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Development of Regional Curves of Bankfull-Channel Geometry and Discharge for Streams in the Non-Urban, Piedmont Physiographic Province, Pennsylvania and Maryland

by Peter J. Cinotto

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CONVERSION FACTORS AND DATUMS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

GLOSSARY

The terms in this glossary were compiled from numerous sources. Some definitions have been modified for use within this report.

Bankfull channel—The active stream channel during the bankfull discharge.

Bankfull cross-sectional area—The cross-sectional area of the bankfull channel measured perpendicular to the streamflow.

Bankfull discharge—The most effective streamflow for moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels (Dunne and Leopold, 1978).

Bankfull mean depth—The mean depth of the bankfull channel measured perpendicular to the streamflow.

Bankfull stage—The elevation of the water surface during bankfull discharge.

Bankfull width—The width of the bankfull channel measured perpendicular to the streamflow.

Drainage area—That area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

Gage height—Water-surface elevation referred to some arbitrary station datum. Gage height commonly is used interchangeably with the more general term “stage.”

Physiographic province—A region of which all parts are similar in geologic structure and climate and which has consequently had a unified geomorphic history; a region whose pattern of relief features or landforms differs significantly from that of adjacent regions.

Regional curve—A regression of the relations among drainage area, selected cross-sectional parameters, and streamflow.

Regulation—A condition where streamflow is controlled by an upstream human-made feature.

Stream reach—A section of stream extending between 10 and 20 bankfull widths in length.

Stream restoration—For this report, adjusting stream dimensions, pattern, and profile to a condition where it effectively accommodates a range of streamflow and sediment and supports diverse habitat.

Watershed—For this report, used interchangeably with drainage area.

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ABSTRACT

Stream-restoration projects utilizing natural-stream designs frequently are based on the bankfull-channel characteristics of stream reaches that can accommodate streamflow and sediment transport without excessive erosion or deposition and lie within a watershed that has similar runoff characteristics. The bankfull channel at an ungaged impaired site or reference reach is identified by use of field indicators and is confirmed with tools such as regional curves. Channel dimensions were surveyed at 14 streamflow-measurement stations operated by the U.S. Geological Survey (USGS) in the Gettysburg-Newark Lowland Section, Piedmont Lowland Section, and the Piedmont Upland Section of the Piedmont **Physiographic Province**[1] in Pennsylvania and Maryland. From the surveyed channel dimensions, regional curves were developed from regression analyses of the relations between drainage area and the cross-sectional area, mean depth, width, and streamflow of the bankfull channel at these sites.

Bankfull cross-sectional area and bankfull discharge have the strongest relation to drainage area as evidenced by R^2 values of 0.94 and 0.93, respectively. The relation between bankfull cross-sectional area and drainage area has a p-value of less than 0.001; no p-value is presented for the relation between bankfull discharge and drainage area because of a non-normal residual distribution. The relation between bankfull width and drainage area has an R^2 value of 0.80 and a p-value of less than 0.001 indicating a moderate linear relation between all stations. The relation between bankfull mean depth and drainage area, with an R^2 value of 0.72 and a p-value of less than 0.001, also indicates a moderate linear relation between all stations.

The concept of regional curves can be a valuable tool to support efforts in stream restoration. Practitioners of stream restoration need to recognize it as such and realize the limitations. The small number of USGS streamflow-measurement stations available for analysis is a major limiting factor in the strength of the results of this investigation, as is the inherent problem of directly associating streamflow-measurement station data to geomorphic analysis of a stream reach. Subjective selection criteria may have unnecessarily eliminated streamflow-measurement stations that could have been included in the regional curves and (or) added those that may belong within a different region. A bankfull discharge with a recurrence interval within the 1- to 2-year range commonly is used as a criterion for the confirmation of the bankfull stage at each streamflow-measurement station. Many researchers accept this range for recurrence interval of the bankfull discharge; however, literature provides contradictory evidence.

INTRODUCTION

Restoration of stream channels with excessive erosion, deposition, or degraded habitat is proposed and is implemented by federal, state, local, and private organizations in an effort to return the impaired streams to more stable and biologically productive conditions. Traditional engineering practices for stream stabilization frequently rely on hardening the stream channel in sections that are affected by erosive forces. Recent **stream-restoration** projects propose to utilize a natural-stream design approach that emphasizes working in concert with natural-stream processes as opposed to combating them. For the purposes of this study, natural-stream design is defined as a design intended to restore an impaired stream reach to a state such that the stream can transport the current sediment load and runoff provided to it from upstream without excessive aggradation or degradation while maintaining habitat and aesthetics consistent with that found in an unimpaired reach within an area of similar physiography.

The **bankfull discharge** is considered to be the most effective flow for moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels (Dunne and Leopold, 1978). The bankfull discharge is, therefore, the channel-form-

[1] Words that are in **bold** are found in the Glossary section of this report.

ing discharge and is responsible for the formation of the **bankfull channel**. As the basis of the restoration design, the bankfull channel is defined and verified by field reconnaissance and direct measurement of channel features. In addition to identifying the bankfull channel on the basis of field indicators, an independent source of information is required to support the findings, such as data obtained from a U.S. Geological Survey (USGS) streamflow-measurement station. According to Leopold (1994), the bankfull discharge has an average recurrence interval of 1.5 years. The recurrence interval for bankfull discharge for this study ranged from the 1-year to 1.5-year event, with an average of 1.3 years.

Some of the more common tools available for supporting the selection of the bankfull channel are **regional curves**. Several studies have attempted to create regional curves for various parts of the United States; one set of regional curves, developed by Dunne and Leopold (1978), is intended to be representative of the bankfull-channel dimensions throughout the eastern United States. The applicability of one set of regional curves to multiple physiographic provinces and (or) other bounding conditions has not been verified.

Characteristics of the bankfull channel are quantified using parameters such as **bankfull cross-sectional area**, **bankfull width**, **bankfull mean depth**, and streamflow. These characteristics are correlated strongly with **drainage area** (Dunne and Leopold, 1978). Regional curves are developed by regression analysis of the bankfull characteristics and drainage area, and provide estimated bankfull channel dimensions and streamflow when drainage area is known. Estimates of bankfull dimensions are helpful for confirming field identification of the bankfull channel.

Background

In 1999, the Pennsylvania Department of Environmental Protection (PaDEP) proposed a study to develop regional curves representative of channel geometry in the Piedmont Lowland and Gettysburg-Newark Lowland Sections of the Piedmont Physiographic Province and to quantify channel characteristics of a **stream reach** for use as a template in a stream-restoration design. The initial field work was completed in 2000 and the report “Regional Curve Development and Selection of a Reference Reach in the Non-Urban, Lowland Sections of the Piedmont Physiographic Province, Pennsylvania and Maryland” by K.E. White (2001) was published. This report builds upon the previous work by White (2001) by adding data from eight additional streamflow-measurement stations, predominantly within the Piedmont Upland Section, and completing a regional curve for the entire Piedmont Physiographic Province that is thought to provide a better representation of the province as a whole. PaDEP and the USGS conducted this study as a cooperative effort.

Purpose and Scope

This report describes the methods used, data collected, and the application of regional curves developed for the Piedmont Physiographic Province. Regional curves developed from channel-characteristic data collected from December 1999 to April 2002 that represent channel dimensions in the Piedmont Physiographic Province within Pennsylvania and Maryland are presented. This report is intended to present regional curves that either confirm the findings of, or more accurately represent, the Piedmont Physiographic Province than existing curves by White (2001) and (or) Dunne and Leopold (1978).

Description of the Study Area

The Piedmont Physiographic Province (fig. 1) is separated into three sections on the basis of changes in physiography within the province: the Piedmont Upland Section, the Piedmont Lowland Section, and the Gettysburg-Newark Lowland Section. Locations of USGS streamflow-measurement stations used in this study are shown in figure 1.

The Piedmont Lowland Section study area in Pennsylvania consists of broad, moderately dissected valleys separated by broad low hills. The section is developed primarily on limestone and dolomite rock. Karst topography is common. Local relief in the section generally is less than 100 ft but may be as high as 300 ft. Land-surface altitudes in the section range from 170 to 630 ft. Drainage is basically dendritic in pattern, but some areas within the section have virtually no pattern because of the well-developed subsurface drainage (Sevon, 2000).

The Gettysburg-Newark Lowland Section study area in Pennsylvania and Maryland consists mainly of rolling hills and valleys developed on sedimentary rocks. There are also isolated higher hills developed on diabase, baked sedimentary

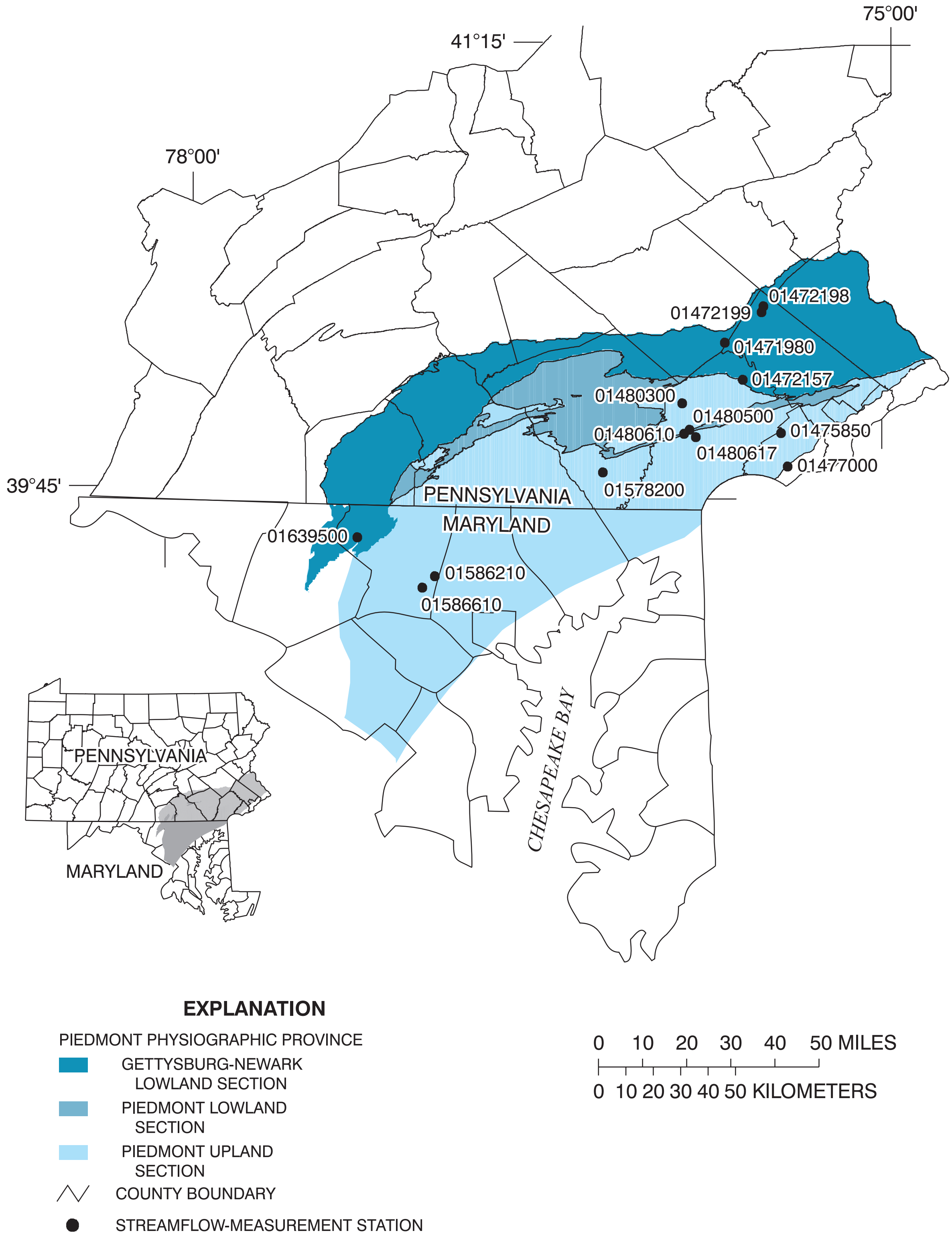

Figure 1. Locations of the Piedmont Physiographic Province, Sections, and U.S. Geological Survey streamflow-measurement stations selected for regional-curve development, Pennsylvania and Maryland.

rock, and conglomerates. Almost all the underlying sedimentary rock dips to the north or northwest, and many smaller drainage ways are oriented normal to the direction of dip so that some of the topography has a northeast-southwest linearity. The basic drainage pattern is dendritic. Relief is generally 100 to 200 ft but locally is up to 600 ft on some of the isolated hills. Altitude in the section ranges from 40 to 1,335 ft (Sevon, 2000).

The Piedmont Upland Section study area in Pennsylvania and Maryland consists mainly of broad, rounded to flat-topped hills and shallow valleys developed on schist, gneiss, and quartzite with some saprolite. The local relief is low to moderate with the lowest altitude approximately 100 ft and the highest point approximately 1,220 ft. The rocks in this section are intensely folded and faulted and the resulting drainage pattern is primarily dendritic (Sevon, 2000).

STUDY DESIGN

This study builds on the previous work by White (2001). Data from eight new USGS streamflow-measurement stations were added to complete regional curves for the entire Piedmont Physiographic Province. Data from USGS streamflow-measurement stations within the Piedmont Physiographic Province (Sevon, 2000) were used to develop the regional curves for this study. Data from stations outside of the Piedmont Physiographic Province were omitted from the study; however, three streamflow-measurement stations used in this study had some part of the **watershed** draining to them outside of the Piedmont Physiographic Province. Subjective filtering criteria utilizing Geographic Information System (GIS) land-use (U.S. Geological Survey, 1996) and stream coverages (Pennsylvania Department of Transportation, 1997; Alexander and others, 1999), and additional station-information criteria, were used to identify streamflow-measurement stations with potentially similar runoff characteristics in Pennsylvania. The range of gaged-watershed size used in the regional curves is required to be large enough to provide confidence in the relation over a range of drainage areas; this range is limited, however, by the existing number of streamflow-measurement stations. The filtering criteria used for selecting streamflow-measurement stations in Pennsylvania used in the analyses in this study are listed below:

- The station is within the boundaries of the Piedmont Physiographic Province; however, a significant percentage of the watershed draining to the station may be outside of the Piedmont Physiographic Province.
- The station has at least 10 years of record.
- If the station has been discontinued, the station must have been operational until at least 1985 to minimize the extent to which any changes in land use may have affected the channel since the station was active.
- No more than 25 percent of the upstream watershed is classified as “urban” land use.
- Streamflow at the station is subjected to no greater than approximately 20 percent **regulation**. No greater than approximately 20 percent of the flowpath in the upstream watershed is subject to regulation.
- The stream must be wadeable.

The filtering criteria above were applied to a comprehensive listing of active and discontinued continuous- and partial-record streamflow-measurement stations operated by the USGS in Pennsylvania. Stations meeting all criteria were considered for inclusion in the analysis. Streams included in this analysis may be subject to anthropogenic influences, such as the sporadic placement of rip rap; however, they must not be channelized, such as concrete-lined or trapezoidal channels. This analysis also did not exclude streams with bedrock outcrops appearing in, or near, the channel. Station descriptions, describing flow conditions and site characteristics, from records in USGS offices and, in some instances, field reconnaissance were used to finalize the list of stations included in the formulation of the regional curves. Streamflow-measurement stations within Maryland were not subjected to the same filtering criteria applied to stations within Pennsylvania because of limited GIS data. The stations in Maryland were, therefore, selected only on the basis of location, land use, and drainage area as per written and oral communications from USGS personnel in the Maryland District Office. On the basis of the listed criteria, 14 streamflow-measurement stations were selected for inclusion in the regional-curves development (table 1). Ancillary descriptors such as land use, percentage of regulation, percentage of the basin underlain by carbonate rocks, and others also are presented in table 1 to assist in the interpretation of the regional curves. For example, the presence of

Table 1. *Streamflow-measurement stations used for regional-curve development in the Piedmont Physiographic Province, Pennsylvania and Maryland*

[<, less than]

U.S. Geological Survey station identification number (see fig. 1)	Station name	Latitude/ longitude	Drainage area (square miles)	Land use (percentage of basin)		Percentage of flowpath in the Piedmont Physiographic Province[1,2]			Percentage of flowpath outside the Piedmont Physiographic Province	Percentage of flowpath subject to regulation in basin	Percentage of basin underlain by carbonate rocks
				Urban	Forest	Gettysburg Newark Lowland	Piedmont Lowland	Piedmont Upland			
[3]01471980	Manatawny Creek near Pottstown, Pa.	Lat 40°16′22″ Long 75°40′49″	85.5	<2	56	15	—	—	85	—	26
[3]01472157	French Creek near Phoenixville, Pa.	Lat 40°09′05″ Long 75°36′06″	59.1	<1	64	38	—	62	—	2	—
[3]01472198	Perkiomen Creek at East Greenville, Pa.	Lat 40°23′38″ Long 75°30′57″	38.0	2	54	51	—	—	49	—	3
[3]01472199	West Branch Perkiomen Creek at Hillegas, Pa.	Lat 40°22′26″ Long 75°31′22″	23.0	2	61	43	—	—	57	—	4
01475850	Crum Creek near Newtown Square, Pa.	Lat 39°58′35″ Long 75°26′13″	15.8	16	61	—	—	100	—	—	—
01477000	Chester Creek near Chester, Pa.	Lat 39°52′10″ Long 75°24′30″	61.1	23	50	—	—	100	—	1	—
01480300	West Branch Brandywine Creek near Honey Brook, Pa.	Lat 40°04′22″ Long 75°51′40″	18.7	1.5	27	—	—	100	—	—	3.4
01480500	West Branch Brandywine Creek at Coatesville, Pa.	Lat 39°59′08″ Long 75°49′40″	45.8	2.1	42	—	—	100	—	<1	1.3
[3]01480610	Sucker Run near Coatesville, Pa.	Lat 39°58′20″ Long 75°51′03″	2.57	11.6	45	—	53	47	—	—	35.7
01480617	West Branch Brandywine Creek at Modena, Pa.	Lat 39°57′42″ Long 75°48′06″	55.0	6	42	—	7	93	—	<1	6
01578200	Conowingo Creek near Buck, Pa.	Lat 39°50′35″ Long 76°11′45″	8.7	.9	20	—	—	100	—	—	—
01586210	Beaver Run near Finksburg, Md.[4]	Lat 39°29′22″ Long 76°54′12″	14.0	—	28	—	—	100	—	<1	—
01586610	Morgan Run near Louisville, Md.[4]	Lat 39°27′07″ Long 76°57′20″	28.0	—	29	—	—	100	—	<1	—
[3]01639500	Big Pipe Creek at Bruceville, Md.[4]	Lat 39°36′45″ Long 77°14′10″	102	—	17	32	—	68	—	—	—

[1] Pennsylvania Department of Transportation, 1997; Sevon, 2000.
[2] Percentage is based on flowpath and not total basin area.
[3] Field assessment data previously published in White, 2001.
[4] Data provided by R.W. James, Jr., U.S. Geological Survey, oral commun., 2001.

carbonate rocks within the watershed leads to the possibility of significant, undetected, underground flow that may alter surficial runoff patterns and affect the regional curves.

Procedures for measurements of hydraulic geometry and stream-type assessment, outlined by Leopold (1994) and Rosgen (1996), were followed for the data collection at each station. Deviations from the established procedure, warranted because of site conditions, are discussed along with the specific details describing the characteristics of each stream reach. Surveyed altitudes are recorded to the hundredth of a foot as per the accuracy of the equipment and survey techniques; however, stream slope data are presented to the thousandth of a foot to provide the user with relative differences between stream slopes and sufficient data for rounding purposes.

REGIONAL-CURVE DEVELOPMENT

Many restoration designs have been developed on the basis of bankfull-channel dimensions because the bankfull channel has the correct pattern, profile, and dimension to accommodate the streamflow and sediment load provided from upstream without excessive erosion or deposition. According to Dunne and Leopold (1978), the bankfull-channel dimensions of width, mean depth, and cross-sectional area are highly correlated with the size of the basin (drainage area) in a given region. A regional curve is a regression of the relation of bankfull-channel dimensions and bankfull discharge to drainage area and provides estimated bankfull-channel dimensions and streamflow for the bankfull channel when drainage area is known. Regional curves are, therefore, useful for verifying the correct **bankfull stage** in the field, and subsequently, for confirming the correct bankfull-channel dimensions and streamflow within regions having similar runoff characteristics.

USGS streamflow-measurement stations provide a source of readily available and reliable information from which regional curves can be developed. The drainage area has been determined accurately for each station, and discharge measurements at each station provide a long-term record of channel dimensions over a broad range of flows. Analysis of station records provides the frequencies of occurrence for a range of streamflows. By identifying the bankfull stage at a streamflow-measurement station, the investigator can determine the recurrence interval of the associated flow. Use of the USGS streamflow-measurement data does not necessarily provide absolute confirmation of the bankfull channel but does support the identification of the bankfull channel when used along with other field indicators. Caution should be observed when using data from a USGS streamflow-measurement station for geomorphic analysis because the measurement section is selected by USGS personnel to provide accurate velocity and area determinations for the computation of streamflow only. These measuring sections may be in slow-velocity, pool-dominated sections and not in riffles as required by most computations involved in fluvial geomorphology. Therefore, the user of these data should review the station descriptions carefully before use and be sure of whether the measurement section used by USGS personnel is a riffle, run, pool, or glide.

Field indicators used in development of the regional curves include longitudinal-profile survey data, cross-section survey data collected in one or more riffle sections, and particle distribution data for each cross section. From these data, the cross-sectional dimensions were determined, the stream reach was classified according to the Rosgen classification system (Rosgen, 1996), and bankfull discharge was calculated and, if possible, also recorded directly from the USGS streamflow-measurement station. Regression of the bankfull-channel dimensions and streamflow for each streamflow-measurement station in relation to its drainage area provided the data necessary for defining the regional-curve relation.

Field data collected during the site assessments are included in table 2. Rosgen stream type and Rosgen valley type refer to a stream and valley classification system based on the morphological characteristics (Rosgen, 1996). When two different stream types are listed for the same streamflow-measurement station (table 2), the stream type changed over the length of the study reach. A change in stream type could possibly lead to increased variance within the associated regional curves. Particle-distribution data, as presented in table 2, are required for classification purposes. In certain cases, dams, or other anthropogenic influences, prevented the stream slope from being computed for the entire study reach; in these cases, stream slope was computed from a smaller, representative reach of unaffected channel. Characteristics of the 14 stream reaches and the data collected are discussed in the following sections.

Table 2. *Data collected during assessment of the stream reaches at the streamflow-measurement stations used for regional-curve development in the Piedmont Physiographic Province, Pennsylvania and Maryland*

[WY, water year; mi^2, square miles; ft, feet; ft^2, square feet; ft^3/s, cubic feet per second; ft/ft, feet per foot; mm, millimeter; D50, particle size larger than 50 percent of the cumulative sample; D84, particle size larger than 84 percent of the cumulative sample]

U.S. Geological Survey station identification number (see fig. 1)	Period of record used for analysis (WY)	Rosgen stream type[1]	Rosgen valley type[1]	Bankfull cross-sectional area (ft^2)	Bankfull width (ft)	Bankfull mean depth (ft)	Estimated bankfull stage (ft)	Estimated bankfull discharge (ft^3/s)	Recurrence interval (years)	Stream slope (ft/ft)	Average D50 (mm)	Average D84 (mm)
[2]01471980	1974–2000	C4	VIII	468	90.1	5.19	6.26	2,340	1.3	0.001	27.7	103
[2]01472157	1969–2000	C3	VIII	316	87.1	3.63	7.78	1,440	1.3	.004	89.4	311
[2]01472198	1982–2000	C4	VIII	304	117	2.65	3.83	1,190	1.4	.002	3.80	42.4
[2]01472199	1982–2000	C4	VIII	202	96.5	1.94	4.79	1,000	1.5	.004	.80	70.4
01475850	1970-2001	[3]C4 / C5	VIII	161	57.5	2.79	5.62	601	1.2	.002	3.20	38.9
01477000	1931-2001	B4c	VI	303	69.6	4.35	7.02	1,772	1.2	.002	48.1	153
01480300	1960-2001	C4	VIII	128	57.4	2.24	4.91	333	1.0	.001	7.33	35.2
01480500	1969-2001	F4 / B4c	VI	179	77.6	2.33	5.60	1,097	1.3	.009	42.2	140
[2]01480610	1964–2000	B5c	VI	24.0	17.8	1.36	4.83	143	1.2	.009	.25	55.7
01480617	1969-2001	C4	VIII	268	97	2.77	6.40	1,643	1.3	.004	24.3	82.4
01578200	1962-2002	E4 / C4	VIII	63.7	29.2	2.22	5.44	260	1.3	.004	43.6	146
01586210	1982-2001	B4c	VI	106	44.4	2.38	3.60	559	1.4	.006	25.3	114
01586610	1982-2001	C4 / B4c	VI	189	68.2	2.77	4.71	970	1.4	.004	27.0	78.9
[2]01639500	1948–2000	C4	VIII	616	101	6.12	7.93	3,060	1.5	.001	22.4	95.8

[1] Rosgen, 1996.
[2] Field assessment data previously published in White, 2001.
[3] If two stream types are listed, the first is for the upstream-most cross section.

Characteristics of Assessed Stream Reaches and Streamflow-Measurement Stations

Manatawny Creek near Pottstown - 01471980.—The continuous streamflow-measurement station is about 180 ft upstream from a bridge. The bridge does not appear to constrict or redirect the bankfull discharge. Discharge measurements at this station usually are made while wading in the approximate location of the cross-section survey. High-water measurements are made from the bridge.

The bankfull channel was defined clearly throughout most of the reach by field indicators such as riparian vegetation, abrupt change in bank angle, and change in depositional material. Four riffles were present within the study reach; however, the cross-section survey was limited to one cross section in a “run” (an area of intermediate relative velocity) because of the presence of a divided channel throughout the upstream half of the reach. A view of the study reach is shown in figure 2. The elevation of the bankfull stage was surveyed to the outside vertical staff gage from which the **gage height** and associated bankfull discharge were determined. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection (White, 2001).

French Creek near Phoenixville - 01472157.—The continuous streamflow-measurement station is about 70 ft downstream from a bridge. The bridge may have a slight effect on the bankfull discharge due to constriction of higher flows and the subsequent hydraulic jump upon exiting the bridge structure. Discharge measurements usually are made while wading in the vicinity of the station. High-water measurements are made from the bridge.

The bankfull channel, in the vicinity of the streamflow-measurement station, was defined poorly because of excessive bank erosion. Directly across from the streamflow-measurement shelter is an auxiliary channel, separated from the main channel by a berm that extends 500 ft downstream. This auxiliary channel is a component of the bankfull channel and contains flowing water during moderate and high streamflow events. Riffles within this area were not surveyed because of the resulting divided channel at the bankfull discharge. Excellent bankfull indicators were identified on a point bar beginning about 700 ft downstream from the station. Two cross sections were surveyed at riffles within this downstream reach. A view of the study reach is shown in figure 3. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the regional curves. The bankfull elevation was extended upstream to the streamflow-measurement station to determine the gage height and streamflow associated with the bankfull stage. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection (White, 2001).

Figure 2. View looking upstream at reach for Manatawny Creek near Pottstown, Pennsylvania (From White, 2001).

Figure 3. View looking downstream at reach for French Creek near Phoenixville, Pennsylvania (From White, 2001).

Perkiomen Creek at East Greenville - 01472198.—The continuous streamflow-measurement station is adjacent to a pool created by a weir immediately downstream from the shelter. A multi-span bridge is 100 ft downstream from the weir and does not appear to constrict the bankfull discharge. Discharge measurements usually are made while wading downstream from the weir and the bridge. High-water measurements are made from the bridge.

The bankfull channel throughout the entire study reach was defined fairly well by an abrupt change in bank angle and intermittent depositional features. Two cross sections were surveyed at riffles within the reach. A section of the stream reach was stabilized previously; however, the surveyed cross sections were beyond the affected stream section. A view of the study reach is shown in figure 4. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The bankfull water-surface elevation could not be extended upstream to the streamflow-measurement station because of the relatively high-profile weir. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection (White, 2001).

West Branch Perkiomen Creek at Hillegas - 01472199.—The continuous streamflow-measurement station is adjacent to a pool created by a weir immediately downstream from the shelter. The rating is considered to be poorly defined above 560 ft^3/s because of the lack of a good location from which to make high-water measurements. Discharge measurements are conducted throughout the stream reach while wading both upstream and downstream from the weir.

The assessed reach was separated from the streamflow-measurement station by a high-profile rock outcrop approximately 300 ft upstream. The bankfull channel was defined clearly throughout most of the assessed reach by riparian vegetation, abrupt changes in bank angle, and depositional features. Two cross sections were surveyed at riffles within the assessed reach. A view of the study reach is shown in figure 5. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. Despite the presence of the rock outcrop, the bankfull elevation could be extended to the outside vertical staff gage adjacent to the streamflow-measurement station to determine the gage height and streamflow associated with the bankfull stage. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection (White, 2001).

Figure 4. View looking downstream at reach for Perkiomen Creek at East Greenville, Pennsylvania (From White, 2001).

Figure 5. View looking upstream at reach for West Branch Perkiomen Creek at Hillegas, Pennsylvania (From White, 2001).

Crum Creek near Newtown Square - 01475850.—The continuous streamflow-measurement station is approximately 120 ft upstream from a bridge that may have a slight effect on the bankfull discharge due to constriction of higher flows and the associated backwater effect. Discharge measurements usually are made while wading in the vicinity of the station. High-water measurements are made from the bridge.

The bankfull channel was defined clearly throughout most of the reach by field indicators such as riparian vegetation and depositional features. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 6. The lower third of the stream reach was affected by fill on the right bank due to development, but both cross sections were upstream and beyond the immediate effect of this fill. The bankfull widths, mean depths, and cross-sectional areas were averaged to determine the input for the development of the regional curves. The elevation of the bankfull stage was surveyed to the outside vertical staff gage from which the gage height and streamflow associated with the bankfull discharge were determined. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection.

Chester Creek near Chester - 01477000.—The continuous streamflow-measurement station is about 30 ft downstream from a bridge that appears to have little or no effect on the bankfull discharge. Discharge measurements usually are made while wading in the vicinity of the station. High-water measurements are made from the bridge. The bankfull channel, in the vicinity of the streamflow-measurement station and throughout the reach, was defined poorly because of heavy bank erosion. The left bank is affected throughout the reach by a road that parallels the stream, and sporadic riprap is present along that bank. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 7. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The elevation of the bankfull stage was extended to the outside vertical staff gage from which the gage height and streamflow associated with the bankfull discharge were determined. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection.

Figure 6. View looking downstream at reach for Crum Creek near Newtown Square, Pennsylvania.

Figure 7. View looking downstream at reach for Chester Creek near Chester, Pennsylvania.

West Branch Brandywine Creek near Honey Brook - 01480300.—The continuous streamflow-measurement station is about 100 ft upstream from a bridge that appears to have a slight effect on the bankfull discharge due to constriction of higher flows and the associated backwater effect. Discharge measurements usually are made while wading in the vicinity of the station. High-water measurements are made from the bridge.

The bankfull channel throughout the reach was well defined by changes in riparian vegetation, depositional features, and a well-defined flood plain above which no features were present. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 8. A road is directly adjacent to the right bank along the upper third of the study reach and sporadic riprap alters the natural channel within this area; however, surveyed cross sections were downstream and beyond the effects of this stream reach. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The bankfull elevation was extended to the outside vertical staff gage from which the gage height and streamflow associated with the bankfull discharge were determined.

The measured channel geometry at the estimated bankfull discharge, as indicated by streamflow-measurement data in the USGS database, was problematic in the confirmation of bankfull at this station. The recurrence interval of the bankfull discharge at this site (1-year flood event) was at the lower boundary of the 1- to 2-year flood-event range commonly associated with the bankfull discharge. This 1-year recurrence interval was also lower than had been noted at all other sites within this study (table 2). However, throughout the entire reach, there are no higher geomorphic features above the well-developed flood plain and the bankfull stage could be extended clearly, without obstruction, to the outside vertical staff gage at the USGS streamflow-measurement station. These findings confirm the association of the bankfull channel to the 1-year flood event.

West Branch Brandywine Creek at Coatesville - 01480500.—The continuous streamflow-measurement station is within the impoundment area of a small dam approximately 150 ft downstream from the gage. Several bridges cross the stream within the range of 400 ft upstream to 1,200 ft downstream from the station. All of these bridges appear to have an effect on the bankfull discharge either by redirecting or constricting flows. The confluence of Rock Run into the West Branch of the Brandywine Creek is approximately 0.6 mi upstream from the gage. Discharge measurements usually are made while wading either 1,000 ft upstream or 600 ft downstream from the gage. High-water measurements are made from the bridge 400 ft upstream from the gage.

The bankfull channel in the vicinity of the gage was defined poorly because of excessive width caused by the dam; therefore, the study reach was downstream and below the dam. The dam currently is filled with sediment and has very little storage or regulation effect on the bankfull discharge. The bankfull channel throughout the study reach was moderately well defined by depositional features, riparian vegetation, and a subtle change in bank angle. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 9. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The bankfull elevation could not be extended to the outside vertical staff gage because of the dam, and calculated values for bankfull discharge subsequently were used to determine the bankfull recurrence interval (1.3-year flood event). The channel geometry at the estimated bankfull discharge, as indicated by streamflow-measurement data in the USGS database, proved not to be effective with bankfull confirmation at this station because discharge measurements commonly are made while wading within a pool-dominated reach. Measurements of streamflow within a pool result in a slightly higher area than an equivalent streamflow in a riffle.

Figure 8. View looking upstream at reach for West Branch Brandywine Creek near Honey Brook, Pennsylvania.

Figure 9. View looking downstream at reach for West Branch Brandywine Creek at Coatesville, Pennsylvania.

Sucker Run near Coatesville - 01480610.—The crest-stage, partial-record station does not collect continuous data but is operated primarily to document peak streamflow. Discharge measurements are made while wading approximately 50 ft downstream of the streamflow-measurement station; cross-section surveys were conducted in this same reach. High-water measurements are made from the bridge immediately upstream from the station. Two bridges, which are 227 ft apart, bound the reach and may constrict the bankfull discharge slightly.

Definition of the bankfull channel, in the vicinity of the streamflow-measurement station, was fair, as evidenced by a subtle change in bank angle. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 10. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The bankfull water-surface elevation was extrapolated to the outside vertical staff gage to determine the gage height and streamflow associated with the bankfull stage. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection (White, 2001).

West Branch Brandywine Creek at Modena - 01480617.—The continuous streamflow-measurement station is approximately 15 ft downstream from a multi-span bridge and approximately 300 ft upstream from a small tributary (Dennis Run). The bridge appears to have a slight effect on the bankfull discharge as indicated by a mid-channel bar that forms directly downstream from the bridge. Discharge measurements commonly are made while wading in the vicinity of the station. High-water measurements are made from the bridge.

The bankfull channel in the vicinity of the gage was moderately well defined by changes in riparian vegetation and depositional features. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 11. The cross sections were at 146 and 242 ft downstream from the bridge, respectively, in order to be above the confluence of Dennis Run and also above the effects of fill from an industrial complex on the left streambank approximately 275 ft downstream. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The elevation of the bankfull stage was extended to surveyed reference marks at the streamflow-measurement station from which the gage height and streamflow associated with the bankfull discharge were determined. The channel geometry at the estimated bankfull discharge, as indicated by streamflow-measurement data in the USGS database, proved not to be effective with bankfull confirmation at this station because wading measurements of streamflow are made within a pool-dominated reach adjacent to the station.

Figure 10. View looking downstream at reach for Sucker Run near Coatesville, Pennsylvania (From White, 2001).

Figure 11. View looking upstream at reach for West Branch Brandywine Creek at Modena, Pennsylvania.

Conowingo Creek near Buck - 01578200.—The crest-stage partial-record station consists of two crest-stage gages mounted approximately 70 ft upstream of a bridge on the left bank and on the downstream left wingwall of the bridge. The bridge appears to have very little effect on bankfull discharge. Discharge measurements commonly are made while wading in the vicinity of the station. High-water measurements are made from the bridge.

The bankfull channel throughout the reach was well defined by riparian vegetation, both subtle and abrupt changes in bank angle, and depositional features. Two cross sections were surveyed at riffles within the study reach approximately 200 ft upstream and 400 ft downstream of the bridge. A view of the study reach is shown in figure 12. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The elevation of the bankfull stage was extended to surveyed reference marks at the streamflow-measurement station from which the gage height and streamflow associated with the bankfull discharge were determined. The study reach was bounded on the upstream end by the confluence of a small tributary and downstream by a large evulsion indicative of accelerated bank erosion. Approximately half of the study reach, upstream from the bridge, was well vegetated and bounded on the left overbank by a large farm pond that appeared to be well above the bankfull stage. The remainder of the study reach, or that part downstream from the bridge, exhibited very little vegetation on the banks and (or) floodplain and showed evidence, in the form of meander scars, of extensive lateral movement of the channel. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection.

Beaver Run near Finksburg - 01586210.—The continuous streamflow-measurement station is mounted directly to the downstream face of a multi-span bridge and approximately 250 ft upstream of a small stone dam. Both the bridge and dam appear to effect the bankfull discharge. The dam increases resistance to streamflow that, in turn, causes increased an flood stage during periods of high flows and an increased bank erosion rate directly adjacent to the structure. The bridge constricts flow and causes both scour and the associated deposition of sediment downstream from the bridge structure.

The bankfull channel in the vicinity of the gage was defined poorly because of the effects of the bridge and dam; however, the bankfull channel was well defined farther downstream by riparian vegetation, subtle changes in bank angle, and depositional features. Two cross sections were surveyed at riffles within the study reach approximately 400 and 600 ft downstream from the gage. A view of the study reach is shown in figure 13. The cross sections were downstream of the small stone dam that has been bypassed along the right bank by bank erosion. This dam, while small and largely filled with sediment, appears to have a significant effect on the bankfull discharge. A farm pond lies in the flood plain beyond the left bank of the stream for almost the entire study reach. The berm around this pond obstructs the floodplain but is above the bankfull channel and has no effect at less-than flood stage. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The bankfull elevation could not be extended to the outside vertical staff gage because of the dam, and calculated values for bankfull discharge subsequently were used to determine the bankfull recurrence interval (1.4-year flood event). The channel geometry at the estimated bankfull discharge, as indicated by streamflow-measurement data in the USGS database, proved not to be effective with bankfull confirmation because wading measurements of streamflow are made within a pool-dominated reach slightly downstream of the bride.

Figure 12. View looking upstream at reach for Conowingo Creek near Buck, Pennsylvania.

Figure 13. View looking upstream at reach for Beaver Run near Finksburg, Maryland.

Morgan Run near Louisville - 01586610.—The continuous streamflow-measurement station is 30 ft downstream from the face of a bridge on the right bank. The outside vertical staff gage is mounted directly to the downstream-right wing-wall of the bridge. The bridge appears to both constrict and redirect flows that affect the bankfull discharge in the vicinity of the bridge.

The bankfull channel upstream and downstream of the gage was moderately well defined by riparian vegetation and depositional features; however, because of the effect of the bridge, the bankfull channel was not well defined within the bridge right-of-way. Two cross sections were surveyed at riffles within the reach. A view of the study reach is shown in figure 14. The cross sections were at 600 ft upstream and 450 ft downstream of the gage because of irregular banks in the vicinity of the bridge. This irregularity appears to be caused by deflected flow through the bridge structure and runoff from the adjacent roadway. The bankfull widths, mean depths, and cross-sectional areas of the two cross sections were averaged to determine the input for the development of the regional curves. The bankfull elevation could not be extended to the outside vertical staff gage because of the bridge, and calculated values for bankfull discharge subsequently were used to determine the bankfull recurrence interval (1.4-year flood event). The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection.

Big Pipe Creek at Bruceville - 01639500.—The continuous streamflow-measurement station is adjacent to a pool created by a low-profile weir 25 ft downstream from the shelter. A multi-span bridge is 300 ft upstream from the station and does not appear to constrict the bankfull discharge. Discharge measurements usually are made while wading upstream from the station. High-water measurements are made from the bridge.

The site assessment was limited to one cross-section survey within the reach because of a storm event and resulting elevated streamflow midway through the assessment. A view of the study reach is shown in figure 15. The bankfull channel was defined clearly throughout most of the reach, with the exception of within the bridge right-of-way, by riparian vegetation and a subtle change in bank angle. The bankfull water-surface elevation passed the outside vertical staff gage from which the gage height and streamflow associated with the bankfull stage were determined. The measured geometry of the channel within the estimated range of bankfull discharge, as taken from streamflow-measurement data in the USGS database, was used to assist with confirmation of bankfull selection (White, 2001).

Figure 14. View looking downstream at reach for Morgan Run near Louisville, Maryland.

Figure 15. View looking upstream at reach for Big Pipe Creek at Bruceville, Maryland (From White, 2001).

Evaluation of Regional Curves

The regional curves presented in figures 16 through 19 show the relation between drainage area and bankfull cross-sectional area, bankfull discharge, bankfull width, and bankfull mean depth, respectively. The 95-percent confidence interval indicates a band within which there is a 95-percent probability that estimates of the mean bankfull-channel geometry or bankfull-channel flow for that particular drainage area will occur. The coefficient of determination, R^2, is a measure of variability accounted for by the regression relations in the observed channel-geometry, and (or) discharge compared to the drainage area. The p-value measures the "believability" of the level of significance of the statistical test. If the p-value is less than 0.05, the test is considered significant and the trend, as represented by the regression line, can be assumed to be real.

Bankfull cross-sectional area (fig. 16) and bankfull discharge (fig. 17) have the strongest relation to drainage area as evidenced by R^2 values of 0.94 and 0.93, respectively. The relation between bankfull cross-sectional area and drainage area has a p-value of less than 0.001. The p-value for the relation between bankfull discharge and drainage area could not be presented because of a non-normal distribution of residuals within this data set and is discussed later. The relation between bankfull width and drainage area (fig. 18) has an R^2 value of 0.80 and a p-value of less than 0.001, indicating a moderate linear relation between all stations. The relation between bankfull mean depth and drainage area (fig. 19), with an R^2 value of 0.72 and a p-value of less than 0.001, also indicates a moderate linear relation between all stations. The moderate relation indicated by the bankfull mean depth and bankfull width regional curves may be due, in part, to variation in Rosgen stream type as noted in table 2. The Cook's Distance statistic is a measure of the influence a particular point has on the regression relations of observed channel-geometry, and (or) discharge compared to the drainage area. Analysis of the Cook's Distance statistic for each regional curve yielded no values greater than 1; therefore, none of the 14 data points has significant influence, or leverage effect, in any regional-curve data set.

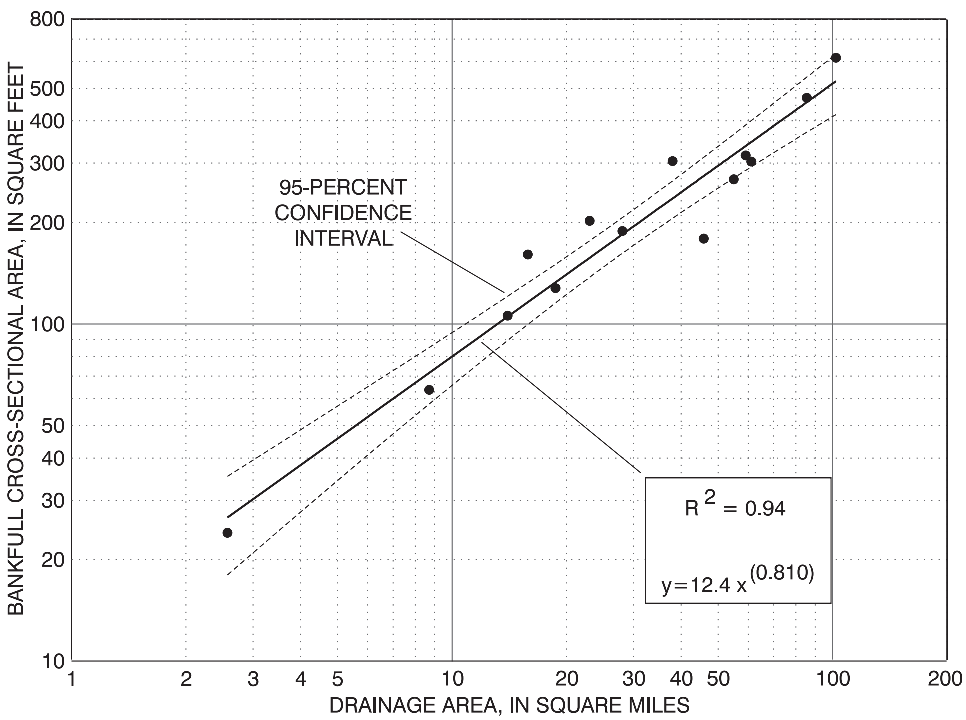

Figure 16. Regional curve representing relation between bankfull cross-sectional area and drainage area in non-urban, Piedmont Physiographic Province, Pennsylvania and Maryland.

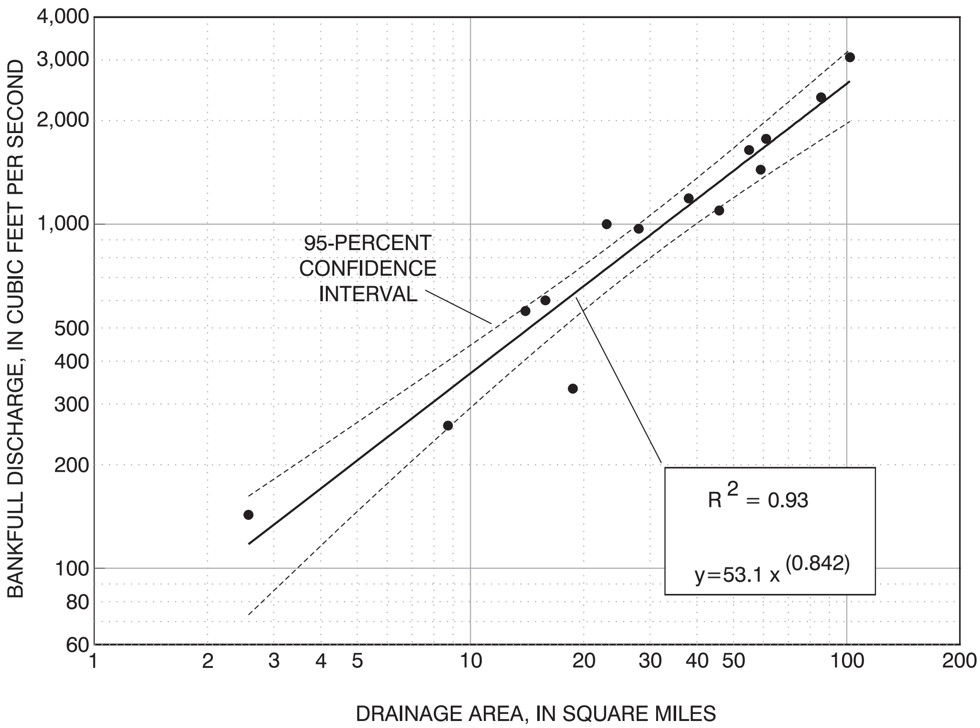

Figure 17. Regional curve representing relation between bankfull discharge and drainage area in non-urban, Piedmont Physiographic Province, Pennsylvania and Maryland.

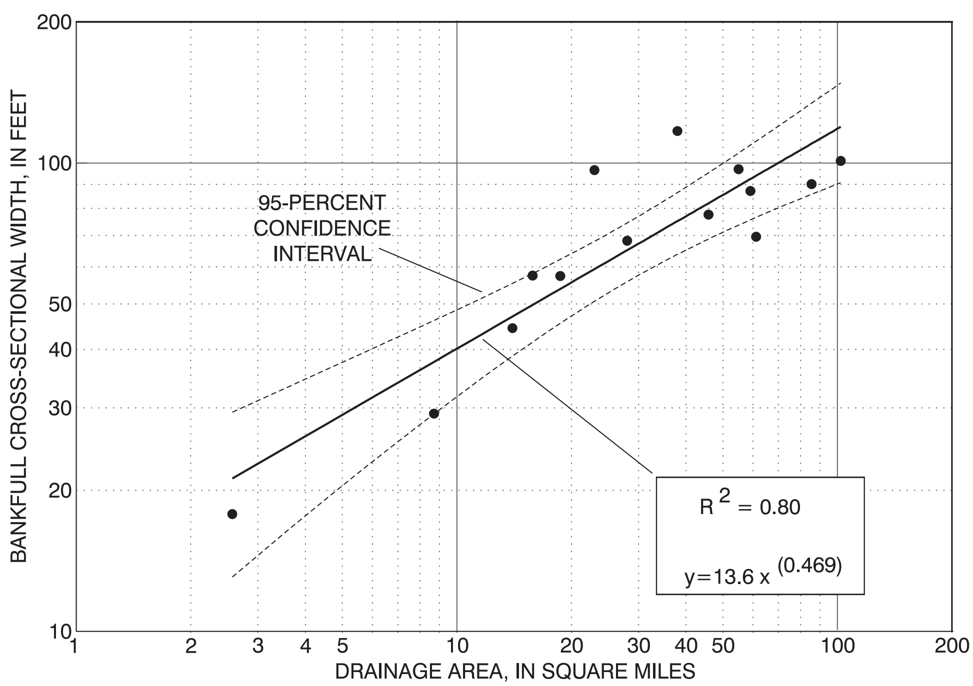

Figure 18. Regional curve representing relation between bankfull cross-sectional width and drainage area in non-urban, Piedmont Physiographic Province, Pennsylvania and Maryland.

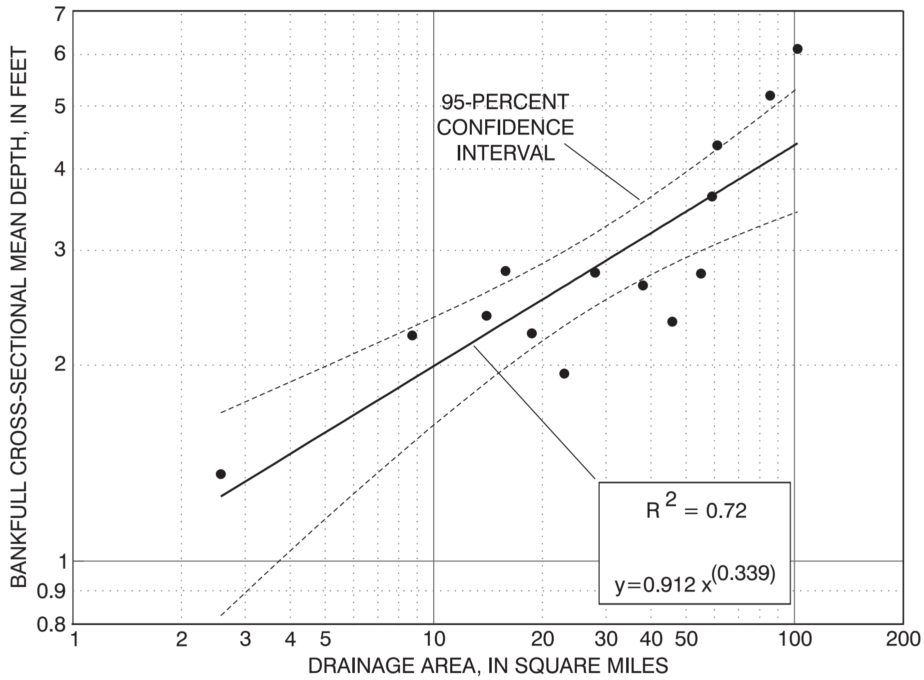

Figure 19. Regional curve representing relation between bankfull cross-sectional mean depth and drainage area in non-urban, Piedmont Physiographic Province, Pennsylvania and Maryland.

Statistical tests for the normality of residuals by analysis of the p-value statistic obtained from the Kolmogorov-Smirnov Goodness-of-fit (GOF) test yielded a value of 0.003 for the relation between bankfull discharge and drainage area. P-values from the Kolmogorov-Smirnov GOF test equal to or less than 0.05 indicate the residuals from the data set should be considered not normal. All other relations reported values above this limit. Non-normal residuals do not necessarily indicate a poor relation; however, they do result in incorrect p-values because the residual distribution does not fit the normal t-distribution used to compute the p-value. For this reason, no p-value is presented for the relation between bankfull discharge and drainage area, and the curve should be used with caution. This non-normality also causes the 95-percent confidence bands presented in figure 17 to be questionable because they are constructed using the assumption of a normal distribution. The 95-percent confidence bands are shown in figure 17 for reference but also should be used with caution. On the basis of regression diagnostics and visual evaluation, users of the bankfull cross-sectional area and bankfull discharge regional curves would expect to obtain better estimates than those of bankfull width and bankfull mean depth.

COMPARISON OF ESTIMATES FROM PIEDMONT PHYSIOGRAPHIC PROVINCE REGIONAL CURVES AND DUNNE AND LEOPOLD REGIONAL CURVES

Bankfull-channel dimensions and streamflows determined from the relations discussed previously herein, those determined from White (2001), and those estimated from Dunne and Leopold (1978) for drainage areas of 5, 25, 50, 75, 100, and 200 mi^2 are shown in table 3. Comparison of estimates computed from regional curves presented by White (2001) and Dunne and Leopold (1978) to those computed from the Piedmont Physiographic Province regional curves yield differences for bankfull cross-sectional area ranging from 29 to -7.2 percent, differences for bankfull mean-depth ranging from 30 to -6.7 percent, differences for bankfull width ranging from 9.1 to -33 percent, and differences for bankfull discharge ranging from 16 to -4.0 percent.

Table 3. *Comparison of estimates from Piedmont Physiographic Province Regional Curves, Piedmont Lowlands Regional Curves, and Dunne and Leopold Regional Curves*

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

Drainage area	Channel characteristics	Piedmont Physiographic Province regional curves—Values computed from equations	Piedmont Lowlands regional curves from White, 2001—Values computed from equations	Dunne and Leopold Regional Curves for southeast Pennsylvania and eastern United States—Values from graphs	Comparison of estimates from White (2001) to Piedmont Physiographic Province curves in percent difference	Comparison of estimates from Dunne and Leopold (1978) to Piedmont Physiographic Province curves in percent difference
5 - mi^2	Bankfull discharge - ft^3/s	210	250	220	16	4.5
5 - mi^2	Bankfull cross-sectional area - ft^2	46	46	65	0.0	29
5 - mi^2	Bankfull mean depth - ft	1.6	1.5	2.3	-6.7	30
5 - mi^2	Bankfull width - ft	29	31	30	6.5	3.3
25 - mi^2	Bankfull discharge - ft^3/s	800	890	800	10	0.0
25 - mi^2	Bankfull cross-sectional area - ft^2	170	180	180	5.6	5.6
25 - mi^2	Bankfull mean depth - ft	2.7	2.8	3.8	3.6	29
25 - mi^2	Bankfull width - ft	62	65	50	4.6	-24
50 - mi^2	Bankfull discharge - ft^3/s	1,400	1,500	1,500	6.7	6.7
50 - mi^2	Bankfull cross-sectional area - ft^2	300	330	320	9.1	6.3
50 - mi^2	Bankfull mean depth - ft	3.4	3.6	4.5	5.6	24
50 - mi^2	Bankfull width - ft	85	90	70	5.6	-21
75 - mi^2	Bankfull discharge - ft^3/s	2,000	2,100	2,000	4.8	0.0
75 - mi^2	Bankfull cross-sectional area - ft^2	410	460	400	11	-2.5
75 - mi^2	Bankfull mean depth - ft	4.0	4.2	4.9	4.8	18
75 - mi^2	Bankfull width - ft	100	110	80	9.1	-25
100 - mi^2	Bankfull discharge - ft^3/s	2,600	2,700	2,500	3.7	-4.0
100 - mi^2	Bankfull cross-sectional area - ft^2	510	590	500	14	-2.0
100 - mi^2	Bankfull mean depth - ft	4.4	4.7	5.5	6.4	20
100 - mi^2	Bankfull width - ft	120	120	90	0.0	-33
200 - mi^2	Bankfull discharge - ft^3/s	4,600	4,600	4,500	0.0	-2.2
200 - mi^2	Bankfull cross-sectional area - ft^2	890	1,100	830	19	-7.2
200 - mi^2	Bankfull mean depth - ft	5.5	6.2	7.0	11	21
200 - mi^2	Bankfull width - ft	160	170	130	6	-23

LIMITATIONS OF THE INVESTIGATION

Subjective filtering criteria may have eliminated, unnecessarily, streamflow-measurement stations that could have been included in the development of the regional curves. Conversely, land-use percentages characterizing the watershed may affect runoff characteristics at a much lower percentage than the criteria would indicate. For example, numerous studies suggest channel stability may be affected by urban land use and regulation at percentages lower than the 20 percent used in this report. While this study has added eight additional data points to the previous work by White (2001), this data set is still statistically small. The continued addition of data from streamflow-measurement stations in this and other physiographic provinces may provide better estimates of the relation of channel characteristics to drainage area in all provinces by increasing the size of the data set.

Physiography is used in this study as one way to categorically analyze the assessment of streamflow-measurement stations. This approach may, or may not, be a significant factor in determining the regional relation of runoff characteristics of a watershed to the geomorphic characteristics at a specific station; for example, large percentages of the drainage areas to some streamflow-measurement stations are in a different physiographic section or province than the station itself.

The regional curves presented in this report should be used only for the confirmation of the bankfull channel conditions in non-urban streams of the Piedmont Physiographic Province. Due to the variation inherent in hydrologic data, regional curves should not be used for direct computation of channel dimensions in steam restoration designs. The assumption made for this investigation is that the bankfull discharge is within the 1- to 2-year recurrence range. Thorne and others (1997) state, "The widely reported assertion that bankfull discharge occurs on average once every 1 to 2 years is now seen as an oversimplification." If runoff patterns at a streamflow-measurement station are such that the bankfull discharge may occur more, or less, often than this 1- to 2-year frequency, the recurrence-interval criteria did not substantiate identification of the bankfull channel as it was intended. In addition, land use and other basin characteristics upstream from the reach where regional curves are to be applied should be similar to those used for the selection criteria in this assessment.

The stability of the reaches included in this study—in terms of sediment transport, hydraulic conveyance, and degradation and (or) aggradation of the stream reaches—has not been confirmed, and long-term monitoring of the reaches has not been completed. Stream channels in transitional states may have introduced increased variance into the regional curves, especially the bankfull width and bankfull mean depth curves. Stream-restoration projects must rely on reference reaches indicative on long-term stability for design criteria and use regional-curve data only to initially confirm or refute the field identification of the bankfull channel conditions.

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Protection, conducted a study to develop regional curves of bankfull-channel geometry and discharge for use in support of stream-restoration efforts. This study took place from 1999 to 2000 in the Lowland Sections of the Piedmont Physiographic Province and continued into 2002 to complete the Upland Section and, therefore, the entire Piedmont Physiographic Province within Pennsylvania and Maryland. Those regional curves were developed from channel-geometry and streamflow data collected at 14 USGS streamflow-measurement stations in the Piedmont Physiographic Province. These streamflow-measurement stations included six from the previous study of the Piedmont Lowland Sections and eight additional streamflow-measurement stations in the Piedmont Upland Section. The watersheds range in size from 2.57 to 102 mi^2. The bankfull channel was identified at each station by use of field indicators and confirmed by use of historical streamflow-measurement data when possible. Width, mean depth, cross-sectional area and discharge of the bankfull channel were plotted as a function of drainage area and a "best fit" regression line was applied to the data. The resulting regression line, and the corresponding equation defining that line, can be used to confirm field identification of bankfull-channel conditions at non-urban stream sites having similar runoff characteristics throughout the Piedmont Physiographic Province given a known drainage area. On the basis of regression diagnostics and visual evaluation, bankfull area and bankfull discharge have a stronger relation to drainage area than do bankfull width and bankfull mean depth.

Regional-curve sets that provide an estimate of bankfull-channel dimensions and streamflow can be a valuable tool to support efforts in stream restoration by assisting in identification of the bankfull channel; however, practitioners of stream restoration need to realize their limitations. The curves developed for this study are based on limited, highly variable data. The small number of streamflow-measurement stations used to create these regressions limits the strength of the regional curves presented.

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