Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State—Hydrologic Regions 1 and 2 in the Adirondack Region of Northern New York

By Christiane I. Mulvihill, Amy Filopowicz, Arthur Coleman, and Barry P. Baldigo

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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
NSCC	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
SUNY-ESF	State University of New York College of Environmental Science and Forestry
USGS	U.S. Geological Survey

Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State—Hydrologic Regions 1 and 2 in the Adirondack Region of Northern New York

By Christiane I. Mulvihill[1], Amy Filopowicz[2], Arthur Coleman[3], and Barry P. Baldigo[1]

Abstract

Equations that relate drainage area to bankfull discharge and channel characteristics (width, depth, and cross-sectional area) at gaged sites are needed to define bankfull-discharge and channel characteristics at ungaged sites and to provide information for watershed assessments, stream-channel classification, and design of stream-restoration projects. Such equations are most accurate if derived from streams within an area of uniform hydrologic, climatic, and physiographic conditions and applied only within that region.

Stream-survey and discharge data from 15 active (currently gaged in 2005) streamflow-gaging stations and 1 inactive (discontinued) streamflow-gaging station in hydrologic Regions 1 and 2 were used in linear-regression analyses to relate drainage area to bankfull discharge and bankfull-channel width, depth, and cross-sectional area. The four resulting equations are the following:

$$\text{bankfull discharge (cubic feet per second)} = 49.6\,(\text{drainage area (square miles)})^{0.849}, \quad (1)$$

$$\text{bankfull-channel width (feet)} = 21.5\,(\text{drainage area (square miles)})^{0.362}, \quad (2)$$

$$\text{bankfull-channel depth (feet)} = 1.06\,(\text{drainage area (square miles)})^{0.329}, \quad (3)$$

$$\text{bankfull-channel cross-sectional area (square feet)} = 22.3\,(\text{drainage area (square miles)})^{0.694}. \quad (4)$$

The coefficients of determination *(R^2)* for these four equations are 0.95, 0.89, 0.89, and 0.97, respectively. The high coefficients of determination for these equations indicate that much variability is explained by drainage area. Recurrence intervals for the estimated bankfull discharge of each stream ranged from 1.01 to 3.80 years; the mean recurrence interval was 2.13 years. The 16 surveyed streams were classified by Rosgen stream type; most were B- and C-type, with a few E- and F-type cross sections.

The hydrologic Regions 1 and 2 equation for the relation between bankfull discharge and drainage area was graphically compared to curves developed for 5 other hydrologic regions in New York State. The 95-percent confidence interval for the hydrologic Regions 1 and 2 curve fully encompassed the curves for Regions 4a, 5, and 6, showing that there are very few differences in the relation between drainage area and bankfull discharge in these four regions. However, the curves for Regions 4 and 7 lay outside the 95 percent confidence intervals of the Region 3 curve, indicating that these 3 regions do not have similar bankfull-discharge to drainage area relations.

Introduction

Streambank erosion and the resulting sedimentation of streams can affect the water quality of reservoirs, endanger aquatic life, and jeopardize private and public lands and associated infrastructure. Streams throughout New York State that have abnormally high rates of erosion and sedimentation are undergoing restoration efforts to improve bank and bed stability. Stream-restoration procedures have traditionally consisted of straightening, widening, and deepening the channel, hardening the banks, and imposing static stream geometry—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 bankfull cross-section dimensions and the relations among channel characteristics, flow patterns, and water-surface profiles. Bankfull discharge and bankfull-channel-characteristics of streams that are ungaged can be

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derived from equations (curves) that define these relations; such equations are themselves derived using data from nearby stable reaches that are gaged. Channel-characteristics data from these nearby reference reaches are the foundations for Natural Channel Design (NCD) restoration techniques to recreate geomorphically[1] stable stream reaches. The channel characteristics obtained through NCD techniques structurally resemble those of natural 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 determining the relations between drainage area and stream-channel characteristics. Bankfull discharge is the flow that reaches the transition between the channel and its flood plain and is thus a morphologically significant streamflow (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 it is reported to occur about every 1 to 2 years, or on average about every 1.5 years, for most streams (Rosgen, 1994). Bankfull discharge is the flow that moves the most sediment over time, owing to the combination of its force and frequency (Wolman and Miller, 1960; Leopold, 1994).

Bankfull discharge influences the relation between drainage area and stream-channel characteristics in two ways. First, bankfull discharge often occurs at a relatively discrete and identifiable stage, enabling a system for classifying streams to be developed on the basis of channel characteristics at bankfull stage (Rosgen, 1996). Second, relations between drainage area and discharge and 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.

A statewide cooperative program led by the USGS is developing regional hydraulic geometry curves through a process established by the New York City Department of Environmental Protection Stream Management Program (NYCDEP-SMP; Miller and Davis, 2003; Powell and others, 2004). This program is overseen by the New York State Hydrologic and Habitat Modification (HHM) subcommittee of the New York State Nonpoint-Source Coordinating Committee (NPSCC). 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 (Chaplin, 2005). The equations, which reflect local precipitation rates, hydrologic conditions, physiographic characteristics, and soil properties, are expected to have higher R^2 values and lower mean square errors--indicating stronger and more accurate models--than the currently available equations which represent relations over 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 estimate the magnitude and frequency of floods for unregulated streams (Lumia, 1991). The New York State Department of State (NYSDOS), Division of Coastal Resources became a cooperator in the study in 2005. Boundaries of the eight hydrologic regions developed by Lumia in 1991 (fig. 1) were used as preliminary hydrologic-region boundaries to group streams with similar characteristics. This report presents drainage areas and associated bankfull characteristics (discharge and channel characteristics) for surveyed streams in hydrologic Regions 1 and 2 in northern New York. Hydrologic Regions 1 and 2 are combined in this report because (1) there are few long-term unregulated (naturally flowing) gaged streams in the Adirondack region of northern New York State and (2) the most recent flood-frequency report for New York State combines hydrologic Regions 1 and 2 into a single hydrologic region (Lumia and others, 2006). Previous studies have developed bankfull-discharge and channel-characteristics equations 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), and Region 7 in western New York (Mulvihill and others, 2006).

Objectives of this statewide study are to (1) complete bankfull surveys on selected streams in all eight 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 across the eight

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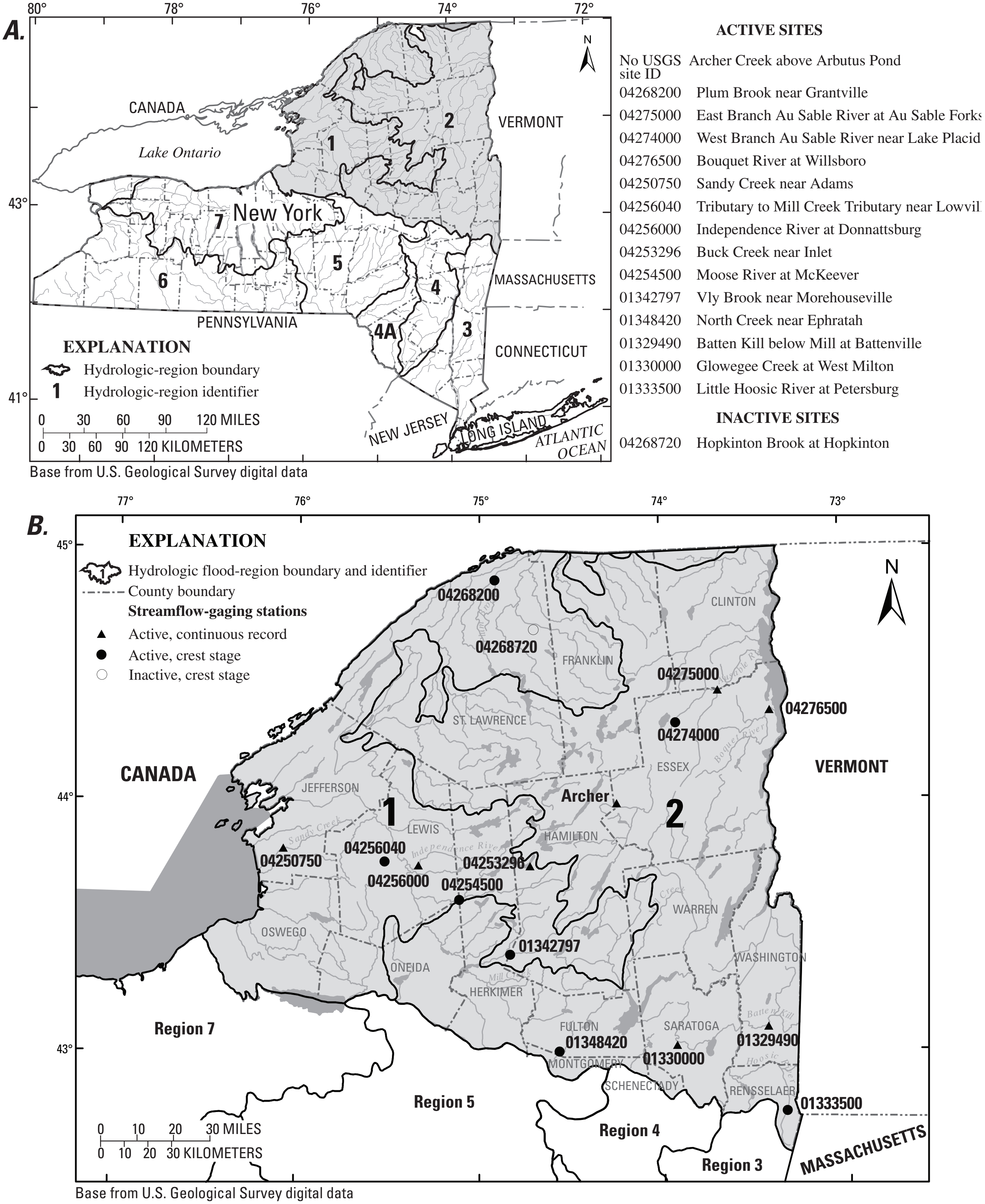
[1] "Geomorphically", in the context of this report, refers to channel slope, shape, and pattern (Rosgen, 1996).



ACTIVE SITES

No USGS site ID	Archer Creek above Arbutus Pond
04268200	Plum Brook near Grantville
04275000	East Branch Au Sable River at Au Sable Forks
04274000	West Branch Au Sable River near Lake Placid
04276500	Bouquet River at Willsboro
04250750	Sandy Creek near Adams
04256040	Tributary to Mill Creek Tributary near Lowvil
04256000	Independence River at Donnattsburg
04253296	Buck Creek near Inlet
04254500	Moose River at McKeever
01342797	Vly Brook near Morehouseville
01348420	North Creek near Ephratah
01329490	Batten Kill below Mill at Battenville
01330000	Glowegee Creek at West Milton
01333500	Little Hoosic River at Petersburg

INACTIVE SITES

04268720	Hopkinton Brook at Hopkinton

Figure 1. Hydrologic regions in New York State: *(A)* Hydrologic-region boundaries as defined by Lumia (1991), and *(B)* Locations of the 15 active and 1 inactive streamflow-gaging stations used in 2004–05 stream survey in hydrologic Regions 1 and 2 in New York State.

regions by stream type in accordance with the Rosgen stream-classification system (Miller and Davis, 2003).

Rosgen's stream-classification system (1996) was created to provide stream descriptions for use in evaluations of channel stability and in the design and simulation of stable conditions for 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 characteristics for a given drainage-basin size and among streams subject to similar climatic conditions (Rosgen, 1994, 1996).

Hydrologic Regions 1 and 2 (fig. 1A) are the sixth and seventh of the eight regions examined in this study. Hydrologic Regions 1 and 2 encompass an area bounded by Vermont to the east, Canada to the north and northwest, Lake Ontario to the west, and the Tug Hill Plateau and foothills of the Adirondack Mountains to the south (Lumia, 1991). As mentioned earlier, these hydrologic regions do not contain many actively gaged streams that are unregulated and have at least 10 years of peak-flow record; therefore, one inactive streamflow-gaging station and one streamflow-gaging station with less then 10 years of record were included in the database for development of the bankfull-discharge and channel-characteristics 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 area, mean main-channel elevation, and a basin-shape index (ratio of basin length to basin width). One of the assumptions tested in this investigation is that stratifying bankfull-discharge and channel-characteristics data by hydrologic region creates individual models that are more accurate than one comprehensive statewide model.

Purpose and Scope

This report (1) describes the methods of site selection and data collection and analysis (2) presents the relations between drainage area and bankfull width, depth, cross-sectional area, and discharge and (3) graphically compares bankfull-discharge equations developed for hydrologic Regions 1 and 2 with equations developed in previous studies for Regions 4, 4a, 5, 6, and 7 in New York State.

Methods

Sixteen reaches at streamflow-gaging stations in hydrologic Regions 1 and 2 were surveyed during 2004–05. The methods used to collect and analyze the data in this report are described in detail in Powell and others (2004).

Site Selection

The streams were selected to represent a wide range of drainage areas so that the resulting equations would be applicable to most streams within the hydrologic regions. 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, if possible. Both crest-stage gages, which record only the annual peak stage, and continuous record stream-flow gaging stations can be used.
- All must be primarily alluvial and unregulated (naturally flowing) and must consist of a single channel at bankfull stage.
- All must either include at least two sequences of a pool and a riffle or be at least 20 bankfull widths long.
- All must have readily identifiable bankfull indicators (defined in the 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 surveyed data can be used reliably in hydraulic analysis and calculation of bankfull discharge.
- All should represent a single Rosgen stream type (1996), if possible.

USGS streamflow-gaging stations are not always on geomorphically stable stream reaches because landowner 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, most streamflow-gaging stations are near bridges and other structures that may cause localized channel instability of stream reaches near gages. To assess channel stability at streamflow-gaging stations used in this study, two methods were employed. At active streamflow-gaging stations, stability was assessed through inspection of the most recent analysis of flow-measurement data for evidence of scour, deposition, and frequent shifting of bed material. At the discontinued streamflow-gaging station (Hopkinton Brook at Hopkinton (04268720)) (fig. 1B and table 1), three discharge measurements (low to medium stage) were made during the study period to define the stage-discharge relation, which was compared with the last known relation from when the streamflow-gaging station was active. Significant discrepancies between the two relations would have been indicative of channel instability.

The selected stream sites were referred to as calibration sites because they were used to develop, or calibrate, the channel-characteristics equations. Hydrologic Regions 1 and 2 contain 20 active streamflow-gaging stations with 10 or more years of peak-flow record. Thirteen of the 20 streamflow-gaging stations were determined to be suitable for calibration surveys. To ensure that the regional curves were as representative as possible, three streamflow-gaging stations were added: Hopkinton Brook at Hopkinton (04268720), which had been discontinued in 1986; Buck Creek near Inlet (04253296), which has only 7 years of peak-flow record; and Archer Creek above Arbutus Pond, which is operated by the State University of New York College of Environmental Science and Forestry (SUNY-ESF). Figure 1B shows the location of the 16 streamflow-gaging stations surveyed in hydrologic Regions 1 and 2

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 upstream and downstream ends of the reach and the locations of cross sections were marked with a 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.

After the preliminary reconnaissance, each reach was surveyed by methods described in Powell and others (2004). Longitudinal-profile and cross-sectional surveys were done. The longitudinal-profile survey consisted of elevation measurements of the rebar markers at the upstream and downstream reach limits; all bankfull indicators; and the thalweg and water surface at each bankfull indicator, cross section, and pool-to-riffle transition. The cross-section surveys consisted of measurements of bed and bank elevations, bankfull indicators, rebars that marked cross sections, and flood-plain width. The reference elevation for all surveys was the elevation used to define the stage-to-discharge relation. Channel material at each reach was characterized using a modification of the transect pebble count procedure described in Powell and others (2004).

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 best-fit linear-regression line through the surveyed bankfull-stage indicators. Bankfull water-surface elevation (stage) and discharge at these sites were derived from these 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 one site (Vly Brook near Morehouseville (01342797)) (fig. 1B and table 1) were obtained through a nonlinear regression technique called a LOWESS smooth (Locally Weighted Scatterplot Smoother; Ott and Longnecker, 2001), because steep slopes upstream and downstream from the gage pool resulted in the best-fit line of bankfull elevation being considerably lower then true bankfull elevation (table 1).

The bankfull stage at the gaging station or staff gage at active stations was calculated as described previously, and the corresponding bankfull discharge was obtained from the most current stage-discharge relation. Bankfull discharge at the inactive station was interpolated from the newly developed stage-discharge relation that was extended to bankfull stage by use of the Johnson method (Kennedy, 1984). Estimates of bankfull discharges for all sites were verified through a hydraulic analysis of the bankfull geomorphic data collected during the gage-calibration survey, as follows. Additional details are given in Powell and others (2004).

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-discharge relation, channel-bed and bankfull water-surface elevations at each cross section, and 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, and 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. Next, 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. 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-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-discharge relation was then used as the bankfull discharge, and the recurrence interval of this discharge was calculated. If the two bankfull discharges differed by more than 10 percent, the stream and reach selection, discharge measurements, elevation of bankfull indicators, and the stage-discharge relation were reviewed for potential 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.

Table 1. Characteristics of streamflow-gaging stations surveyed in hydrologic Regions 1 and 2 in New York State, 2004–05.

[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]
Archer Creek above Arbutus Pond[3]	1995–present	0.52	26.5	1.95	B3a, C3b
Buck Creek near Inlet (04253296)	1989–90, 2001–present	1.28	79	1.90[4]	B4, E4b
Tributary to Mill Creek Tributary near Lowville (04256040)	1976–86 1993–present	1.66	150[5]	2.80	B4, C4b
Vly Brook near Morehouseville (01342797)	1993–present	3.28	133[6]	1.40	B3, C3b
North Creek near Ephratah (01348420)	1975–present	6.52	100	1.01	B4c ,C4
Hopkinton Brook at Hopkinton (04268720)	1962–86	20.0	550[5]	3.00	C3
Glowegee Creek at West Milton (01330000)	1948–63, 1990–present	26.0	507	1.22	C5
Plum Brook near Grantville (04268200)	1959–63, 1964–present	43.9	678	1.95	C4
Little Hoosic River at Petersburg (01333500)	1949, 1951–96, 1997–present	56.1	2,500[5]	3.00	C3
Independence River at Donnattsburg (04256000)	1942–present	88.7	2,420	2.80	C3
West Branch Au Sable River near Lake Placid (04274000)	1920–27, 1928–68, 1983–present	116	3,100	1.70	C5c-
Sandy Creek near Adams (04250750)	1957–present	137	5,030	1.80	C3
East Branch Ausable River at Au Sable Forks (04275000)	1925–present	198	6,440	2.10	C4, F4
Bouquet River at Willsboro (04276500)	1904–08, 1923–68, 1980, 1985, 1987–89, 1990–present	270	6,200[5]	3.80	B3c
Moose River at McKeever (04254500)	1869, 1901–22, 1923–70, 1982, 1985, 1987–present	363	6,440	1.40	C4c-
Batten Kill below Mill at Battenville (01329490)[7]	1923–68, 1998–present	396	6,320	2.30	B4c, C4

Table 1. Characteristics of streamflow-gaging stations surveyed in hydrologic Regions 1 and 2 in New York State, 2004–05.—Continued

[mi², square miles; ft³/s, cubic feet per second. Streamflow-gaging station locations are shown in fig. 1B]

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[1] From stage-discharge relation.

[2] From Rosgen (1994):
B3: average-gradient, moderately entrenched, riffle-dominated channel with cobbles;
B3a: high-gradient, moderately entrenched, riffle-dominated channel with cobbles;
B3c: very low-gradient, moderately entrenched, riffle-dominated channel with cobbles;
B4: average-gradient, moderately entrenched, riffle-dominated channel with gravel;
B4c: very low-gradient, moderately entrenched, riffle-dominated channel with gravel;
C3: low-gradient, cobble-dominated channel with well defined flood plains;
C3b: high-gradient, cobble-dominated channel with well defined flood plains;
C4: low-gradient, gravel-dominated channel with well defined flood plains;
C4b: high-gradient, gravel-dominated channel with well defined flood plains;
C4c-: very low-gradient, gravel-dominated channel with well defined flood plains;
C5: low-gradient, sand-dominated channel with well defined flood plains;
C5c-: very low-gradient, sand-dominated channel with well defined flood plains;
E4b: sinuous, high-gradient channel with gravel;
F4: sinuous, low-gradient, highly entrenched gravel-dominated channel;
Channel materials from longitudinal-profile pebble count (table 2).

[3] Station operated by Adirondack Ecological Center (SUNY-ESF).

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

[5] Bankfull discharge from HEC-RAS analysis.

[6] Bankfull gage height from LOWESS smooth.

[7] Survey data collected at former streamflow-gaging-station location 0.76 miles downstream.

At four sites (Tributary to Mill Creek Tributary near Lowville (04256040), Hopkinton Brook at Hopkinton (04268720), Little Hoosic River at Petersburg (01333500), and Bouquet River at Willsboro (04276500) (fig. 1B and table 1), the bankfull discharges from the stage-discharge relation did not agree with the bankfull-discharge from the HEC-RAS analysis. At these sites it was assumed that localized channel constrictions at the streamflow-gaging station (bridges and culverts) and (or) significant flattening of the water-surface slope at the streamflow-gaging station distorted the true elevation of bankfull stage. Therefore, the bankfull discharge from the HEC-RAS analysis, calculated at cross sections not affected by channel-constricting influences, was assumed to be the best estimate of bankfull discharge.

Regional Equations for Bankfull Discharge and Channel Characteristics of Streams

The relations between bankfull-discharge, depth, width, and cross-sectional area and drainage area for hydrologic Regions 1 and 2 are presented in the following sections. The period of record, drainage area, bankfull discharge and 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 estimated bankfull discharges and drainage areas for the 16 stream sites used to develop the relation between bankfull discharge and drainage area are in table 1. The bankfull-discharge equation for streams in hydrologic Regions 1 and 2 (fig. 2) is:

$$\text{bankfull discharge (ft}^3\text{/s)} = 49.6\ (\text{drainage area(mi}^2))^{0.849}, \qquad (5)$$

and the coefficient of determination (R^2) is 0.95. 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 streamflows based on 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.

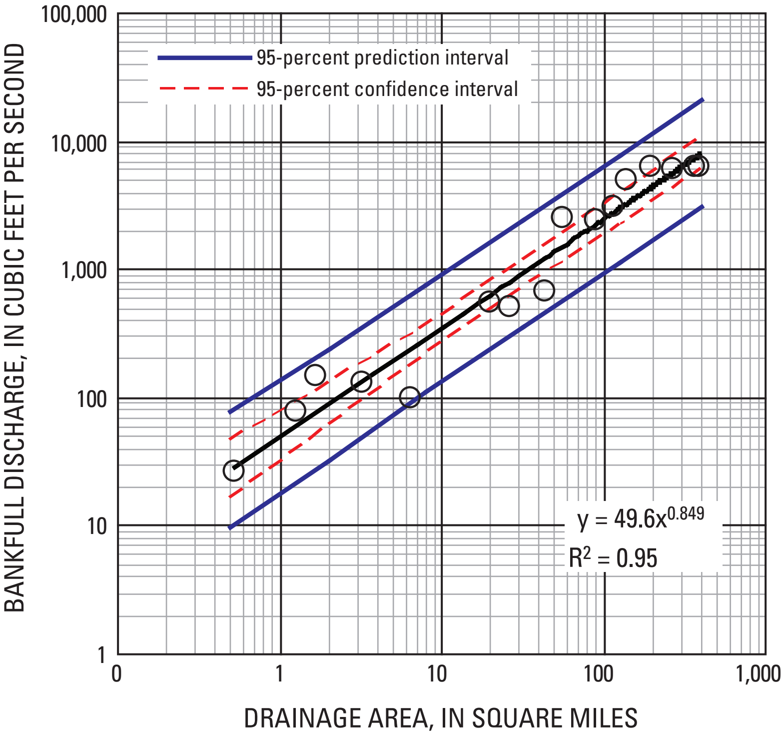

Figure 2. Bankfull discharge as a function of drainage area with 95 percent prediction limit and 95 percent confidence interval for streams surveyed in hydrologic Regions 1 and 2 in New York State.

Bankfull-Discharge Recurrence Intervals

The recurrence interval for the estimated bankfull discharge of each stream was obtained from discharge-frequency relations for each study site that were developed 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); resulting data were analyzed by means of U.S. Geological Survey flood-frequency programs (Kirby, 1981). Other studies have reported that the average recurrence interval for bankfull discharge typically ranges from about 1 to 2 years (Dunne and Leopold, 1978; Rosgen, 1996; Harman and Jennings, 1999). The bankfull-discharge recurrence interval for streams surveyed in hydrologic Regions 1 and 2 ranged from 1.01 to 3.80 years and averaged 2.13 years (table 1). Previous bankfull studies in New York State determined an average bankfull-discharge recurrence interval of 1.54 years and a range of 1.2 to 2.7 years in hydrologic Regions 4 and 4a (fig.1A; Miller and Davis, 2003), an average of 1.51 years and a range of 1.11 to 3.40 years in hydrologic Region 5 (fig. 1A; Westergard and others, 2005), an average of 1.54 years and a range of 1.01 to 2.35 years in hydrologic Region 6 (fig. 1A; Mulvihill and others, 2005), and an average of 2.13 years and a range of 1.05 to 3.60 years in hydrologic Region 7 (fig. 1A; Mulvihill and others, 2006).

Stream-Channel Characteristics in Relation to Drainage Area

Bankfull-channel width, depth, and cross-sectional area for 16 streams in hydrologic Regions 1 and 2 are listed in table 2. Data were collected at three or four cross sections at each stream, and these data were used to develop the bankfull width, depth, and cross-sectional area regression equations. The equations are as follows:

$$\text{bankfull-channel width (ft)} = 21.5\ (\text{drainage area(mi}^2))^{0.362}, \quad (6)$$

$$\text{bankfull-channel depth (ft)} = 1.06\ (\text{drainage area(mi}^2))^{0.329}, \quad (7)$$

$$\text{bankfull-channel cross-sectional area (ft}^2) = 22.3\ (\text{drainage area(mi}^2))^{0.694}. \quad (8)$$

Results are plotted in figure 3; coefficients of determination (R^2) for the equations are 0.89, 0.89, and 0.97, respectively. The high coefficients of determination (R^2) indicate that much of the range in these variables is explained by drainage area.

The raw data for Regions 1 and 2 equations and the corresponding 95-percent confidence and prediction intervals are plotted for bankfull width, depth, and cross-sectional

Table 2. Stream classification and bankfull-channel characteristics for streamflow-gaging stations surveyed in hydrologic Regions 1 and 2 in New York State, 2004–05.

[ft, feet; ft^2, square feet; mi^2, square miles; mm, millimeters; na, not available. Streamflow-gaging station 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]
Archer Creek above Arbutus Pond	0.52	63	19.6	1.1	21.4	41.7	2.1	17.8	0.074	245	1.25	B3a
		135	29.0	0.7	19.7	53.1	1.8	41.4				B3a
		153	11.6	1.2	13.9	33.3	2.9	9.7				C3b
		162	16.9	.9	14.7	53.2	3.1	18.8				C3b
Buck Creek near Inlet (04253296)	1.28	138	14.2	1.8	24.9	41.0	2.9	7.9	.033	47.2	1.11	E4b
		166	15.4	1.2	18.2	28.0	1.8	12.8				B4
		193	17.9	1.8	31.3	42.0	2.3	9.9				E4b
Tributary to Mill Creek Tributary near Lowville (04256040)	1.66	0	27.6	.9	24.2	47.8	1.7	30.7	.023	26.0	1.14	B4
		57	30.5	1.1	33.0	36.5	1.2	27.7				B4
		121	28.6	.8	21.6	36.0	1.3	35.8				B4
		153	46.7	.8	37.1	202	4.3	58.4				C4b
Vly Brook near Morehouseville (01342797)	3.28	35	34.5	1.5	50.6	50.5	1.5	23.0	.025	147	1.17	B3
		78	34.3	1.2	42.3	66.0	1.9	28.6				B3
		139	41.3	1.4	56.4	57.0	1.4	29.5				B3
		382	30.4	1.8	53.5	173	5.7	16.9				C3b
North Creek near Ephratah (01348420)	6.52	81	37.4	2.1	78.4	340	9.1	17.8	.019	32.2	1.22	C4
		507	51.5	1.8	93.6	90.0	1.7	28.6				B4c
		562	62.3	1.8	111	107	1.7	34.6				B4c
		594	74.8	1.5	115	104	1.4	49.9				B4c
Hopkinton Brook at Hopkinton (04268720	20.0	97	72.3	2.1	154	190	2.6	34.4	.014	68.4	1.24	C3
		146	61.5	2.0	125	180	2.9	30.8				C3
		226	67.5	3.3	220	149	2.2	20.5				C3
Glowegee Creek at West Milton (01330000)	26.0	242	51.6	3.9	199	310	6.0	13.2	.001	.2	1.73	C5
		316	49.6	4.1	201	215	4.3	12.1				C5
		350	48.0	4.0	193	223	4.6	12.0				C5

Table 2. Stream classification and bankfull-channel characteristics for streamflow-gaging stations surveyed in hydrologic Regions 1 and 2 in New York State, 2004–05.—Continued

[ft, feet; ft^2, square feet; mi^2, square miles; mm, millimeters; na, not available. Streamflow-gaging station 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]
Plum Brook near Grantville (04268200)	43.9	250	58.5	4.9	287	269	4.6	11.9	0.002	45.8	1.62	C4
		337	55.5	4.6	257	144	2.6	12.1				C4
		487	56.6	3.2	180	213	3.8	17.7				C4
		732	69.0	3.1	215	226	3.3	22.3				C4
Little Hoosic River at Petersburg (01333500)	56.1	1044	94.1	3.5	330	367	3.9	26.9	.004	65.6	1.19	C3
		1172	66.1	4.7	309	420	6.4	14.1				C3
		1264	96.4	3.7	356	408	4.2	26.1				C3
		1424	78.2	4.5	354	505	6.5	17.4				C3
Independence River at Donnattsburg (04256000)	88.7	1385	129	4.1	531	330	2.6	31.4	.005	86.5	1.90	C3
		1500	131	4.2	554	300	2.3	31.2				C3
		1723	88.2	4.9	434	245	2.8	18.0				C3
West Branch Au Sable River near Lake Placid (04274000)	116	406	114	7.6	859	410	3.6	14.9	<.001	2.0	1.35	C5c-
		731	123	6.8	830	445	3.6	18.0				C5c-
		843	113	6.5	737	392	3.5	17.3				C5c-
Sandy Creek near Adams (04250750)	137	1137	116	5.8	671	na	na	20.1	.002	77.0	1.55	na
		1421	108	5.6	608	3450	31.9	19.3				C3
		1572	108	5.6	606	3450	31.9	19.3				C3
East Branch Au Sable River at Au Sable Forks (04275000)	198	647	179	5.1	912	230	1.3	35.1	.002	55.4	1.23	F4
		892	176	6.4	1132	1160	6.6	27.5				C4
		1102	323	3.5	1134	1252	3.9	92.4				C4
Bouquet River at Willsboro (04276500)	270	746	172	5.6	969	272	1.6	30.8	.003	122.3	1.69	B3c
		877	182	5.5	1006	265	1.5	33.1				B3c
		1008	146	6.1	886	261	1.8	23.9				B3c
		1155	145	5.2	761	268	1.8	27.9				B3c

Table 2. Stream classification and bankfull-channel characteristics for streamflow-gaging stations surveyed in hydrologic Regions 1 and 2 in New York State, 2004–05.—Continued

[ft, feet; ft^2, square feet; mi^2, square miles; mm, millimeters; na, not available. Streamflow-gaging station 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]
Moose River at McKeever (04254500)	363	1497	229	9.6	2208	560	2.4	23.9	<.001	19.9	1.04	C4c-
		1828	222	8.6	1901	na	na	25.8				na
		2074	228	9.3	2108	600	2.6	24.5				C4c-
Batten Kill below Mill at Battenville (01329490)	396	1865	197	8.0	1584	572	2.9	24.7	.001	39.1	1.46	C4
		2057	193	5.5	1074	328	1.7	35.2				B4c
		3227	151	7.4	1117	449	3.0	20.5				C4

[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):
B3: average-gradient, moderately entrenched, riffle-dominated channel with cobbles,
B3a: high-gradient, moderately entrenched, riffle-dominated channel with cobbles,
B3c: very low-gradient, moderately entrenched, riffle-dominated channel with cobbles,
B4: average-gradient, moderately entrenched, riffle-dominated channel with gravel,
B4c: very low-gradient, moderately entrenched, riffle-dominated channel with gravel,
C3: low-gradient, cobble-dominated channel with well defined flood plains,
C3b: high-gradient, cobble-dominated channel with well defined flood plains,
C4: low-gradient, gravel dominated channel with well defined flood plains,
C4b: high-gradient, gravel-dominated channel with well defined flood plains,
C4c-: very low-gradient, gravel-dominated channel with well defined flood plains,
C5: low-gradient, sand-dominated channel with well defined flood plains,
C5c-: very low-gradient, sand-dominated channel with well defined flood plains,
E4b: sinuous, high-gradient channel with gravel,
F4: sinuous, low-gradient, highly entrenched gravel-dominated channe.

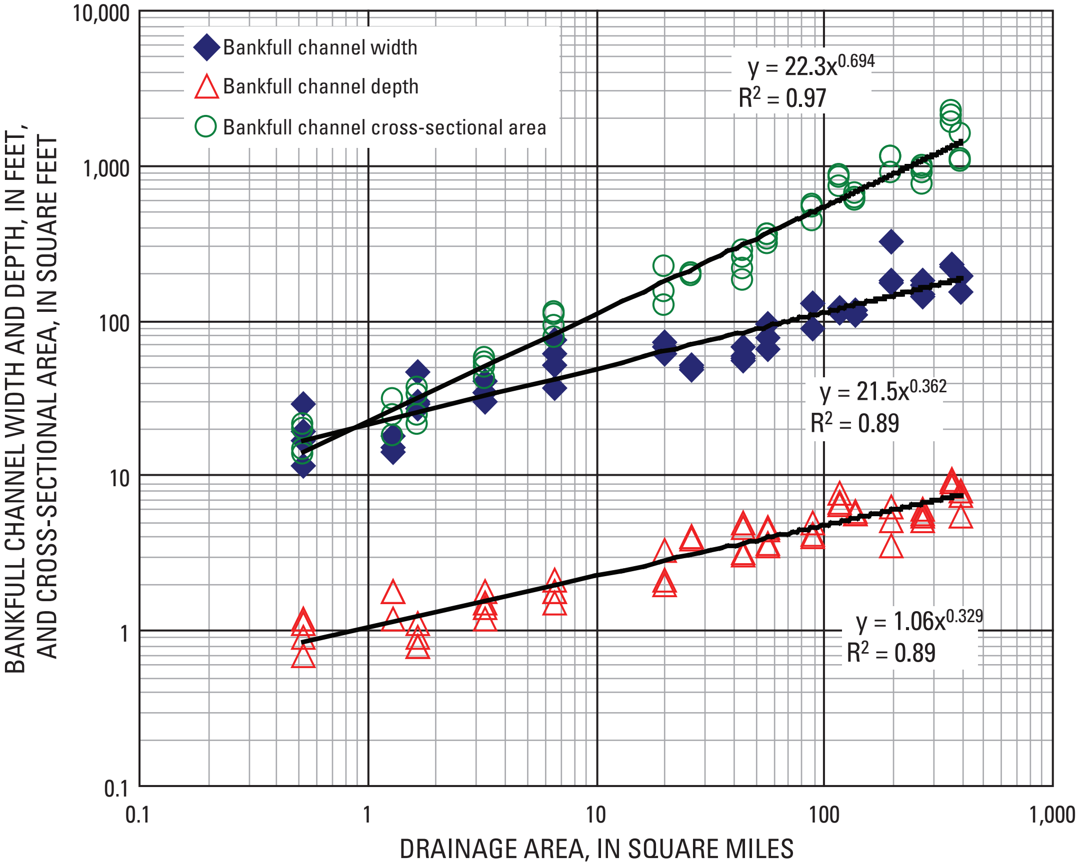

Figure 3. Bankfull width, depth, and cross-sectional area as a function of drainage area with best-fit lines, regression equations, and R^2 values for streams surveyed in hydrologic Regions 1 and 2 in New York State.

area as a function of drainage area in figures 4A , B and C, respectively. The confidence and prediction intervals shown on these graphs were calculated using all available cross-section data; these bands are narrower than they would have been if only the mean values for each parameter at each site had been used.

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 streams; the values obtained are listed 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*: the 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 Jennings, 1999). D50 values were obtained through a modified Wolman pebble count (modified to account for bank and within-channel 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(s) (table 1) on the basis of the stream-channel measures taken at each cross section. Each cross section was also classified

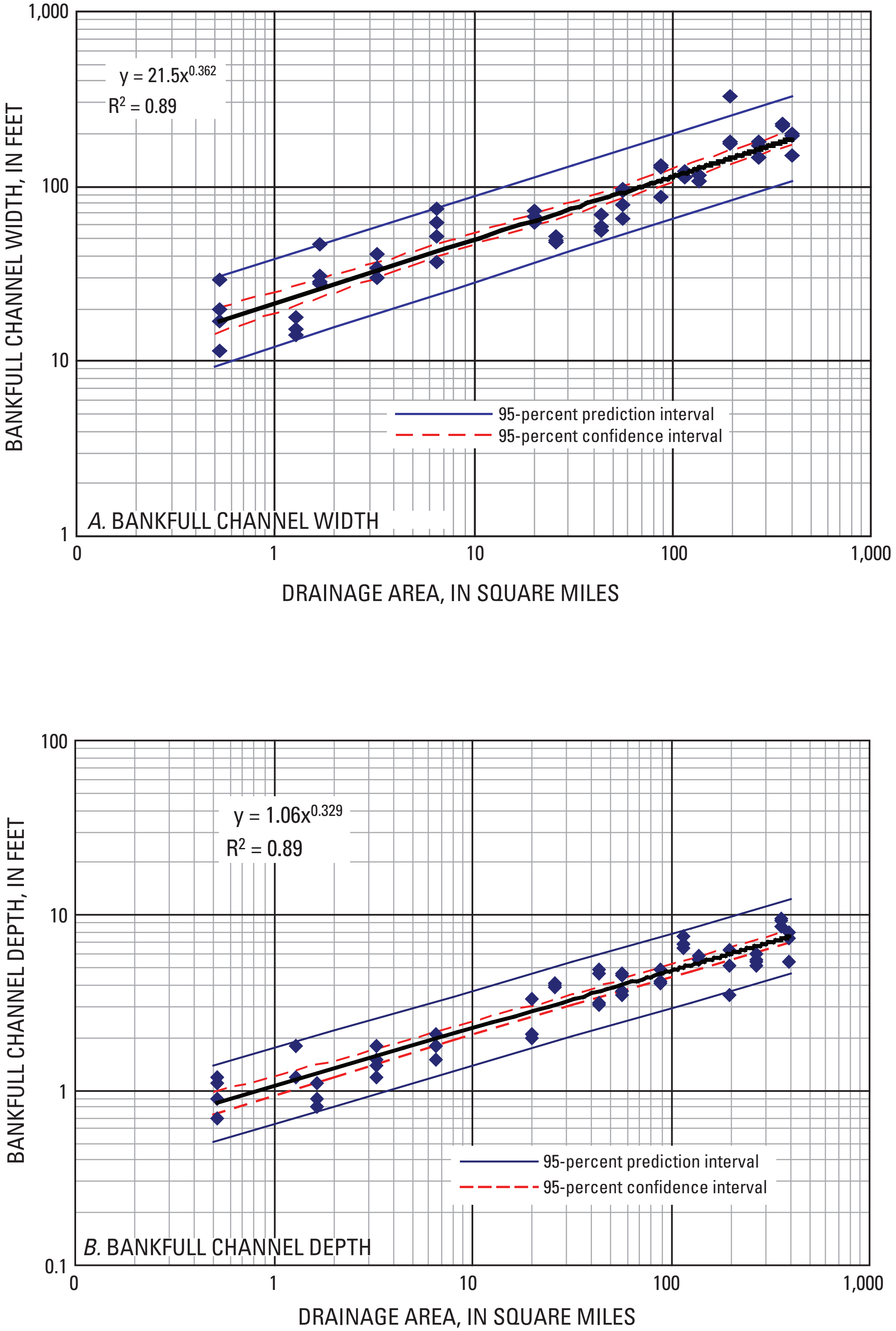

Figure 4. Channel characteristics as a function of drainage area with 95 percent prediction limits and 95 percent confidence intervals for streams in hydrologic Regions 1 and 2 in New York State: (*A*) bankfull-channel width, *(B)* bankfull-channel depth, and *(C)* bankfull-channel cross-sectional area.

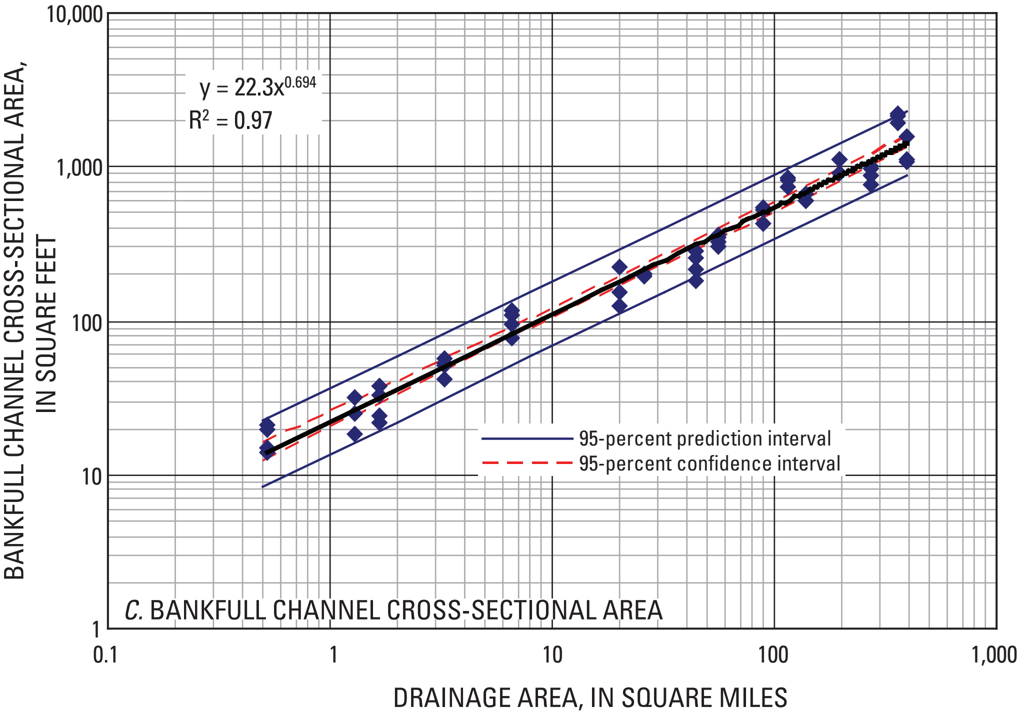

Figure 4. Channel characteristics as a function of drainage area with 95 percent prediction limits and 95 percent confidence intervals for streams in hydrologic Regions 1 and 2 in New York State: *(A)* bankfull-channel width, *(B)* bankfull-channel depth, and *(C)* bankfull-channel cross-sectional area.—Continued

individually by Rosgen stream type (table 2). Stream types A through G represent seven major stream categories that differ in entrenchment, gradient, width-to-depth ratio, and sinuosity (Rosgen, 1996). Within each major category, the numbers 1 through 6 are assigned to delineate dominant channel material ranging from bedrock to silt and clay (Rosgen, 1996).

For 9 of the 16 streams surveyed, the stream type in all cross sections was the same (table 2). For 6 of the 16 streams surveyed, one cross section was classified as a different stream type: Buck Creek near Inlet (04253296), Tributary to Mill Creek Tributary near Lowville (04256040), Vly Brook near Morehouseville (01342797), North Creek near Ephratah (01348420), East Branch Au Sable River at Au Sable Forks (0427500), and Batten Kill below Mill at Battenville (01329490) (fig. 1 and table 2). One stream, Archer Creek above Arbutus Pond, had two B cross sections and two C cross sections (table 2).

In all streams surveyed, almost all cross sections were classified as type B or C. Exceptions were Buck Creek near Inlet (04253296), which had two E cross sections, and the East Branch Au Sable River at Au Sable Forks (04275000), which had one F cross section (table 2). The majority of the streams surveyed differed from one another only in the degree of vertical containment of the river channel (Rosgen, 1994) because the only difference between B and C streams is the entrenchment ratio.

Comparison of Hydrologic Regions 1 and 2 Bankfull-Discharge Equation to Equations for Other Regions in New York State

The hydrologic Regions 1 and 2 equation for the relation between bankfull discharge and drainage-area was graphically compared to curves developed for 5 other regions in New York State to evaluate region-to-region differences and the ability of regional curves to produce results that are more accurate than what would be obtained from one comprehensive statewide model (fig. 5). The 95-percent confidence interval for the hydrologic Regions 1 and 2 curve fully encompasses the curves for Regions 4a, 5, and 6 (fig. 5), showing that there are very few differences in the relation between drainage area and bankfull discharge in these four regions. However, the curves for Regions 4 and 7 lay outside the 95-percent confidence intervals of the Region 3 curve (fig 5), indicating that these 3 regions do not have similar bankfull discharge to drainage-area relations. For example, a stream with a drainage area of 10 mi^2 would have an estimated bankfull discharge of 200 ft^3/s in Region 7, 350 ft^3/s in Regions 1 and 2, and 700 ft^3/s in Region 4 (fig. 5). These differences demonstrate that streams fairly close to one another do not always have similar flow regimes and that regional equations designed for a specific geographic area are valuable tools for anyone involved in local watershed management and planning.

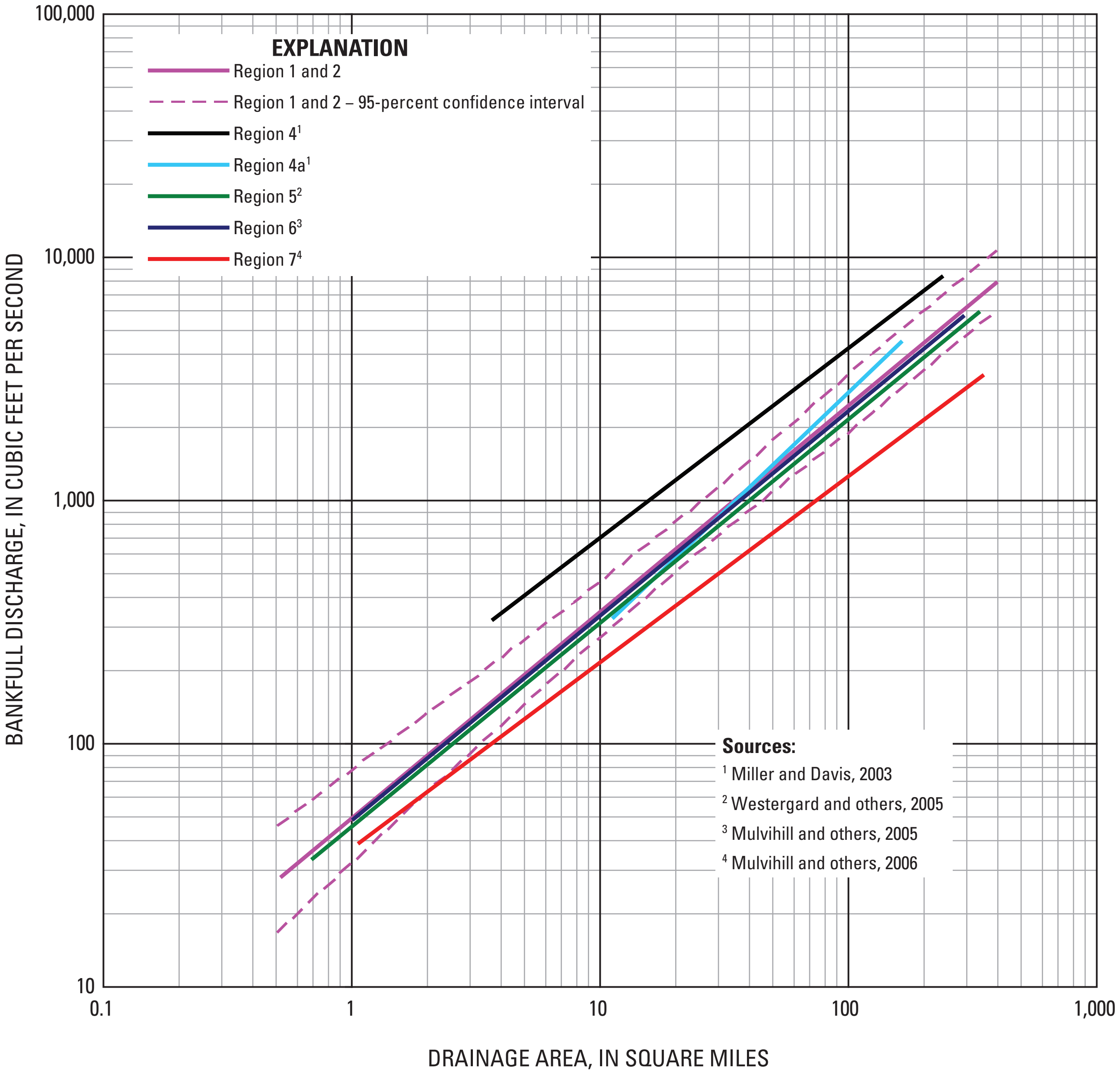

Figure 5. Bankfull discharge as a function of drainage area for hydrologic Regions 1 and 2 and published curves for five other regions in New York State.

Limitations of this Study

An assumption made in this study—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 found 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 were longer or shorter than that frequency, the bankfull channel could be incorrectly identified (White, 2001). The average bankfull recurrence interval for streams surveyed in hydrologic Regions 1 and 2 was 2.13 years, higher than the average 1.5-year frequency reported by Rosgen (1996) but still within the 1- to 2.5-year range reported by Leopold (1994).

The relatively few active USGS streamflow-gaging stations in hydrologic Regions 1 and 2 that met selection criteria also limited this investigation. To ensure that the equations were as representative as possible, three additional gages were added; one that had been inactive since 1986 (Hopkinton Brook at Hopkinton (04268720)), one that had only 7 years of peak-flow record (Buck Creek near Inlet (04253296)), and one that was operated by SUNY-ESF (Archer Creek above Arbutus Pond).

The use of one site that had been inactive since 1986 and seven sites in which more than one stream type were included in the study reach necessitated several assumptions. In analyzing data from the inactive streamflow-gaging station, it was assumed that (1) the recurrence interval of bankfull discharge had not changed since the site was last active; (2) the flow pattern at the site had not been significantly altered by floods, diversions, ground-water recharge, or changes in land use since the site was discontinued; and (3) three low- to medium-flow discharge measurements were sufficient to define a stage-discharge relation that could reliably be extended to bankfull stage. In data analysis for the sites representing several stream types, it was assumed that averaging measurements from cross sections of differing types was an accurate measure of overall reach characteristics. Also, the recurrence interval at Buck Creek near Inlet was estimated from 7 years of peak-flow record, though 10 years of peak-flow record is generally thought to be the minimum for recurrence-interval calculations. The recurrence interval at this streamflow-gaging station will be updated when additional data become available.

At four other sites it was assumed that localized channel constrictions at the streamflow-gaging station (bridges and culverts) and (or) a significant flattening of the water-surface slope at the streamflow-gaging station distorted the true elevation of bankfull stage. In these cases, the bankfull discharge from HEC-RAS analysis, calculated at cross sections not affected by channel-constricting influences, was assumed to be the best estimate of bankfull discharge (table 1). At one site, bankfull stage and discharge were obtained through a regression technique called a LOWESS smooth (Locally Weighted Scatterplot Smoother) (Ott and Longnecker, 2001) because steep slopes upstream and downstream from the gage pool resulted in the best-fit bankfull elevation being considerably lower then true bankfull.

Regional channel-characteristics equations can be more accurate than those representing an entire state or larger 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, however, and must accept that these regression equations (curves) are designed only to provide estimates of bankfull-channel characteristics and discharges; the equations are not intended to substitute for the field measurement and verification of bankfull-channel characteristics and streamflow (White, 2001).

Summary and Conclusions

Equations relating bankfull discharge and channel characteristics (width, depth, and cross-sectional area) to the size of the drainage area at gaged streams are needed to estimate bankfull discharge and channel characteristics at ungaged streams and to provide information used in the design of stream-restoration projects. The USGS, in cooperation with the New York City Department of Environmental Protection, New York State Department of Environmental Conservation, New York State Department of Transportation, and the New York State Department of State, undertook a study to develop these equations for streams in the Adirondack region of New York State (hydrologic Regions 1 and 2). Fifteen active and one inactive streamflow-gaging stations were chosen in accordance with established guidelines. Stream-survey data and discharge records from these sites were used in linear-regression analyses to relate bankfull discharge and bankfull-channel width, depth, and cross-sectional area to drainage area. The resulting equations are the following:

$$\text{bankfull discharge (ft}^3\text{/s)} = 49.6\ (\text{drainage area (mi}^2))^{0.849}, \tag{9}$$

$$\text{bankfull-channel width (ft)} = 21.5\ (\text{drainage area (mi}^2))^{0.362}, \tag{10}$$

$$\text{bankfull-channel depth (ft)} = 1.06\ (\text{drainage area (mi}^2))^{0.329}, \tag{11}$$

$$\text{bankfull-channel cross-sectional area (ft}^2) = 22.3\ (\text{drainage area (mi}^2))^{0.694}. \tag{12}$$

The high coefficients of determination *(R^2)* for the four regression equations (0.95, 0.89, 0.89 and 0.97, 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 by means of regression equations that relate measured discharges to known recurrence intervals. The recurrence intervals for bankfull discharge of the 16 surveyed streams in hydrologic Regions 1 and 2 ranged from 1.01 to 3.80 years, with a mean recurrence interval of 2.13 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-type, with a few E- and F-type cross-sections.

The hydrologic Regions 1 and 2 equation for the relation between bankfull discharge and size of drainage area was compared with equations developed for five other regions in New York State. The hydrologic Regions 1 and 2 equation was found to be similar to three of the five other regions. Large differences between the hydrologic Regions 1 and 2 curve and curves for two other hydrologic regions indicate a need to develop equations by region for greatest accuracy.

Acknowledgments

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