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New York State Department of Environmental Conservation
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Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State–Hydrologic Region 3 East of the Hudson River

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Cover. Valatie Kill, June 2006, Rensselaer County, New York.

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
foot (ft)	0.3048	meter (m)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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

List of Acronyms

NCD	Natural channel design
HEC-RAS	Hydraulic engineering center river analysis system
HHM	Hydrologic and habitat modification
NPSCC	Nonpoint-source coordinating committeee
NYCDEP-SMP	New York City Department of Environmental Protection-Stream Management Program
NYSDEC	New York State Department of Environmental Conservation
NYSDOS	New York State Department of State
NYSDOT	New York State Department of Transportation
USGS	U.S. Geological Survey

Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State—Hydrologic Region 3 East of the Hudson River

By Christiane I. Mulvihill and Barry P. Baldigo

Abstract

Equations that relate drainage area to bankfull discharge and channel characteristics (such as width, depth, and cross-sectional area) at gaged sites are needed to define bankfull discharge and characteristics at ungaged sites and can be used for stream-restoration and protection projects, stream-channel classification, and channel assessments. These equations are intended to serve as a guide for streams in areas of similar hydrologic, climatic, and physiographic conditions. New York State contains eight hydrologic regions that were previously delineated on the basis of high-flow (flood) characteristics. This report presents predictive equations for bankfull characteristics (discharge and channel characteristics) for streams east of the Hudson River, referred to as Hydrologic Region 3.

Stream-survey data and discharge records from 12 streamflow-gaging stations were used in regression analyses to relate drainage area to bankfull discharge and bankfull channel width, depth, and cross-sectional area. The four predictive equations are:

bankfull discharge (cubic feet per second) =
83.8 (drainage area (square miles))$^{0.679}$, (1)

bankfull-channel width (feet) =
24.0 (drainage area (square miles))$^{0.292}$, (2)

bankfull-channel depth (feet) =
1.66 (drainage area (square miles))$^{0.210}$, (3)

bankfull-channel cross-sectional area (square feet) =
39.8 (drainage area (square miles))$^{0.503}$. (4)

The coefficients of determination (R^2) for these four equations are 0.93, 0.85, 0.77, and 0.92, respectively. The high coefficients of determination for bankfull discharge and cross-sectional area indicate that much of the range in the variables is explained by the size of the drainage area; the smaller correlation coefficients for bankfull channel width and depth indicate that other factors also affect these relations. Recurrence intervals for the estimated bankfull discharge of each stream ranged from 1.16 to 3.35 years; the mean recurrence interval was 2.08 years. The 12 surveyed streams were classified by Rosgen stream type; most were B and C type, with occasional E- and F-type cross sections. The Region 3 equation (curve) for bankfull discharge was compared with those previously obtained for seven other hydrologic regions in New York State. The differences confirm that the hydraulic geometry of streams is affected by local climatic and physiographic conditions.

Introduction

Streambank erosion and the resulting sedimentation of streams can affect the water quality of reservoirs, endanger aquatic life, and threaten riparian habitat, private and public lands, and associated infrastructure. Streams throughout New York State that have abnormally high rates of erosion and sedimentation often require costly restoration efforts to stabilize the stream channel and banks and minimize further erosion to both. Stream-restoration projects have traditionally consisted of straightening, widening, and deepening the channel, hardening the banks, and imposing static stream characteristics—all of which can cause permanent ecological disruption. Recent stream-restoration projects, in contrast, have begun to use an approach that strives toward replication of stable-reach characteristics, such as the relation between drainage-area and channel cross-section characteristics, and the relations among channel characteristics, flow patterns, and water-surface profiles. Bankfull discharge and bankfull-channel characteristics of streams that are not gaged can be derived by using equations (curves) that have been developed using data from nearby stable reaches that are gaged. Channel-characteristics data from these nearby reference reaches provide the foundations for Natural Channel Design (NCD) restoration techniques to recreate geomorphically[1]

[1] Refers to channel slope, shape, and pattern (Rosgen, 1996).

stable stream reaches. The stream characteristics obtained through NCD techniques structurally resemble those of stable, undisturbed streams and, thus, can slow erosion and sedimentation and allow regeneration of aquatic ecosystems that are more diverse and functionally complete than those that typically result from the hardening of streambeds and banks.

Bankfull discharge is the most useful stream feature for defining the relations between drainage area and stream-channel characteristics. Bankfull discharge is the flow that reaches the transition between the channel and its floodplain and is thus morphologically significant (Leopold and others, 1964). It may be functionally defined and identified as the stage or flow at which the stream is about to overtop its banks (Leopold and others, 1964; Leopold, 1994) and is reported to occur every 1 to 2 years, or 1.5 years on average (Rosgen, 1994). Bankfull discharge is the flow that moves the most sediment over time because of its force and frequency (Wolman and Miller, 1960; Leopold, 1994).

Bankfull discharge affects the relation between drainage area and stream-channel characteristics in two ways. First, it often occurs at a relatively discrete and identifiable stage; thus, the channel characteristics at bankfull stage form the basis for a system of stream classification (Rosgen, 1996). Second, relations between drainage area and discharge, and between drainage area and channel characteristics are relatively constant at bankfull stage in stable streams of a given class within a certain hydrologic region (Leopold and others, 1964; Rosgen, 1996).

Stable-channel characteristics for an unstable, ungaged stream can be estimated from equations that are based on data from stable streams that are subject to similar precipitation rates and climatic conditions, and whose drainage basins have similar soils, recharge patterns, flow patterns, and physiographic characteristics as the unstable stream. Deriving channel-characteristics equations from stable streams within a given hydrologic region can minimize differences in each variable and thereby increase the accuracy of the equations.

The New York State Hydrologic and Habitat Modification (HHM) subcommittee of the New York State Nonpoint-Source Coordinating Committeee (NPSCC) is overseeing a statewide cooperative effort to develop such equations through a system created by the New York City Department of Environmental Protection Stream Management Program (NYCDEP-SMP; Miller and Davis, 2003; Powell and others, 2003). Similar efforts are being conducted in other parts of the northeastern United States, including Vermont (Jaquith and Kline, 2001), coastal and central Maine (Dudley 2004), and the Pennsylvania-Maryland Piedmont area (White, 2001; Cinotto 2003). The equations, which reflect local precipitation rates, hydrologic conditions, physiographic characteristics, and soil properties, are expected to provide more reliable results than the currently available channel-characteristics equations which represent widespread and disparate geographic regions, such as those of Dunne and Leopold (1978), which represent the eastern United States.

Approach

In 2001, the U.S. Geological Survey (USGS), in cooperation with the New York State Department of Environmental Conservation (NYSDEC), the New York State Department of Transportation (NYSDOT), and the New York City Department of Environmental Protection, began a 6-year study to define the relations between drainage area and channel characteristics for the eight hydrologic regions of New York State (excluding Long Island) that were previously established to predict flood flows of unregulated streams (Lumia, 1991, fig. 1A). The New York State Department of State (NYSDOS)— Division of Coastal Resources joined as a cooperating agency in 2005. Equations have been developed for Regions 4 and 4a in the Catskills (Miller and Davis, 2003), Region 5 in central New York (Westergard and others, 2005), Region 6 in southwestern New York (Mulvihill and others, 2005), Region 7 in western New York (Mulvihill and others, 2006), and Regions 1 and 2 in the Adirondacks (Mulvihill and others, 2007).

Objectives of the study are to: (1) complete bankfull surveys on selected streams in all of the hydrologic regions to verify and (or) redefine these boundaries; (2) assess all streams for key features of the Rosgen (1996) stream-classification system: namely, channel-entrenchment ratio (ratio of flood-plain width to bankfull-channel width), channel width-to-depth ratio, water-surface slope, channel materials, and channel sinuosity (ratio of stream length to valley length); and (3) assess the accuracy of statewide bankfull equations by grouping channel-characteristics relations within each hydrologic region by stream type in accordance with the Rosgen stream-classification system (Miller and Davis, 2003).

Rosgen's (1996) stream-classification system was created to provide reliable stream descriptions for use in evaluations of channel stability and in the design and simulation of stable conditions in ungaged stream reaches. The geomorphic characteristics defined by Rosgen (1996) that correspond to bankfull stage were chosen for their consistency among streams with similar physiographic conditions for a given drainage-basin size, and among streams subject to similar climatic conditions (Rosgen, 1994, 1996).

Region 3 (fig. 1B) is the subject of this report and the last of the eight hydrologic regions studied. Region 3 encompasses an area bounded by Connecticut and Massachusetts to the east, the Hudson River and its southern tributaries to the west and southwest, and the Poesten Kill and its tributaries to the north (Lumia, 1991). This region does not contain many actively gaged streams that are unregulated and have at least 10 years of peak-flow record; therefore, two gages with less than 10 years of peak flow record were included in the development of the equations.

The hydrologic regions defined by Lumia (1991) were based on multiple linear-regression analyses that related the 50-year peak discharge to basin characteristics such as drainage area, main-channel slope, basin storage, mean annual precipitation, percentage of basin covered by forest

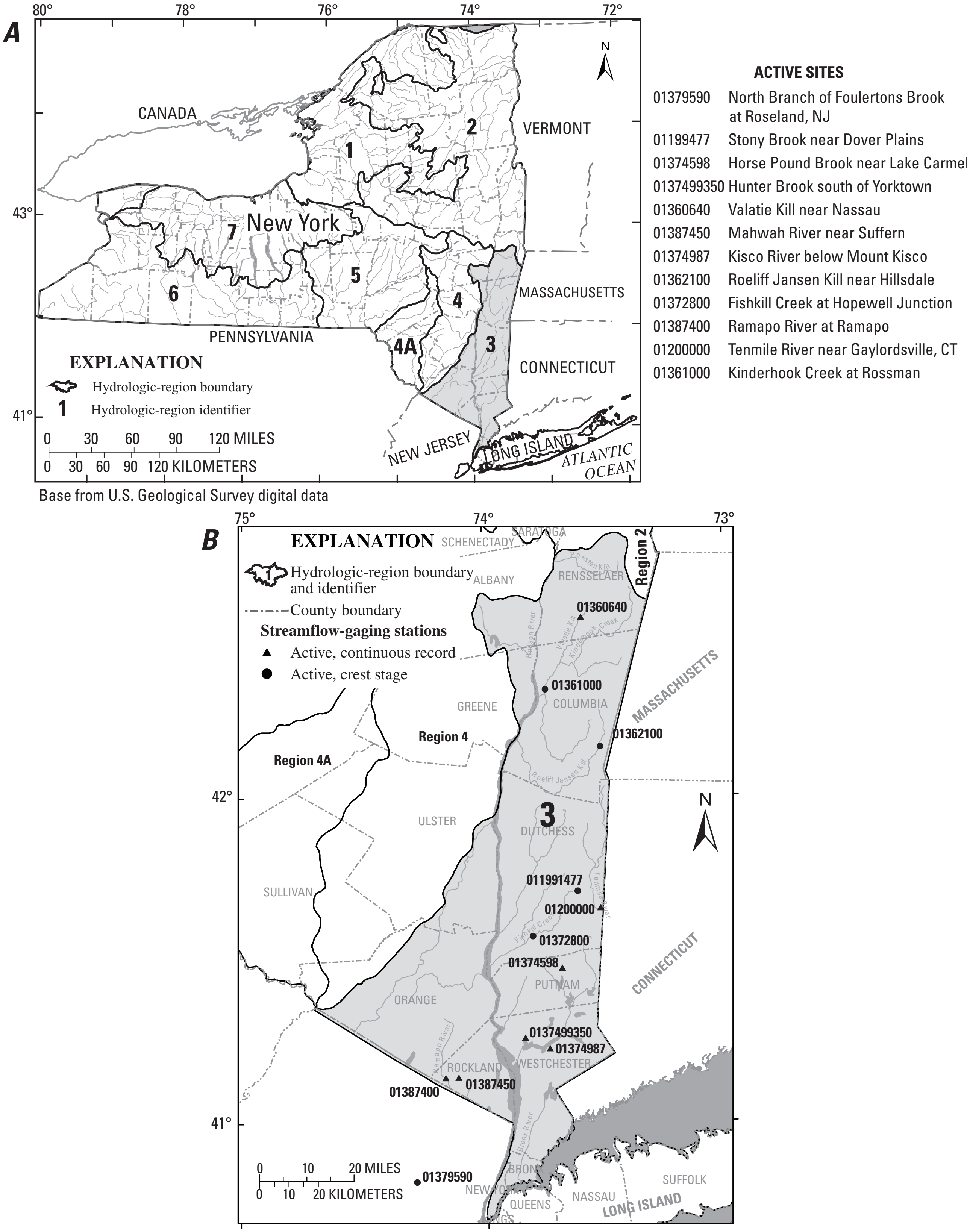

Figure 1. Hydrologic regions of New York State: *(A)* hydrologic-region boundaries as defined by Lumia (1991) and *(B)* locations of the 12 streamflow-gaging stations used in 2005–06 stream survey in Region 3. (Names, period of record, drainage area, bankfull discharge, recurrence interval, and reach type are given in table 1; channel characteristics are given in table 2.)

area, mean main-channel elevation, and a basin-shape index (ratio of basin length to basin width). These boundaries can later be compared with those developed from bankfull survey data collected during this and other studies, and adjusted if necessary.

Purpose and Scope

This report (1) describes the methods of site selection and data collection and analysis; (2) presents predictive equations for estimating bankfull discharge, width, depth, cross-sectional area for streams in Region 3; and (3) compares bankfull-discharge equations developed for Region 3 with previously developed equations for Regions 1–2, 4, 4a, 5, 6, and 7.

Methods

Twelve streams were surveyed during 2005–06. The methods used to collect and analyze the resulting data are described in detail in Powell and others (2003).

Site Selection

The streams were selected to represent a wide range of drainage-area sizes (table 1) so that the resulting equations would be applicable to a majority of streams within the hydrologic region. Other selection criteria (Miller and Davis, 2003) for study reaches are listed below:

- All must contain a USGS streamflow-gaging station with at least 10 years of annual peak-discharge data, when possible.
- All must be primarily alluvial, unregulated, and consist of a single channel at bankfull stage.
- All must include at least two sequences of a pool and a riffle, or be at least 20 bankfull widths in length.
- All must have readily identifiable bankfull indicators (defined in following section).
- All must meet the minimum requirements for slope-area calculation of discharge (uniform channel characteristics; flow confined to a single, trapezoidal channel; and water-surface elevation drop of at least 0.50 ft within the reach (Dalrymple and Benson, 1967), so that survey data can be used reliably in hydraulic analysis and calculation of bankfull discharge.
- All should represent a single Rosgen (1996) stream type, if possible.

USGS streamflow-gaging stations are not always located on geomorphically stable stream reaches because factors such as land-owner permission, access to the station, and the need for the safe measurement of high flows often dictate where a station is located. As a result, bridges and other structures may cause localized channel instability at stream reaches near stations. To assess channel stability at stations used in this study, recent flow-measurements and rating curves were inspected for evidence of scour, deposition, and frequent shifting of bed material.

The selected sites were referred to as calibration sites because they were used to develop, or calibrate, the channel-characteristics equations. Region 3 contains 13 active stations with 10 or more years of peak-flow record; 10 of these were found suitable for station calibration surveys. Two additional stations were added to ensure that the regional curves were as representative as possible; these were Hunter Brook south of Yorktown (0137499350) which has 8 years of record and North Branch of Foulertons Brook at Roseland, N.J., (01379590) which has 7 years of record.

Data Collection

Preliminary reconnaissance of all sites entailed marking bankfull indicators, cross-section locations, and reach boundaries. Bankfull indicators consisted of: (1) topographic break from vertical bank to flat flood plain; (2) topographic break from steep slope to gentle slope; (3) change in vegetation (for example, from treeless to trees); (4) textural change in sediment; (5) scour break, or elevation below which no fine debris (needles, leaves, cones, seeds) occurs; and (6) back of point bar, lateral bar, or low bench (Castro and Jackson, 2001; Miller and Davis, 2003).

The upper and lower ends of the reach and the locations of cross sections were marked with rebar driven into the streambank above bankfull stage on one bank. Three to five cross sections at each site were placed in riffles or runs, away from channel-constricting structures such as bridges and culverts.

Each study reach was surveyed by methods described in Powell and others (2003). Longitudinal-profile and cross-sectional surveys were conducted. The longitudinal-profile survey consisted of elevation measurements of the follwing features: the rebar markers at the upper and lower reach limits; all bankfull indicators; and the thalweg and water surface at each bankfull indicator, cross section, and pool-to-riffle transition. The cross-sectional surveys consisted of surveying bed and bank elevations, bankfull indicators, rebar that marked cross sections, and the flood-plain width. The reference elevation for all surveys was the elevation that was used to define the stage-to-discharge relation at active sites and to develop the stage-to-discharge relation at inactive sites. Channel-bed material throughout the reach was characterized through a modified Wolman pebble count (Harrelson and others, 1994).

Data Analysis

All field data were compiled for graphical analysis. At most sites, a bankfull-elevation profile along the study reach was constructed by plotting a linear-regression line through the surveyed bankfull-stage indicators. Bankfull water-surface elevation (stage) and discharge at these sites were derived from best-fit lines, rather than from surveyed bankfull indicators, to smooth local variations in slope that can result from intermittent disruptions such as debris piles or bedrock outcrops. Bankfull stage and discharge at two sites Fishkill Creek at Hopewell Junction—(01372800) and Kinderhook Creek at Rossman(01361000)—were obtained through a regression technique called a LOWESS smooth (Locally Weighted Scatterplot Smoother; Ott and Longnecker, 2001) because sharp changes in channel slope and difficult-to-identify bankfull indicators caused the best-fit bankfull line to misrepresent the true elevation of bankfull stage.

The bankfull stage at the station or staff plate at all sites was calculated as described above, and the corresponding bankfull discharge was obtained from the most current stage-to-discharge relation. Estimates of bankfull discharges were verified through a hydraulic analysis of the bankfull geomorphic data collected during the station-calibration survey as described below. Additional details are provided in Powell and others (2003).

1. The computer program NCALC (Jarrett and Petsch, 1985) was used to compute Manning's *n*, the roughness coefficient for the reach. Data required for this computation were discharge from the stage-to-discharge relation, channel-bed and bankfull water-surface elevations at each cross section, and the distance along the thalweg between cross sections (Jarrett and Petsch, 1985).

2. The computer program HEC-RAS (U.S. Army Corps of Engineer's Hydraulic Engineering Center River Analysis System; Brunner, 1997) was used to calculate bankfull discharge from the water-surface elevation as follows: first, the reference elevation for the survey was entered as the starting elevation; Manning's *n* (from the NCALC analysis), channel-bed elevations at each cross section, the distance along the thalweg between cross sections, and several estimated discharges were input for each cross section; the discharge at the water-surface elevation calculated by HEC-RAS that most closely approximated the surveyed bankfull water-surface elevation was chosen as the bankfull discharge at each cross section; and finally, the average of these discharges from all cross sections in the reach was used as the bankfull discharge for the reach.

3. The bankfull discharge obtained from the stage-to-discharge relation was compared with the bankfull discharge obtained from the HEC-RAS analysis. If the two discharges differed by 10 percent or less, the discharge obtained from the stage-to-discharge relation was then used as the bankfull discharge, and the recurrence interval of this discharge was calculated. If the two discharges differed by more than 10 percent, the site and reach selection, discharge measurements, elevation of bankfull indicators, and development of the stage-to-discharge relation were reviewed for sources of error. If no errors were found, the discharge that more closely fit the expected 1- to 2-year bankfull recurrence interval was chosen.

The bankfull discharges from the stage-to-discharge rating agreed with the bankfull discharges from the HEC-RAS analysis at all 12 sites.

Regional Equations for Bankfull Discharge and Channel Characteristics of Streams

Relations between bankfull discharge, depth, width, cross-sectional area, and drainage area for Region 3 are presented below. The period of record, drainage area, bankfull discharge, associated recurrence intervals, and Rosgen (1994) stream type for each site are summarized in table 1.

Regionalized Relation between Bankfull Discharge and Drainage Area

The equation that estimates bankfull discharge for streams in Region 3 (fig. 2) is:

$$\text{bankfull discharge (ft}^3\text{/s)} = 83.8\ (\text{drainage area(mi}^2))^{0.67}, \qquad (5)$$

and has a coefficient of determination (R^2) of 0.93. The 95-percent confidence and prediction intervals for the equation are shown in figure 2. The 95-percent confidence interval defines the range within which results from data collected on a different set of streams in the same region would have a 95-percent probability of occurring, whereas the wider 95-percent prediction interval defines the range within which the bankfull discharge estimated for a single stream of a given drainage area in the region would have a 95-percent probability of occurring. Comparing results from equations developed for other regions and their 95-percent confidence and prediction intervals with those obtained for streams of Region 3 can help identify regional differences in stream characteristics.

Bankfull-Discharge Recurrence Intervals

The recurrence interval for the estimated bankfull discharge of each stream was obtained from discharge-

Table 1. Characteristics of streamflow-gaging stations surveyed in Region 3 of New York, 2005–06.

[mi^2, square miles; ft^3/s, cubic feet per second. Streamflow-gaging-station locations are shown in fig. 1B]

Site name and USGS station number	Period(s) of record	Drainage area (mi^2)	Bankfull discharge[1] (ft^3/s)	Recurrence interval of bankfull discharge (years)	Reach stream type[2]
North Branch of Foulertons Brook at Roseland, N.J. (01379590)	1999–present	0.42	72	3.00[3]	E4b
Stony Brook near Dover Plains (01199477)	1974–present	1.93	88	1.40	B4a
Horse Pound Brook near Lake Carmel (01374598)	1996–present	3.94	196	3.35	C4, B4c
Hunter Brook south of Yorktown (0137499350)	1999–present	7.42	679	2.30[4]	B3c, F3
Valatie Kill near Nassau (01360640)	1990–present	9.48	227	1.16	C4
Mahwah River near Suffern (01387450)	1958–present	12.30	324	1.20	C4
Kisco River below Mount Kisco (01374987)	1995–present	17.6	613	2.00	B3c
Roeliff Jansen Kill near Hillsdale (01362100)	1956–present	27.5	690	1.80	B4c
Fishkill Creek at Hopewell Junction[5] (01372800)	1957–1976, 1986–present	57.3	1110	2.80	C4
Ramapo River at Ramapo (01387400)	1979–present	86.9	2120	1.80	F3
Tenmile River near Gaylordsville, Conn. (01200000)	1929–present	203	3020	2.01	C4
Kinderhook Creek at Rossman[5] (01361000)	1906–1968, 1987–present	329	5640	2.10	F3

[1] From stage-discharge relation.

[2] From Rosgen (1994):
B3c: low-gradient, moderately entrenched, riffle-dominated channel with cobbles;
B4a: steep gradient, moderately entrenched, riffle-dominated channel with gravel;
B4c: low-gradient, moderately entrenched, riffle-dominated channel with gravel;
C4: low-gradient, gravel-dominated channel with well defined flood plains;
E4b: sinuous, high-gradient channel with gravel;
F3: sinuous, low-gradient, highly entrenched cobble-dominated channel.
Channel materials from longitudinal-profile pebble count (table 2).

[3] Recurrence interval estimated from 7 years of record.

[4] Recurrence interval estimated from 8 years of record.

[5] Bankfull gage height from LOWESS smooth.

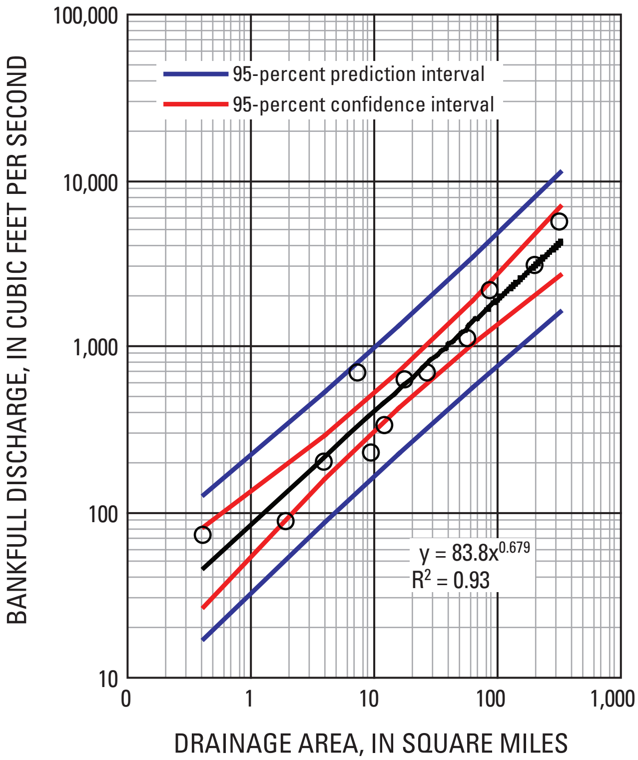

Figure 2. Bankfull discharge as a function of drainage area with 95-percent prediction limit and 95-percent confidence interval for streams surveyed in Region 3, in New York State.

frequency relations that were developed for each of the study sites by fitting the logarithms of the annual peak-discharges to a Pearson type III distribution according to guidelines recommended by the U.S. Water Resources Council (1981). The resulting data were analyzed using U.S. Geological Survey flood-frequency programs (Kirby, 1981). Previous investigations reported that the average recurrence interval for bankfull discharge typically ranges from 1 to 2 years (Dunne and Leopold, 1976; Rosgen, 1996; Harman and Jennings, 1999). The bankfull-discharge recurrence interval for streams surveyed in Region 3 ranged from 1.16 to 3.35 years and averaged 2.08 years (table 1). Previous investigations in Regions 4 and 4a found an average bankfull-discharge recurrence interval of 1.54 years and a range of 1.2 to 2.7 years (Miller and Davis, 2003) (fig. 1A); an average of 1.51 years and a range of 1.11 to 3.40 years in Region 5 (Westergard and others, 2004) (fig. 1A); an average of 1.54 years and a range of 1.01 to 2.35 years in Region 6 (Mulvihill and others, 2005) (fig. 1A); an average of 2.13 and a range of 1.05 to 3.60 years in Region 7 (Mulvihill and others, 2006) (fig. 1A); and an average of 2.13 years and a range of 1.01 to 3.80 years in Regions 1 and 2 (Mulvihill and others, 2007) (fig. 1A).

Stream-Channel Characteristics in Relation to Drainage Area

Regression equations for bankfull channel width, depth, and cross-sectional area for streams in Region 3 are as follows:

$$\text{bankfull-channel width (ft)} = 24.0\,(\text{drainage area}(\text{mi}^2))^{0.292}, \quad (6)$$

$$\text{bankfull-channel depth (ft)} = 1.66\,(\text{drainage area}(\text{mi}^2))^{0.210}, \quad (7)$$

$$\text{bankfull-channel cross-sectional area (ft}^2) = 39.8\,(\text{drainage area}(\text{mi}^2))^{0.503}. \quad (8)$$

Results are plotted in figure 3; coefficients of determination *(R^2)* for the equations were 0.85, 0.77, and 0.92, respectively. The high coefficient of determination *(R^2)* for cross-sectional area indicates that 92 percent of the variability is explained by drainage area. The lower coefficients of determination for the equations that relate bankfull width and bankfull depth to drainage area suggest that other factors such as basin shape, vegetation, and channel materials (Leopold 1994) could also affect this relation.

The raw data for Region 3 equations and the corresponding 95-percent confidence and prediction intervals are provided in plots of mean bankfull width, depth, and cross-sectional area as a function of drainage area in figures 4A through 4C, respectively.

Stream Classification

The Rosgen classification system (Rosgen, 1996) categorizes streams on the basis of channel morphology to provide consistent, quantitative descriptions of stream condition (Harman and Jennings, 1999). This study used the following criteria and measurements to classify each reach by the Rosgen stream type; the values obtained are provided in table 2.

- *Entrenchment ratio*: a field measurement of channel incision, defined as the flood-plain width divided by the bankfull width (Harman and Jennings, 1999). The flood-plain width is measured at the elevation of twice the maximum depth at bankfull.

- *Width-to-Depth ratio*: bankfull width divided by the mean bankfull depth (Harman and Jennings, 1999).

- *Water-surface slope*: the difference between the water-surface elevation at the upstream end of a riffle to the upstream end of another riffle at least 20 bankfull widths downstream, divided by the distance between the riffles along the thalweg (Harman and Jennings, 1999).

- *Median size (D50) of bed material:* the median particle size, or the diameter that exceeds the diameter of 50 percent of all streambed particles (Harman and

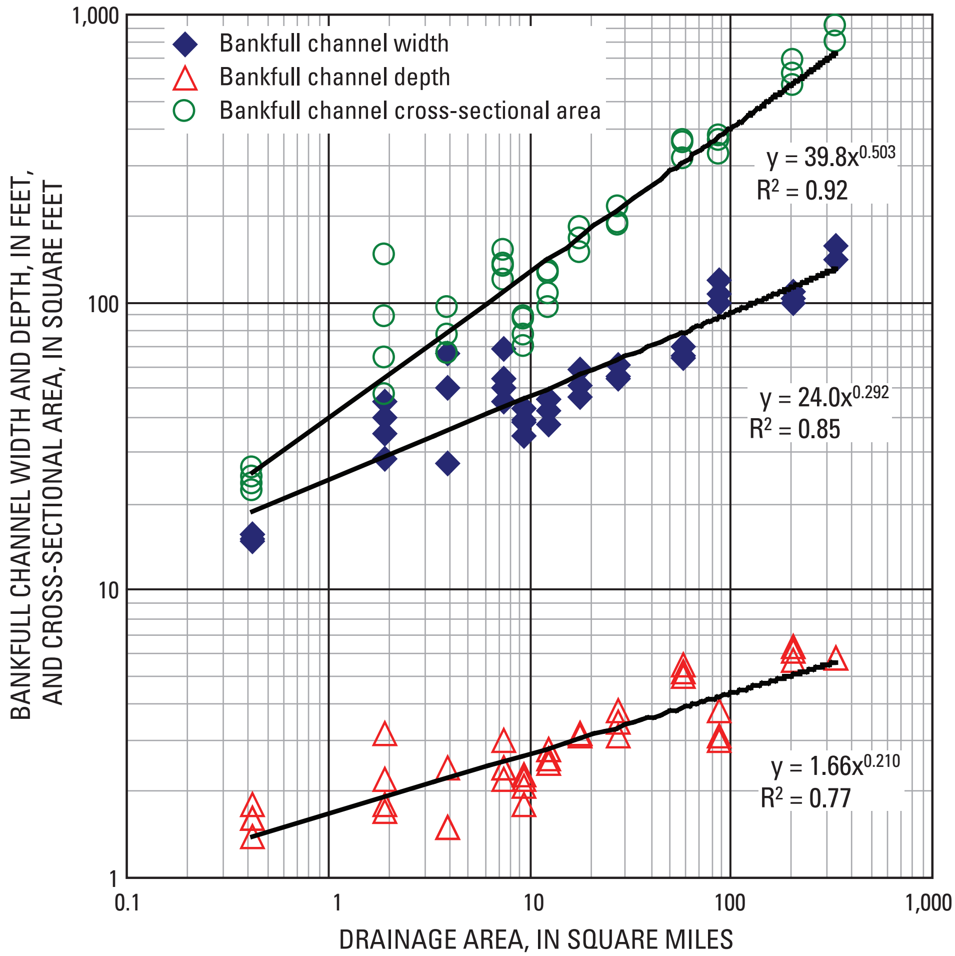

Figure 3. Bankfull width, depth, and cross-sectional area as a function of drainage area with best-fit lines, regression equations, and R^2 values for all streams surveyed in Region 3 in New York State.

Jennings, 1999). D50 values were obtained through a modified Wolman pebble count (modified to account for bank and inchannel material, sand and smaller particle sizes, and bedrock (Rosgen, 1996)).

- *Sinuosity:* stream length divided by valley length (Harman and Jennings, 1999).

Each reach was classified by Rosgen stream type according to the average of stream-channel measures taken at each cross section (table 1). Each cross section was also classified individually by Rosgen stream type (table 2). Stream types A through G represent seven major stream categories that differ in entrenchment ratio, water-surface slope, width-depth ratio, and sinuosity (Rosgen, 1996, table 2). Within each major category, the numbers 1 through 6 are assigned to dominant channel material ranging from bedrock to silt and clay (Rosgen, 1996).

Two of the 12 streams surveyed had one or more cross sections that were classified as a different stream type. These were Horse Pound Brook near Lake Carmel (01374598) and Hunter Brook south of Yorktown (0137499350) (table 1). Almost all cross sections in the 12 streams surveyed were classified as type B or C; exceptions were Ramapo River at Ramapo (01387400) and Kinderhook Creek at Rossman (01361000), which are F type streams, and North Branch of Foulertons Brook at Roseland, N.J. (01379590), which is an E type stream. The primary difference between B and C streams is the entrenchment ratio (width of the flood-prone area at an elevation twice the maximum bankfull depth/bankfull width; Rosgen, 1994), therefore, the majority of the streams surveyed differed from one another only in the degree of vertical containment of the river channel (Rosgen, 1994).

Comparison of Region 3 Equations to Equations for Other Regions in New York State

Results from the Region 3 equation for the relation between bankfull discharge and drainage area were compared with those developed for six other hydrologic regions in

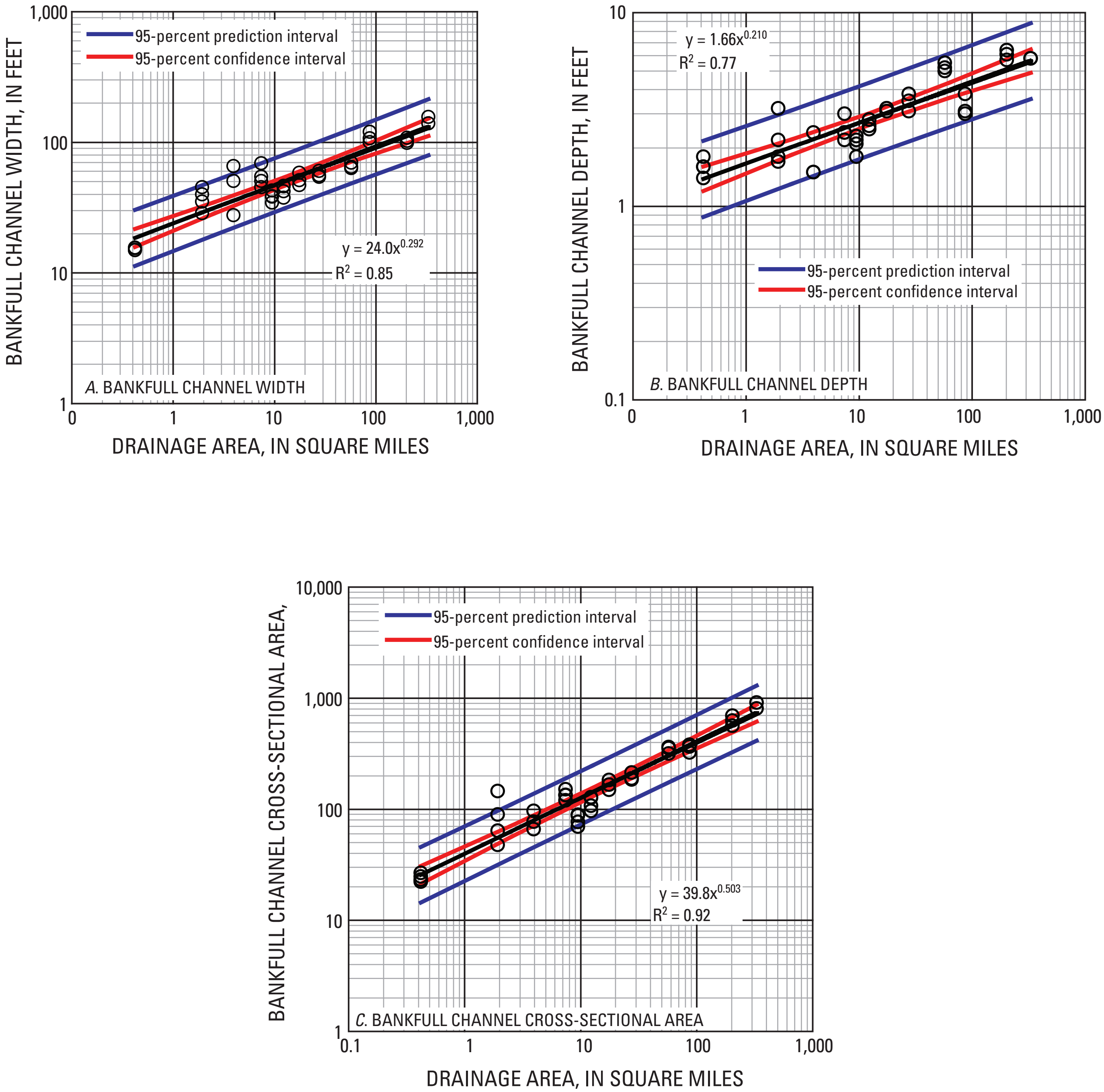

Figure 4. Selected channel characteristics as a function of drainage area with 95-percent prediction limits and 95-percent confidence intervals for streams in Region 3 in New York State: *(A)* bankfull channel width, *(B)* bankfull channel depth, and *(C)* bankfull channel cross-sectional area.

Table 2. Stream classification and bankfull-channel characteristics for cross sections at the 12 streamflow-gaging stations surveyed in Region 3 in New York State.

[ft, feet; ft^2, square feet; mi^2, square miles; mm, millimeters. Site locations are shown in fig. 1B.]

Site name and station-identification number	Drainage area (mi^2)	Cross-section downstream stationing (ft)	Bankfull width (ft)	Bankfull depth (ft)	Bankfull cross-sectional area (ft^2)	Width of flood plain (ft)	Entrench-ment ratio[1]	Width-to-depth ratio	Water surface slope	D50 (mm)[2]	Sinuosity[3]	Cross-section stream type[4]
North Branch of Foulertons Brook at Roseland, N.J. (01379590)	0.42	33	14.9	1.8	26.7	477	32.0	8.3	0.020	41	1.13	E4b
		66	15.5	1.4	22.3	168	10.8	11.1				E4b
		152	15.0	1.6	23.3	28	1.9	9.4				E4b
		231	15.6	1.6	24.8	91	5.8	9.8				E4b
Stony Brook near Dover Plains (01199477)	1.93	142	28.7	1.7	47.7	56	2.0	16.9	.052	46	1.08	B4a
		454	45.4	3.2	145.4	96	2.1	14.2				B4a
		497	40.0	2.2	89.6	73	1.8	18.2				B4a
		533	35.2	1.8	64.1	65	1.8	19.6				B4a
Horse Pound Brook near Lake Carmel (01374598)	3.94	550	50.6	1.5	77.4	162	3.2	33.7	.009	34	1.07	C4
		602	65.9	1.5	96.5	131	2.0	43.9				B4c
		641	27.7	2.4	66.3	156	5.6	11.5				C4
Hunter Brook south of Yorktown (0137499350)	7.42	233	54.6	2.4	133.4	109	2.0	22.8	.019	166	1.40	B3c
		494	69.3	2.2	151.3	93	1.3	31.5				F3
		559	50.5	2.4	119.9	63	1.2	21.0				F3
		607	45.4	3.0	134.6	70	1.5	15.1				B3c
Valatie Kill near Nassau (01360640)	9.48	125	38.3	2.3	89.0	185	4.8	16.7	.002	25	1.21	C4
		173	34.5	2.2	76.8	197	5.7	15.7				C4
		227	42.7	2.1	87.6	242	5.7	20.3				C4
		337	38.7	1.8	69.6	232	6.0	21.5				C4
Mahwah River near Suffern (01387450)	12.3	440	46.3	2.8	128.1	547	11.8	16.5	.002	19	1.49	C4
		784	45.9	2.8	126.6	359	7.8	16.4				C4
		901	37.7	2.6	96.4	380	10.1	14.5				C4
		1006	42.1	2.5	107.2	368	8.7	16.8				C4
Kisco River below Mount Kisco (01374987)	17.6	265	47.0	3.2	149.6	72	1.5	14.7	.009	103	1.41	B3c
		324	51.3	3.2	166.2	81	1.6	16.0				B3c
		424	58.4	3.1	183.0	84	1.4	18.8				B3c

Table 2. Stream classification and bankfull-channel characteristics for cross sections at the 12 streamflow-gaging stations surveyed in Region 3 in New York State.—Continued

[ft, feet; ft^2, square feet; mi^2, square miles; mm, millimeters. Site locations are shown in fig. 1B.]

Site name and station-identification number	Drainage area (mi^2)	Cross-section downstream stationing (ft)	Bankfull width (ft)	Bankfull depth (ft)	Bankfull cross-sectional area (ft^2)	Width of flood plain (ft)	Entrenchment ratio[1]	Width-to-depth ratio	Water surface slope	D50 (mm)[2]	Sinuosity[3]	Cross-section stream type[4]
Roeliff Jansen Kill near Hillsdale (01362100)	27.5	318	54.4	3.5	189.1	115	2.1	15.5	0.005	20	1.31	B4c
		383	55.8	3.8	213.8	118	2.1	14.7				B4c
		435	60.4	3.1	185.2	85	1.4	19.5				B4c
Fishkill Creek at Hopewell Junction (01372800)	57.3	822	64.8	5.5	355.7	174	2.7	11.8	.001	8	1.22	C4
		899	69.9	5.2	363.4	185	2.6	13.4				C4
		986	63.5	5.0	316.6	208	3.3	12.7				C4
Ramapo River at Ramapo (01387400)	86.9	1337	120.1	3.1	367.4	144	1.2	38.7	.004	84	1.37	F3
		1542	107.2	3.0	324.5	123	1.1	35.7				F3
		1896	100.1	3.8	379.9	121	1.2	26.3				F3
Tenmile River near Gaylordsville, Conn. (01200000)	203	272	108.4	6.4	696.5	386	3.6	16.9	.002	59	1.41	C4
		373	102.5	6.1	626.3	383	3.7	16.8				C4
		467	98.9	5.7	564.5	379	3.8	17.4				C4
Kinderhook Creek at Rossman (01361000)	329	396	139.6	5.8	806.5	157	1.1	24.1	.002	171	1.11	F3
		1047	156.4	5.8	910.5	177	1.1	27.0				F3

[1] Entrenchment ratio: flood-plain width divided by bankfull width (Harman and Jennings, 1999).

[2] D50: median particle size, the diameter that exceeds that of 50 percent of all streambed particles in the reach.

[3] Sinuosity: ratio of stream length to valley length (Harman and Jennings, 1999).

[4] from Rosgen (1994):
B3c: low-gradient, moderately entrenched, riffle-dominated channel with cobbles;
B4a: steep gradient, moderately entrenched, riffle-dominated channel with gravel;
B4c: low-gradient, moderately entrenched, riffle-dominated channel with gravel;
C4: low-gradient, gravel-dominated channel with well defined flood plains;
E4b: sinuous, high-gradient channel with gravel;
F3: sinuous, low-gradient, highly entrenched cobble dominated channel.

New York State (fig. 5). The 95-percent confidence interval for the Region 3 curve almost fully encompasses the curves for Regions 1–2, 4a, 5, and 6 (fig. 5) and thereby indicates that there are very few differences in the relations between drainage area and bankfull discharge in these six regions. The curves also indicate, however, that a stream with a drainage area of 10mi^2 would have an average bankfull discharge of 200 ft^3/s in Region 7, 400 ft^3/s in Region 3, and 700 ft^3/s in Region 4 (fig. 5). These differences indicate that streams close to one another do not always have similar flow regimes, and that regional curves designed for a specific geographic area, such as those described herein, are useful for those concerned with local watershed management and planning.

Limitations of this Study

An assumption made in this investigation—that the bankfull discharge was within the 1- to 2-year recurrence-interval range—may be an oversimplification (Thorne and others, 1997), even though similar recurrence intervals have been obtained in other studies (Harman and Jennings, 1999; Rosgen, 1994). Channel characteristics associated with a 1- to 2-year recurrence interval were used to aid in the identification of bankfull indicators during initial site inspections, but if the bankfull recurrence interval at a site was longer or shorter than that frequency, the bankfull channel could be incorrectly identified (White, 2001). The average bankfull recurrence interval for streams surveyed in Region 3 was 2.08 years,

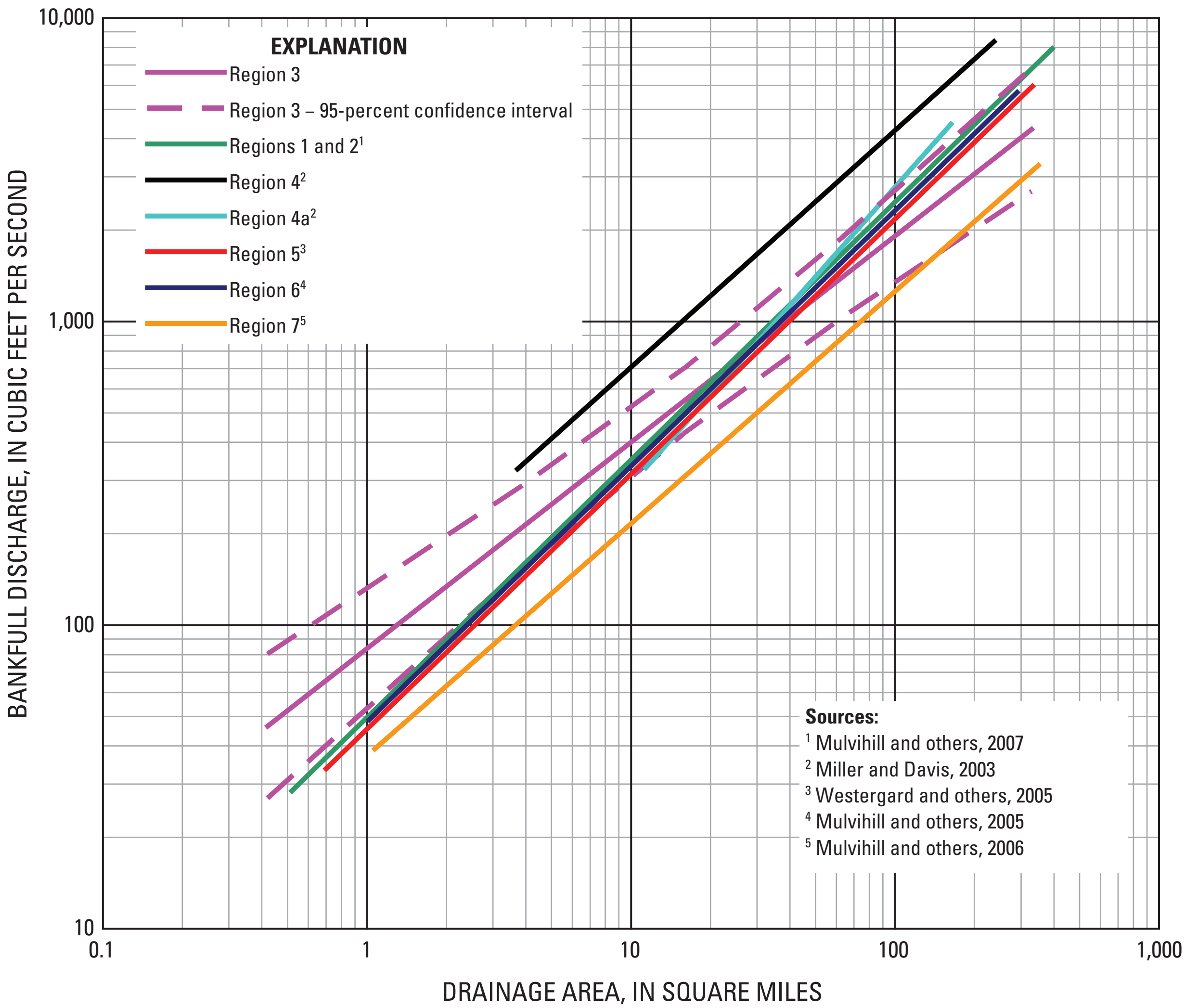

Figure 5. Bankfull discharge as a function of drainage area for Region 3 and published curves for six other regions in New York State.

which is longer than the average 1.5-year frequency predicted by Rosgen (1996), but still within the 1- to 2.5-year range predicted by Leopold (1994).

Another limiting factor in this investigation was the small number of active USGS streamflow-gaging stations in Region 3 that met selection criteria. Therefore, two additional stations were added to ensure that the curves were as representative as possible—one of these had eight years of record (Hunter Brook South of Yorktown (0137499350) and the other had seven years of record and was in New Jersey (North Branch of Foulertons Brook at Roseland, N.J. (01379590). The justification for using a station outside New York State is that this stream is relatively close to the New York State border, and data from stations in neighboring states also were used in the delineation of the hydrologic regions (Lumia, 1991).

The use of these two sites which had been active for less than 10 years was based on the assumption that existing records were sufficient for field verification of bankfull stage; the actual recurrence interval of bankfull discharge can be recalculated when additional data become available. The data analysis for the two sites representing more than one stream type—(Horse Pound Brook near Lake Carmel (01374598) and Hunter Brook South of Yorktown (0137499350)—was based on the assumption that averaging measurements from cross sections of differing types provided an accurate measure of overall reach characteristics.

Sharp changes in channel slope and difficult-to-identify bankfull indicators at two sites, Fishkill Creek at Hopewell Junction (01372800) and Kinderhook Creek at Rossman (01361000), caused the best-fit bankfull line to misrepresent the true elevation of bankfull stage; therefore, these values were obtained through a regression technique called a LOWESS smooth (Ott and Longnecker, 2001).

Regional channel-characteristics equations can be more reliable than those representing an entire state or large area in the design of stream-restoration projects, enhancement of fish habitat, and adjustment of instream and riparian structures (Castro and Jackson, 2001). Users of these regional relations must recognize their limitations and accept that these regression equations are only designed to provide preliminary estimates of bankfull-channel characteristics and discharges, and are not intended to substitute for the field measurement and verification of bankfull-channel characteristics and streamflow (White, 2001).

Summary and Conclusions

Equations that relate bankfull discharge and channel characteristics (width, depth, and cross-sectional area) to the size of the drainage area at gaged stream sites are needed to predict bankfull discharge and channel characteristics at ungaged streams and to serve as a guide in the design of stream-restoration projects. The USGS, in cooperation with the New York City Department of Environmental Protection, and the New York State Departments of Environmental Conservation, Transportation, and State began a study in 2001 to develop such equations for streams throughout New York State. This report presents results for streams in Region 3 east of the Hudson River. Twelve sites were chosen in accordance with established guidelines. Stream-survey data and discharge records from these sites were used in regression analyses to relate four factors (bankfull discharge, bankfull channel width, depth, and cross-sectional area) to drainage area. The resulting equations were:

$$\text{bankfull discharge (ft}^3\text{/s)} = 83.8\,(\text{drainage area (mi}^2))^{0.67}, \quad (9)$$

$$\text{bankfull-channel width (ft)} = 24.0\,(\text{drainage area (mi}^2))^{0.292}, \quad (10)$$

$$\text{bankfull-channel depth (ft)} = 1.66\,(\text{drainage area (mi}^2))^{0.210}, \quad (11)$$

$$\text{bankfull-channel cross-sectional area (ft}^2) = 39.8\,(\text{drainage area (mi}^2))^{0.50}. \quad (12)$$

The coefficients of determination *(R^2)* for all of these (0.93, 0.85, 0.77 and 0.92, respectively) indicate that much of the variation in these factors is explained by the size of the drainage area.

Recurrence intervals of bankfull discharges were calculated for each stream through regression equations that relate measured discharges to known recurrence intervals. The recurrence intervals for bankfull discharge of the 12 surveyed streams in Region 3 ranged from 1.16 to 3.35 years, and the mean recurrence interval was 2.08 years. Streams were classified by Rosgen stream type on the basis of specific channel characteristics at each surveyed cross section. Most streams were B and C types; a few had E and F type cross sections. Results from the Region 3 equation for the relation between bankfull discharge and drainage area were compared with equations developed for seven other regions in New York State. Differences indicate a need to develop equations by region to improve their accuracy.

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