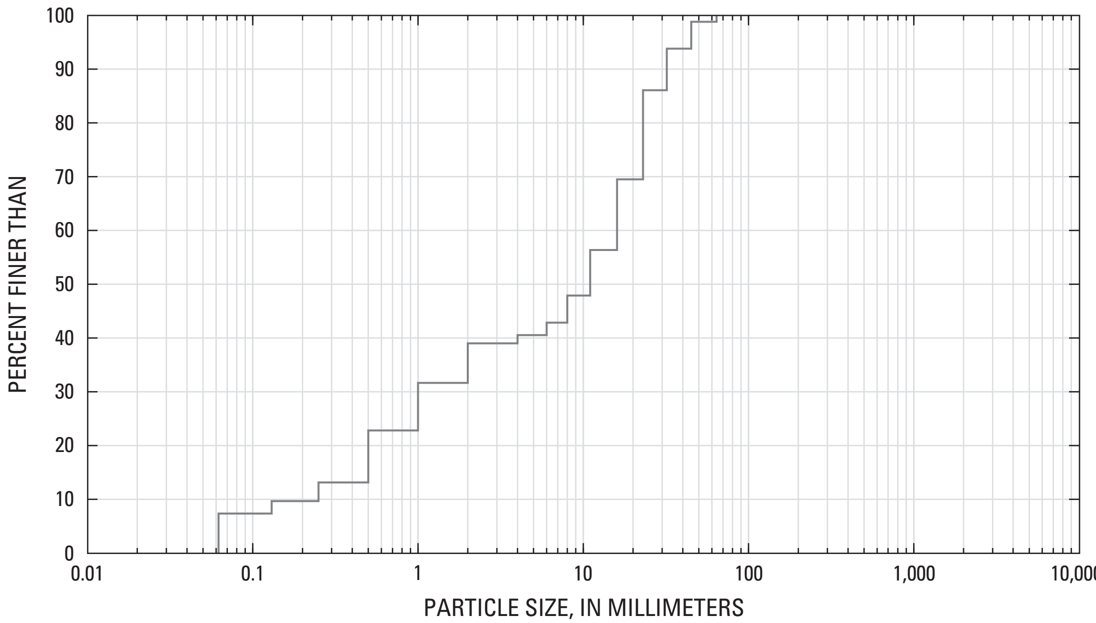


Figure A9. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Choptank River near Greensboro, MD September 1, 2005.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
7.34	31.66	61.00	0.00	0.00	0.00	0.50	11.00	23.00

Total count = 259

Figure A10. Particle-size distribution of bed material in the study reach of Choptank River near Greensboro, MD, September 1, 2005.

Station 02042710
Collins Run Tributary near Providence Forge, VA

View looking upstream at reach of Collins Run Tributary near Providence Forge, VA

The study reach at Collins Run Tributary was 475 ft long, ending just downstream from an 85-ft-long single-box culvert. The upstream and downstream crest-stage partial-record streamflow-gaging stations (CSG) had been bolted to the wing walls of the culvert. The culvert opening was only 4 ft high and 4 ft wide, and given the low bankfull features near the culvert, it is likely that it causes a backwater affect at bankfull flows. The channel seemed to be transitioning with some scour and undercut banks, but bankfull features were identifiable.

The stream was narrow and shallow with few depths deeper than 1.5 ft during the time of survey. Throughout the reach the channel maintained a riffle-run-pool sequence. Slopes at riffles within this reach were easily identifiable during the survey as well as coarse bed material. The bed material was dominated by sand with small gravel present in the riffles.

Bankfull features in this reach were low benches on the inside of a slightly entrenched channel. There are many banks that are undercut with new point bars forming within the entrenched channel. The features that were selected are the low banks throughout the survey. The low banks, which were surveyed, seem to represent a slightly less than 1-year event. The banks were not highly vegetated throughout the reach. Many were covered with grass, ferns, and moss, but often sand and clay were exposed. The buffer and floodplain was a young forest with deciduous trees, including oak, sweet gum, sycamore, tulip, and holly. The understory was dominated by upland plants and was abundant with small Pawpaw trees and understory shrubs.

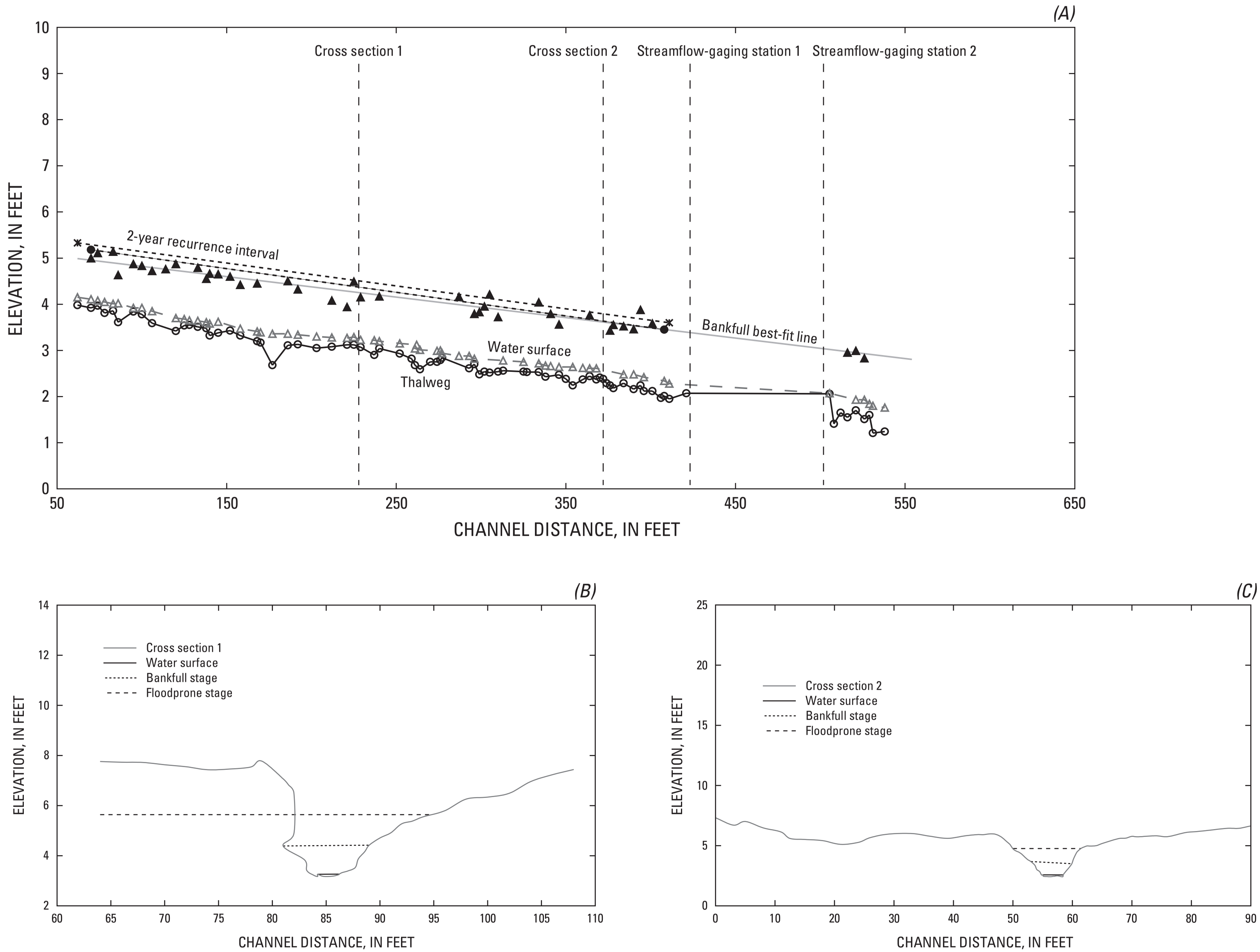
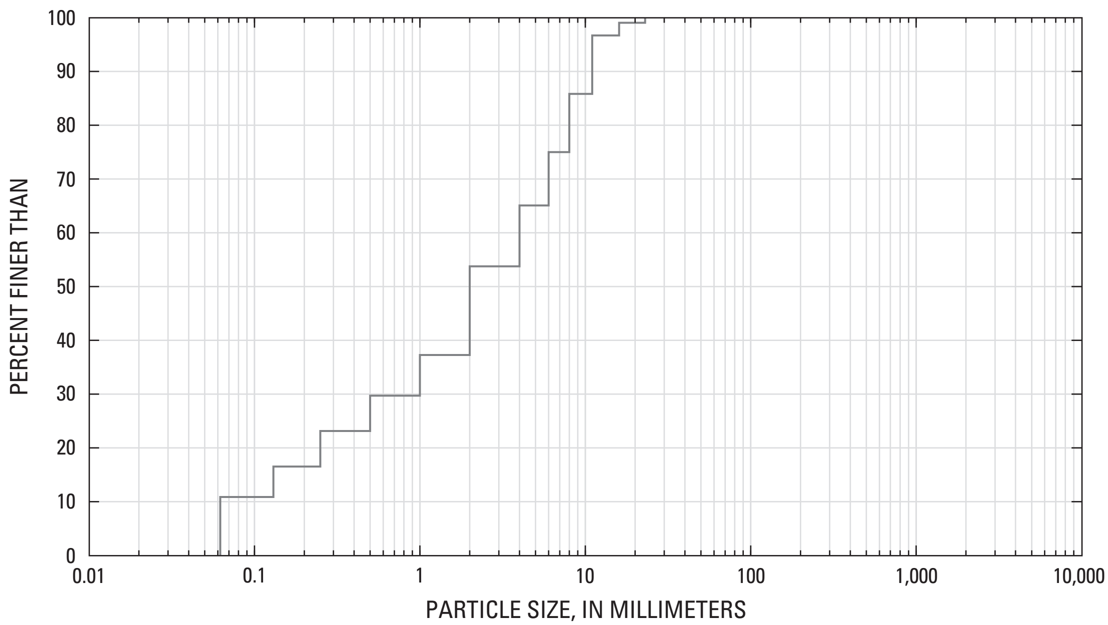


Figure A11. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Collins Run Tributary near Providence Forge, VA, July 15, 2005 and May 6, 2006.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
10.85	42.92	46.23	0.00	0.00	0.00	0.13	2.00	8.00

Total count = 212

Figure A12. Particle-size distribution of bed material in the study reach of Collins Run Tributary near Providence Forge, VA, July 15, 2005, and May 6, 2006.

Station 01492550
Mill Creek near Skipton, MD

View looking downstream from cross section 2 at reach of Mill Creek near Skipton, MD

The study reach at Mill Creek was 1,000 ft long, passing through a 2-box culvert under a two-lane bridge for a length of 100 ft, then ending 125 ft downstream. The discontinued crest-stage partial-record streamflow-gaging station (CSG) had been located on the upstream side of the bridge at station 750. While the bridge did not seem to have much backwater affect on the reach, the numerous wetland drainages into the reach had an effect on the elevation of the bankfull features. The reach had one large drain that appeared to be a side-channel pond.

The stream was narrow in the upper reaches and widened downstream. It was dominated by run-pool sequences. The riffles were somewhat difficult to identify because of the slight change in channel slope throughout the reach. The bed material was entirely sand, with much coarse woody debris, increasing the channel roughness slightly.

The bankfull features selected were located at the top of the bank. Bankfull features were slightly lower than the 1-year recurrence interval. This site was one surveyed by McCandless (2003) who adjusted the peak-flow analysis to remove an outlier; thus, the calculation of recurrence interval by McCandless is slightly higher than the one presented in this report because of the difference in peak-flow statistic calculations.

The vegetation on the banks was herbaceous with small shrubs, saplings, and some mature deciduous trees. In the active floodplain, red maple made up the overstory, with an understory of privet, multiflora rose, and skunk cabbage within hydric soils and standing water. On the left bank near station 500, the valley slope increased, and the vegetation changed to an upland community of beech, maple, and oak.

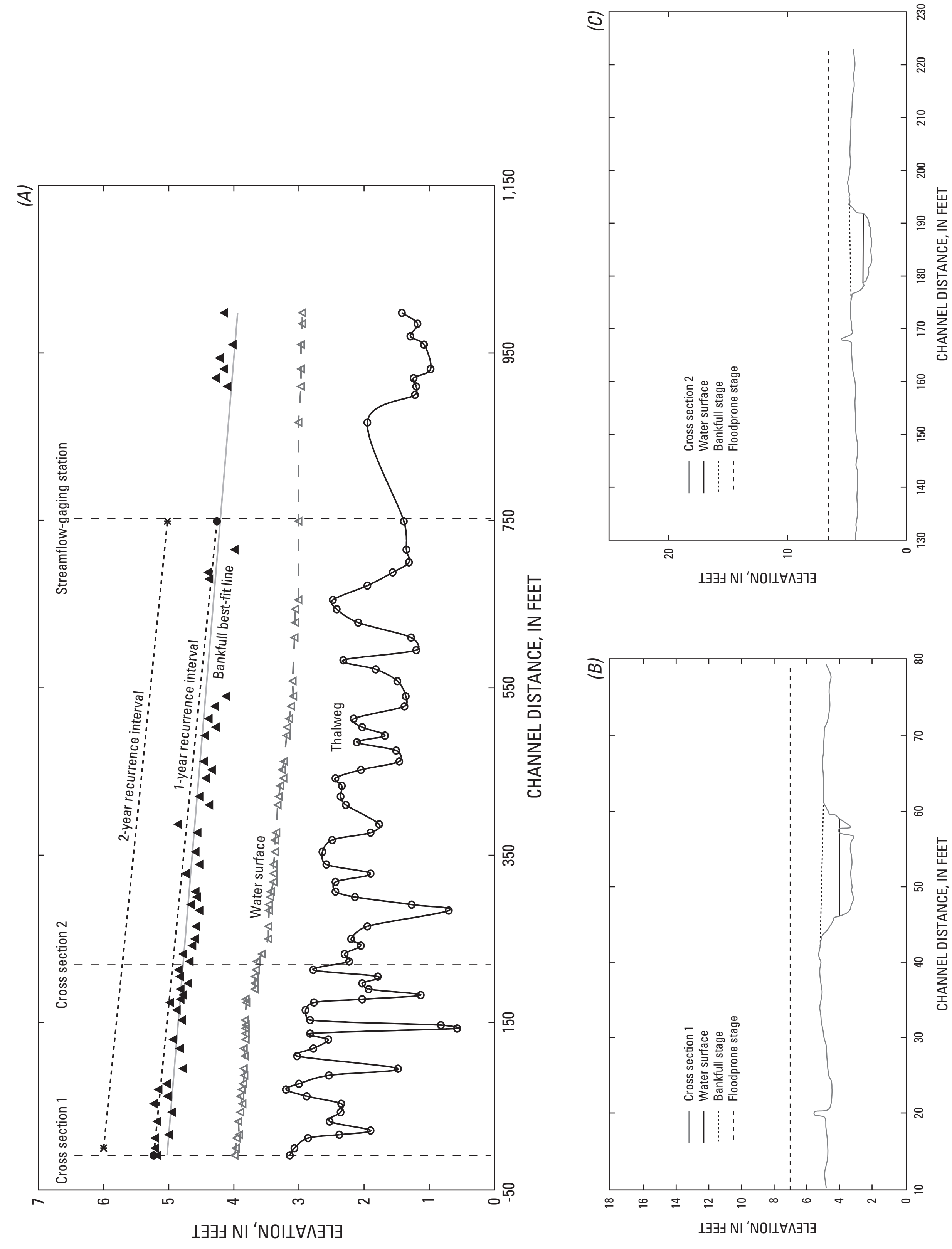
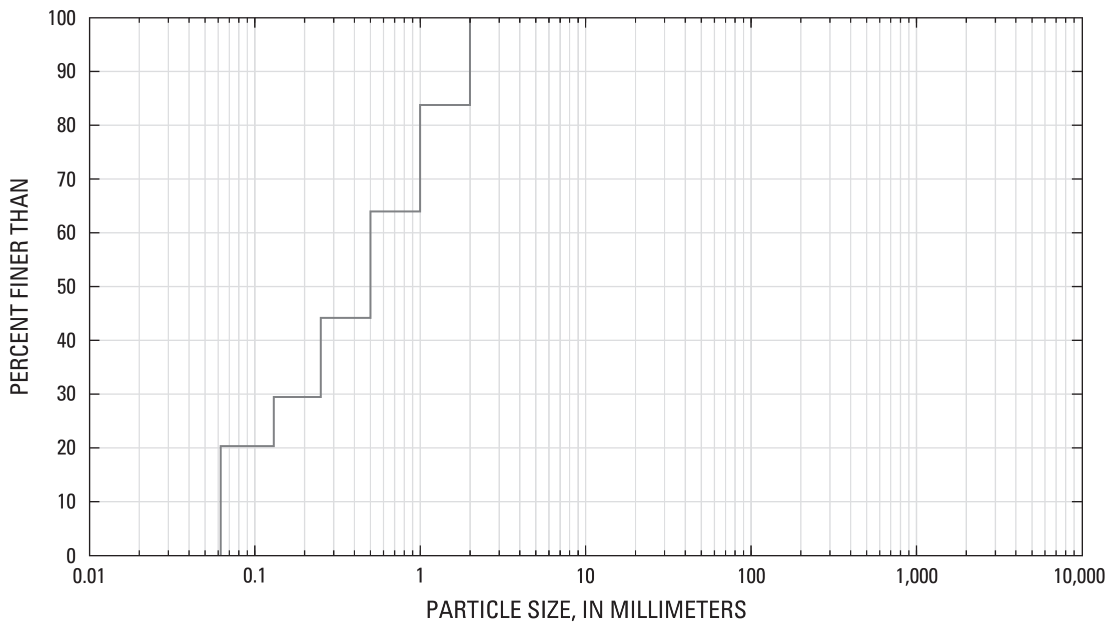


Figure A13. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Mill Creek near Skipton, MD, April 12, 2006.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
20.30	79.70	0.00	0.00	0.00	0.00	0.06	0.50	2.00

Total count = 197

Figure A14. Particle-size distribution of bed material in the study reach of Mill Creek near Skipton, MD, April 12, 2006.

Station 01674200
Reedy Creek near Dawn, VA

View looking downstream at reach of Reedy Creek near Dawn, VA

The study reach at Reedy Creek was 810 ft long, passing under a bridge in the center of the reach at station 386 for a length of 41 ft, and then continuing 383 ft downstream. The discontinued crest-stage partial-record streamflow-gaging station (CSG) had been bolted to the upstream wing wall of the bridge at station 381. The bridge had a deep scour pool downstream for approximately 20 ft. There was a backwater effect in the vicinity of the bridge during the survey due to the presence of a small beaver dam at station 544. The beaver dam was not at the bankfull elevation, so it was assumed that the influence would not be great during bankfull flows.

The stream was consistently wide throughout the reach, dominated by shallow runs less than 2 ft deep during the survey and pools of 5 ft or less during the survey. The riffles were easy to identify, though they were often formed by the woody debris in the channel. Bed material was dominated by sand, but contained small gravel and a little cobble in riffles.

Bankfull features surveyed in this reach were the top of the bank, although lower features were surveyed. The most consistent features between the longitudinal profile and cross-section surveys were represented by the top of the bank. For more than 60 ft on either side of the channel there was little gain in elevation. The banks and flood plain were densely vegetated with herbaceous vegetation and shrubs, —green briar (smilax), blueberry, dog wood, and privet—and mature deciduous trees—maple, oak, and holly. The floodplain contained pockets of forested wetland on both banks upstream and downstream from the gage.

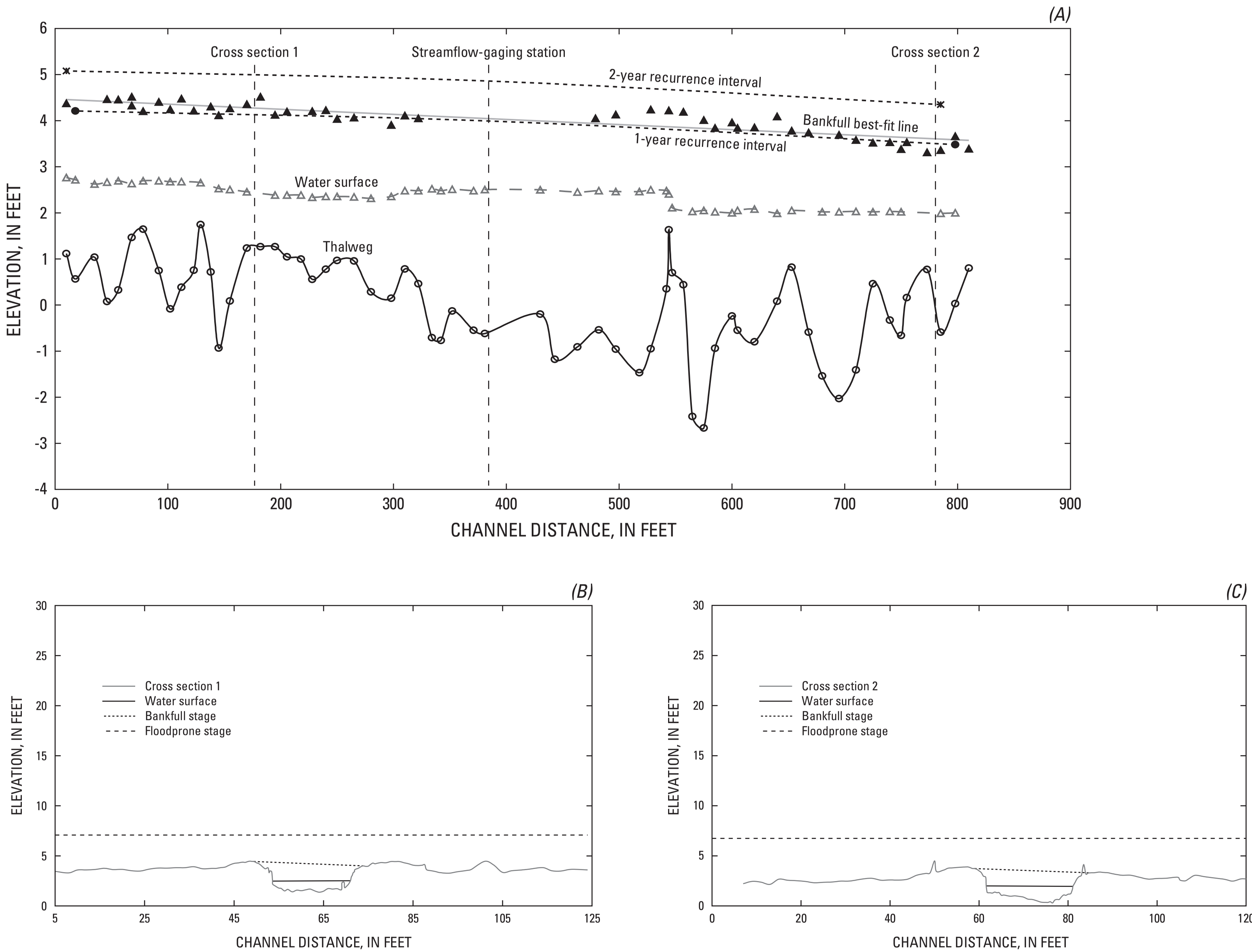
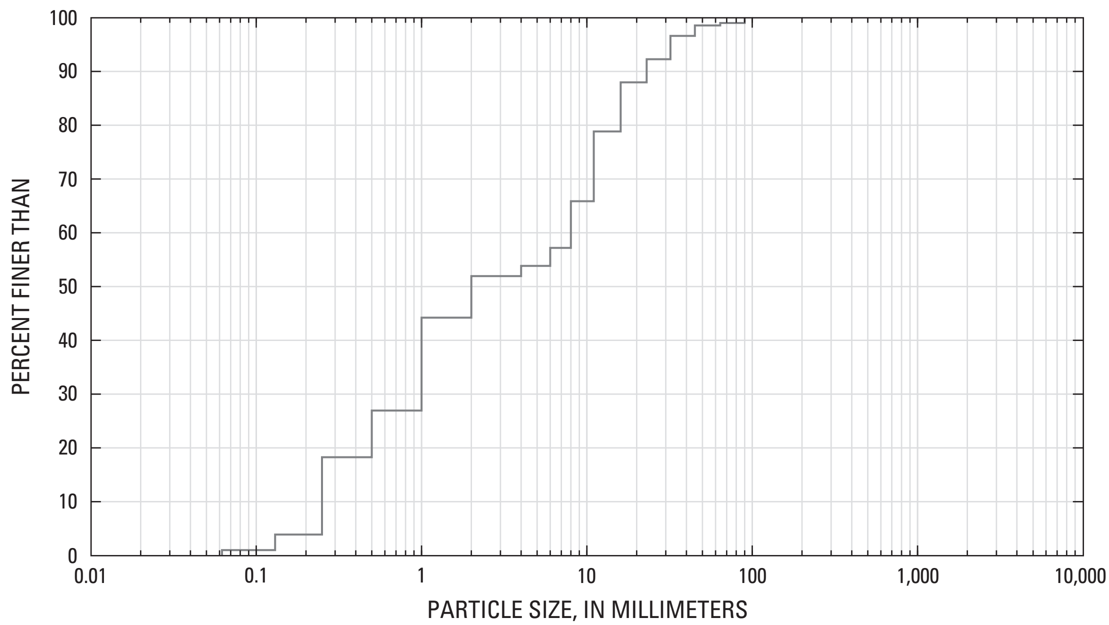


Figure A15. *(A)* Longitudinal profile, *(B)* riffle cross section 1, and *(C)* riffle cross section 2, in the study reach of Reedy Creek near Dawn, VA, May 11, 2005.



Composite material

Size classification, in percent						Percent finer, in millimeters		
Siltclay	Sand	Gravel	Cobble	Boulder	Bedrock	D16	D50	D84
0.96	50.96	47.12	0.96	0.00	0.00	0.25	2.00	16.00

Total count = 208

Figure A16. Particle-size distribution of bed material in the study reach of Reedy Creek near Dawn, VA, May 11, 2005.

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