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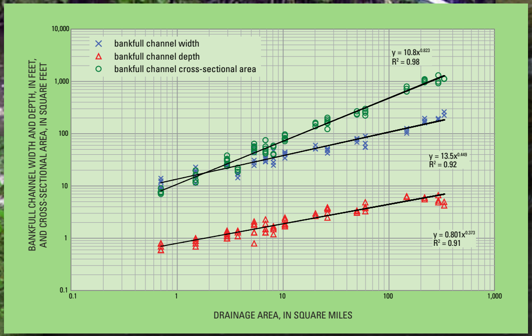
Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 5 in Central New York



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Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State:
Hydrologic Region 5 in Central New York

By Britt E. Westergard, Christiane I. Mulvihill, Anne G. Ernst, and Barry P. Baldigo

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For additional information about this report write to:
U.S. Geological Survey
425 Jordan Road
Troy, NY 12180
Email: askny@usgs.gov
World Wide Web: http://ny.usgs.gov/

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Abstract

Equations that relate drainage area to bankfull discharge and channel dimensions (width, depth, and cross-sectional area) at gaged sites are needed to define bankfull discharge and channel dimensions at ungaged sites and to provide information for the 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. A study to develop equations to predict bankfull data for ungaged streams in New York established eight regions that coincided with previously defined hydrologic regions. This report presents drainage areas and bankfull characteristics (discharge and channel dimensions) for streams in central New York (Region 5) selected for this pilot study.

Stream-survey data and discharge records from seven active (currently gaged) sites and nine inactive (discontinued gaged) sites were used in regression analyses to relate size of drainage area to bankfull discharge and bankfull channel width, depth, and cross-sectional area. The resulting equations are: bankfull discharge = 45.3 (drainage area)$^{0.856}$; bankfull channel width = 13.5 (drainage area)$^{0.449}$; bankfull channel depth = 0.801 (drainage area)$^{0.373}$; bankfull channel cross-sectional area = 10.8 (drainage area)$^{0.823}$. The high correlation coefficients (R^2) for these four equations (0.96, 0.92, 0.91, 0.98, respectively) indicate that much of the variation in the variables is explained by the size of the drainage area. Recurrence intervals for the estimated bankfull discharge of each stream ranged from 1.11 to 3.40 years; the mean recurrence interval was 1.51 years. The 16 surveyed streams were classified by Rosgen stream type; most were mainly C-type reaches, with occasional B- and F-type reaches. The Region 5 equation was compared with equations developed for six other areas in the Northeast. The major differences among results indicate a need to refine equations so they can be applied by water-resources managers to local planning and design efforts.

Introduction

Erosion and sedimentation in streams can affect the water quality of reservoirs and endanger private and public lands and associated infrastructure across New York State. Many 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 restorations have traditionally consisted of procedures such as 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, however, 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 dimensions, and the relations among channel dimensions, flow patterns, and water-surface profiles. Equations for these relations developed from stable-reach data at gaged streams can provide a basis for channel restorations in nearby unstable, ungaged streams and for replication of geomorphically stable reaches that support healthy ecosystems.

Bankfull discharge is an important stream feature for determining the relationships between drainage area size and stream-channel dimensions. Bankfull discharge is 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 onto the flood-plain (Leopold and others, 1964; Leopold, 1994), and is reported to occur every one to two years, or 1.5 years on average (Rosgen, 1994). Bankfull discharge is the flow that moves the most sediment over time, due to the combination of its force and frequency (Wolman and Miller, 1960; Leopold, 1994). These characteristics of bankfull discharge influence the relations between drainage area and stream-channel dimensions in two ways. First, relations between drainage area and discharge, and between drainage area and channel dimensions, are relatively constant at bankfull stage in stable streams of the same class and within the same hydro-physiographic region (Leopold and others, 1964; Rosgen, 1996). Second, bankfull discharge occurs at a discrete and identifiable stage, and so a system for classifying streams has been developed based on channel dimensions at bankfull stage (Rosgen, 1996).

Predicting stable-channel characteristics for an unstable, ungaged stream requires equations based on data from stable streams that are close to the ungaged stream; are subject to similar precipitation rates and climatic conditions; and have similar soils, recharge patterns, flow patterns, and physiographic characteristics. Deriving channel-geometry equations from streams within the same hydrophysiographic region can minimize the range in each variable and 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 (NSCC) is overseeing a statewide cooperative effort to develop such equations through a system developed 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 North America, including Vermont (Jaquith and Kline, 2001), southern Ontario (Annable, 1996), and the Pennsylvania-Maryland Piedmont area (White, 2001). These equations, which reflect localized precipitation rates, hydrologic conditions, physiographic characteristics, and soil properties, are expected to provide more reliable results than the currently available channel-geometry equations that represent widespread geographic regions, such as the eastern United States (Dunne and Leopold, 1978).

Approach

In 2001, the U.S. Geological Survey (USGS), in cooperation with the New York City Department of Environmental Protection (NYCDEP), the New York State Department of Environmental Conservation (NYSDEC), and the New York State Department of Transportation (NYSDOT), and with assistance from the Delaware County Soil and Water Conservation District (DCSWCD) and the Greene County Soil and Water Conservation District (GCSWCD), began a six-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). Those boundaries (fig. 1, inset map) were used as preliminary hydrophysiographic-region boundaries to group streams with similar characteristics. Objectives of the ongoing 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 stream classification system of Rosgen (1996) — 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 statewide bankfull equations by grouping channel-geometry relations across the eight regions 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 consistent stream descriptions for use in evaluations of channel stability and in the design and simulation of stable conditions in ungaged stream reaches. The geomorphologic characteristics defined by Rosgen (1996) that correspond to bankfull stage were chosen for their consistency among streams having similar physiographic conditions for a given drainage-basin size, and among streams subject to similar climatic conditions (Rosgen, 1994, 1996).

Region 5 (fig. 1) was selected as a pilot-study area because it contains streams that supply New York City's reservoir system and, thus, could be studied in cooperation with the NYCDEP-SMP. Region 5 extends north to the Mohawk River and its southern tributaries, south to the New York-Pennsylvania border, west to the Tioughnioga and Chenango Rivers and their tributaries, and east to the West Branch Delaware River and its tributaries (Lumia, 1991). This region contains only seven actively gaged sites that meet the selection criteria; therefore, records from nine inactive gaged sites also were used in the development of the equations. All sites were on unregulated streams and had at least 10 years of record.

The hydrologic regions used by Lumia (1991) to define the eight flood regions were based on multiple linear regression analyses that related high flows with 2- to 500-year recurrence intervals to basin characteristics such as drainage area, main-channel slope, percent basin storage, mean annual precipitation, percentage of basin covered by forest area, mean main-channel elevation, and a basin-shape index. The region boundaries were based on 50-year peak-discharges. These boundaries will be compared with those developed from the bankfull survey data collected during this and subsequent studies, and can be adjusted if necessary.

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) compares bankfull-discharge equations developed for Region 5 with previously developed equations from other areas throughout the Northeast.

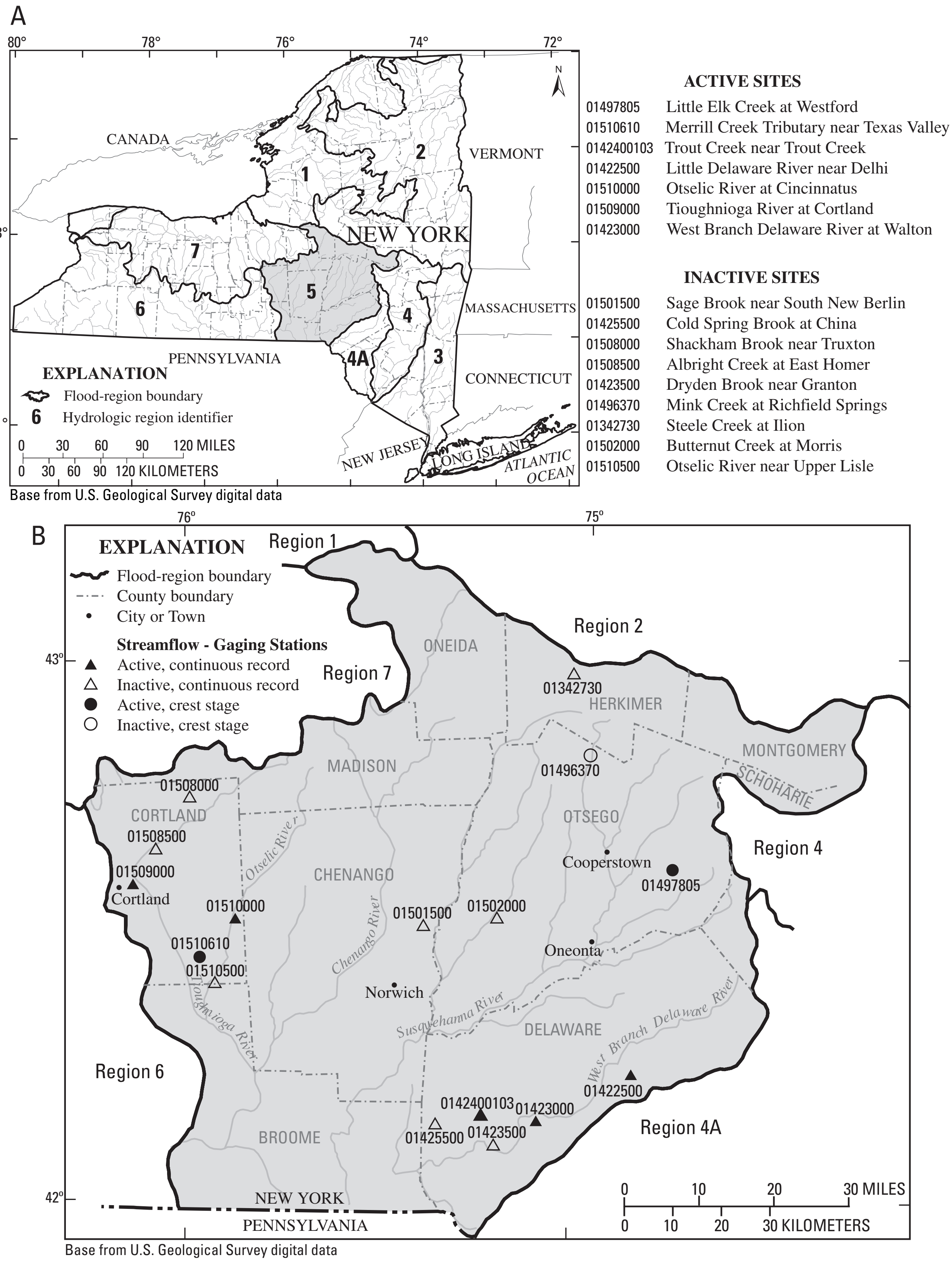

Figure 1. Map showing flood regions in New York: A. Hydrologic-region boundaries as defined by Lumia (1991). B. Locations of the seven active and nine inactive streamflow-gaging stations used in 2001-02 stream survey in Region 5.

Methods

The 16 sites were surveyed by three agencies during the 2001-02 field season. The USGS surveyed three active sites and the eight inactive sites, the DCSWCD surveyed three active sites, and the NYCDEP surveyed one active site and one inactive site. The analysis combined data from all 16 sites. The methods used to collect and analyze the data in this report are described in detail in Powell and others (2003) and summarized below.

Site Selection

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

- All must have a USGS streamflow-gaging station with at least 10 consecutive years of annual peak-discharge data.
- 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.
- All must meet the minimum requirements for slope-area calculation of discharge (uniform channel geometry; flow contained in single, trapezoidal channel; and water-surface elevation drop between cross sections of at least 0.50 ft; Dalrymple and Benson, 1967), so that surveyed data can reliably be used in hydraulic analysis and calculation of bankfull discharge.
- The gage must be in the reach.
- All should represent a single Rosgen (1996) stream type if possible, although this was not possible at 6 of the 16 sites.

Sites selected for gage-calibration surveys were not necessarily stable as a result of localized channel instability from bridges or other controls. Site stability was assessed in two ways. At active sites, site 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 inactive sites, three to five discharge measurements were made during the study period to determine the stage-to-discharge relation (rating), and this new rating was plotted against the last known rating from the time the site was active to assess any change and evaluate channel stability.

The selected sites were referred to as calibration sites because they were used to develop or calibrate the channel-geometry equations. Region 5 contained only 9 active sites with 10 or more years of record, and 2 of these, on the basis of site visits, were unsuitable for gage calibration surveys. Therefore, an additional 9 sites (out of 27 possible) that had been inactive for 7 to 35 years were also selected.

Data Collection

Preliminary reconnaissance of all sites entailed marking bankfull indicators, cross-section locations, and reach boundaries. Bankfull indicators (fig. 2) 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). Identification of bankfull indicators was complicated at some locations by dense vegetation, which made indicators difficult to locate, or by several possible indicators found at different elevations at a given cross section. Where this was found, multiple indicators were flagged, and the data-analysis techniques described below were used to determine which bankfull-stage indicator was most accurate.

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 or both banks. The survey at active sites consisted of at least three cross sections – two in riffles and one where stage is recorded or, if known, where discharge measurements are made. The survey at inactive sites consisted of one or two sets of three cross sections (each set within a riffle) and one cross section where stage was recorded or, if known, where discharge measurements were made (Powell and others, 2003). Cross sections in riffles were placed away from channel-constricting structures such as bridges and culverts.

After the preliminary reconnaissance, each study reach was surveyed by methods described in Powell and others (2003). A longitudinal profile survey was conducted. This consisted of surveying from one of the streamflow-gaging station reference marks of known elevation to rebar marking reach boundaries; all bankfull-indicator flags; and the thalweg and water surface at each bankfull-indicator flag, cross section, and transition between riffles and pools. The cross-section surveys consisted of surveying bed and bank elevations, bankfull-indicator flags, rebar that marked cross sections, and the flood-plain width. Channel-bed material throughout the reach and at each cross section was characterized through a modified Wolman pebble count (Harrelson and others, 1994).

Data Analysis

All field data were compiled for graphical analysis. A bankfull-elevation profile along the reach was constructed by plotting a best-fit line through the surveyed bankfull-stage indicators. At six sites, bankfull indicators were present at more than one elevation; in these cases, multiple lines were plotted, and the bankfull stage and associated discharge that agreed best with the 1.5-year bankfull recurrence interval were used.


A. Westergard (2002)


B. Baldigo (2002)

Figure 2. Examples of bankfull indicators for Region 5 in New York: A. Active bank scour and change in amount of vegetation, Shackham Brook near Truxton (01508000). B. Topographic break from steep slope to gentle slope, Butternut Creek at Morris (01502000). Dotted line indicates bankfull height.

At active sites, the bankfull stage at the gage or staff plate was identified and the corresponding bankfull discharge was taken from the most current stage-to-discharge relation. At inactive sites, the newly developed stage-to-discharge relation was extended to bankfull stage through Johnson's method (Kennedy, 1984) and the corresponding bankfull discharge was obtained. At all sites, the estimate of bankfull discharge was verified through a hydraulic analysis of the bankfull geomorphologic data collected during the streamflow-gaging station calibration survey, as described below. (Additional details are given in Powell and others, 2003).

(1) The computer program NCALC (Jarrett and Petsch, 1985) was used to compute Manning's n, the roughness coefficient of the channel. 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). For this report, all bankfull water-surface elevations were taken from the best-fit line rather than from surveyed bankfull indicators to ensure that elevations decreased downstream.

(2) The computer program HEC-RAS (U.S. Army Corps of Engineer's Hydraulic Engineering Center River Analysis System; Brunner, 1997) was used to determine bankfull discharge by calculating water-surface elevation, as follows: first, the gage datum 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 resulted in an output elevation closest to the surveyed bankfull water-surface elevation was chosen as the bankfull discharge at that location; 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 stage-to-discharge relation was considered accurate; the discharge obtained from this relation was then used as the bankfull discharge and the recurrence interval of this discharge was calculated. If the two discharges varied 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 better fit the expected 1.5-year bankfull recurrence interval was chosen.

In this study, major differences between the two discharges were noted at three of the nine inactive sites: Cold Spring Brook at China, Sage Brook near New South Berlin, and Butternut Creek at Morris (table 1). The differences at Cold Spring Brook at China and Sage Brook near South New Berlin were attributed to the undetermined effect of crumbling weirs on the stage-to-discharge relation; the difference at Butternut Creek at Morris was attributed to the location of the discharge-measurement reference point, which was at the top of the reach where reliable bankfull indicators were not found. At all three sites, the bankfull discharge obtained from the HEC-RAS analysis was used because it fit the 1.5-year recurrence interval better than the bankfull discharge obtained from the stage-to-discharge relation.

The stage-to-discharge relation for Merrill Creek Tributary near Texas Valley, an active site, was discarded because bankfull discharges may have been affected by backwater; the bankfull discharge estimate from the HEC-

RAS analysis was used for this site. The stage-to-discharge relation for Steele Creek at Ilion was unavailable, so the bankfull discharge estimate from the HEC-RAS analysis was used for that site as well.

Regional Equations for Bankfull Discharge and Channel Characteristics of Streams

Regional relations between drainage area and bankfull discharge, depth, width, and cross-sectional area were developed based on data from all 16 sites and are presented below. 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 Size

Drainage area size was related to bankfull discharge though regression analysis. Active and inactive streamflow-gaging stations were initially analyzed separately because hydraulic geometry may have changed at inactive sites. Separate equations for active and inactive sites in Region 5 showed that the 95-percent confidence intervals for both equations had almost complete overlap (fig. 3A). The 95-percent confidence interval defines the range within which there is a 95-percent probability that equations derived from another set of streams in the same region would fall, and the overlap indicated little or no difference between active and inactive sites. Subsequent analyses, therefore, combined data from all sites. The regression equation for all sites in Region 5 (fig. 3B) was bankfull discharge = 45.3 (drainage

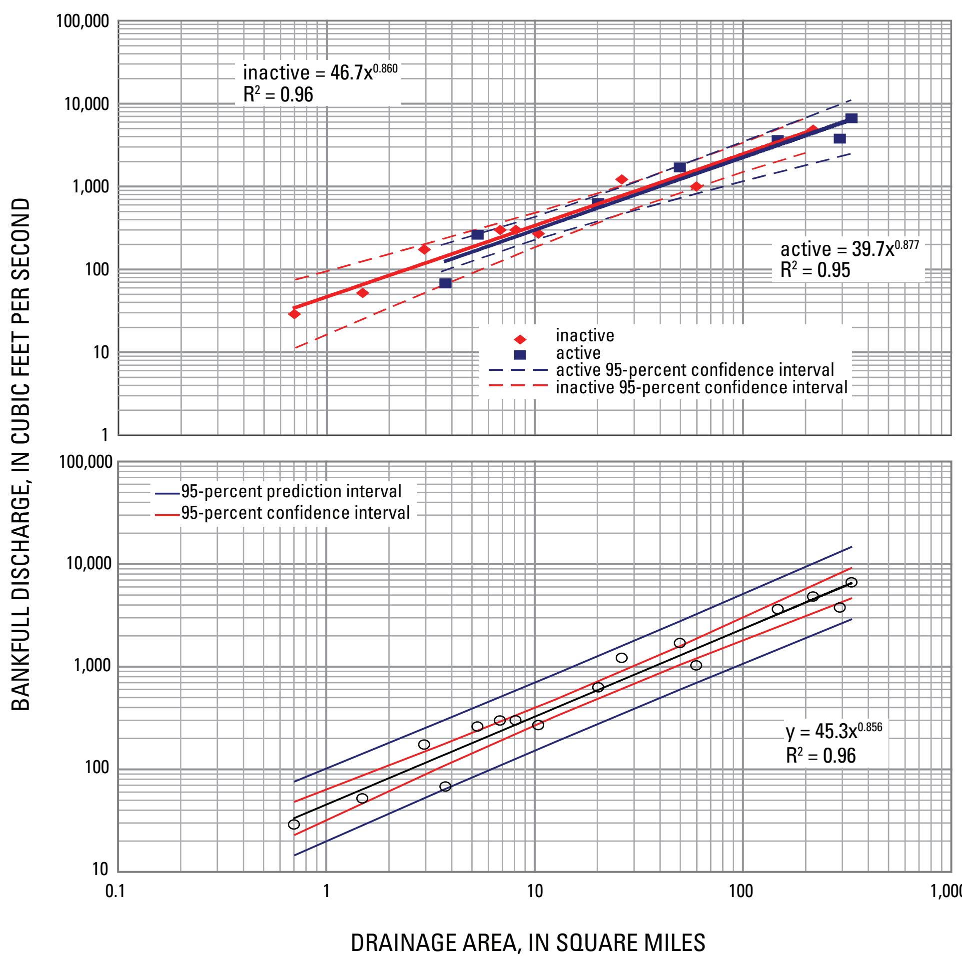

Figure 3. Graph showing bankfull discharge (*y*) as a function of drainage area size (*x*) for streams surveyed in Region 5 in New York: A. 95-percent confidence intervals for active and inactive sites. B. 95-percent confidence and prediction intervals for all sites.

Table 1. Characteristics of streamflow-gaging stations surveyed in Region 5 in New York, 2001-02.

[ft^3/s, cubic feet per second. Site locations are shown in fig. 1.]

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 D50[7] (mm)	Reach stream type[2]
Sage Brook near South New Berlin (01501500)[3]	1932-68	0.7	29[6]	1.65	21.4	B4, C4b
Cold Spring Brook at China (01425500)[3]	1935-68	1.49	52[6]	1.25	71.1	B3, C3, F4b
Shackham Brook near Truxton (01508000)[3]	1932-68	2.95	174	1.80	35.2	C4
Little Elk Creek at Westford (01497805)[4]	1978-present	3.73	68	1.24	na	C4, F4
Merrill Creek tributary near Texas Valley (01510610)[3]	1976-81, 1983-present	5.32	261[6]	1.11	55.6	B4c, C4
Albright Creek at East Homer (01508500)[3]	1938-68	6.81	299	1.50	65.8	B3c, C3, F3
Dryden Brook near Granton (01423500)[3]	1952-67	8.1	300	1.60	93.2	C3
Mink Creek at Richfield Springs (01496370)[3]	1969-86	10.4	270	1.58	3.0	C4, B4c
Trout Creek near Trout Creek (0142400103)[4]	1952-1967, 1996-present	20.2	630	1.25	na	C4
Steele Creek at Ilion (01342730)[3]	1964-65, 1966-69, 1971-74, 1976-83	26.2	1220[6]	3.40	44.7	C4
Little Delaware River near Delhi (01422500)[4]	1937-1970, 1997-present	49.8	1700	1.48	na	C4
Butternut Creek at Morris (01502000)[3]	1938-95	59.7	1000[6]	1.11	57.1	C4
Otselic River at Cincinnatus (01510000)[3]	1938-1964, 1969-present	147	3640	1.38	na	C
Otselic River near Upper Lisle (01510500)[3]	1937-69	217	4830	1.40	73.3	B3c
Tioughnioga River at Cortland (01509000)[3]	1938-present	292	3770	1.16	18.6	F4
West Branch Delaware River at Walton (01423000)[5]	1950-present	332	6640	1.33	na	C4

[1] from stage-to-discharge relation except as noted.

[2] from Rosgen (1994): B3: moderately entrenched, riffle-dominated channel with cobbles; B3c: lower gradient B3-type stream; B4: moderately entrenched, riffle-dominated channel with gravel; B4c: lower gradient B4-type stream; C: low-gradient alluvial channel; C3: low-gradient alluvial channel with cobbles; C4: low-gradient alluvial channel with gravel; C4b: steeper gradient C4-type stream; F3: low-gradient, entrenched meandering channel with cobbles; F3b: steeper gradient F3-type stream; F4: low-gradient entrenched meandering channel with gravel; F4b: steeper gradient F4-type stream.

[3] surveyed by U.S. Geological Survey.

[4] surveyed by Delaware County Soil and Water Conservation District.

[5] surveyed by New York City Department of Environmental Protection.

[6] discharge from HEC-RAS analysis.

[7] D50: median particle size; the diameter that exceeds that of 50 percent of all particles measured in the reach pebble count.

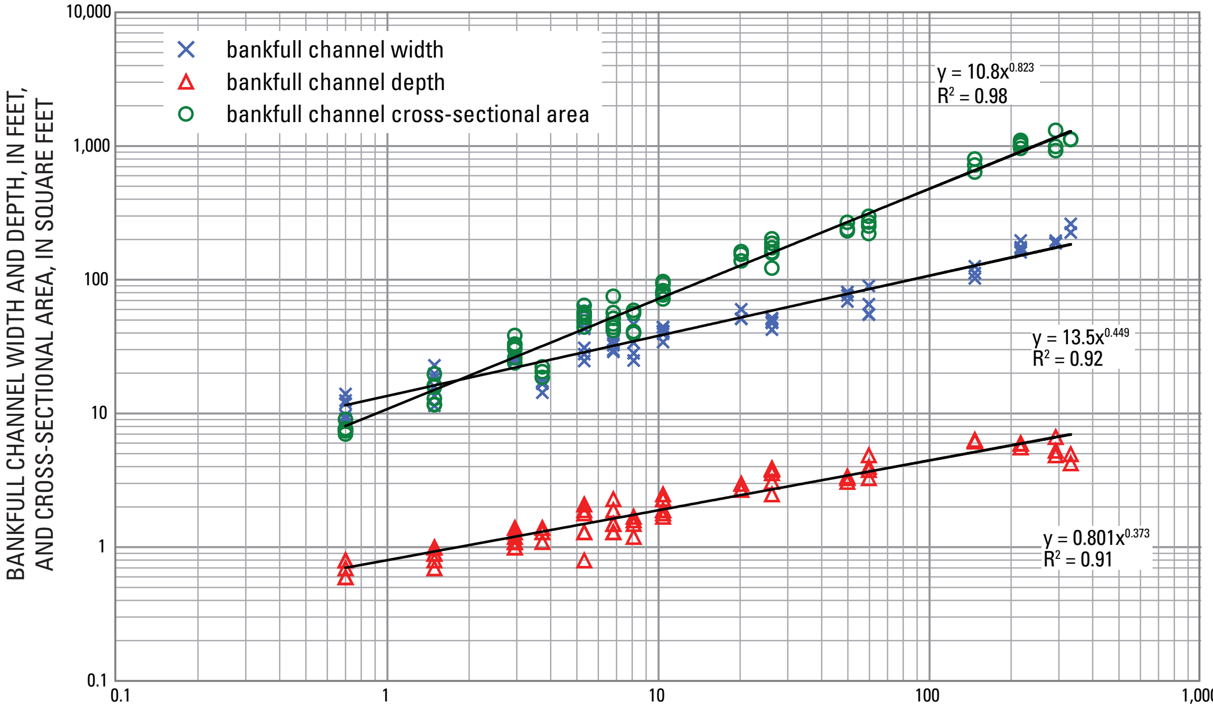

Figure 4. Graph showing bankfull channel width, depth, and cross-sectional area (*y*) as a function of drainage area size (*x*) for all streams surveyed in Region 5 in New York, with best-fit lines, regression equations, and correlation coefficient (R^2) values.

area)$^{0.856}$ =and had a correlation coefficient (R^2) of 0.96. Comparing overlap of equations developed for other regions and their 95-percent confidence intervals with those developed for streams of Region 5 can help ascertain regional differences in stream characteristics. The larger 95-percent prediction interval in the comparison defines the 95-percent probability range of bankfull discharges estimated for a single stream of a given drainage area sampled in the region.

Bankfull-Discharge Recurrence Intervals

The recurrence interval for the estimated bankfull discharge of each stream was calculated from regression equations relating measured discharges to known recurrence intervals (Lumia, 1991; written commun.). Previous investigations reported that the average recurrence interval for bankfull discharge is 1.5 years, and 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 5 ranged from 1.11 to 3.4 years (table 1). The mean bankfull-discharge recurrence interval was 1.51 years, although for most sites it was less than 1.5 years. Note that the findings for this study are not surprising, as bankfull indicators were initially identified using an anticipated 1.5-year recurrence interval. Previous investigations in nearby Regions 4 and 4a (fig. 1) 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).

Stream-Channel Dimensions in Relation to Drainage Area Size

Drainage area size was separately related to three stream-channel variables – mean bankfull channel width, depth, and cross-sectional area – through regression analysis (fig. 4). The regression equations for all sites in Region 5 were: bankfull channel width = 13.5 (drainage area)$^{0.449}$; bankfull channel depth = 0.801 (drainage area)$^{0.373}$; and bankfull channel cross-sectional area = 10.8 (drainage area)$^{0.823}$. The equations had correlation coefficients (R^2) of 0.92, 0.91, and 0.98, respectively. The high correlation coefficients (R^2) indicate that much of the variation in a given variable (width, depth, area) is explained by the drainage area.

The raw data for regional equations and corresponding 95-percent confidence and prediction intervals are given in plots of mean bankfull channel width, depth, and cross-sectional area as a function of drainage area size (fig. 5). The 95-percent confidence intervals define a range of values that has a 95-percent probability of encompassing the results for other streams within the same region. The prediction intervals predict the 95-percent probability ranges for estimates of channel dimensions for a single stream of a given drainage area in the region.

Stream and Reach Classification

The Rosgen classification system (Rosgen, 1996) categorizes streams on the basis of channel morphology

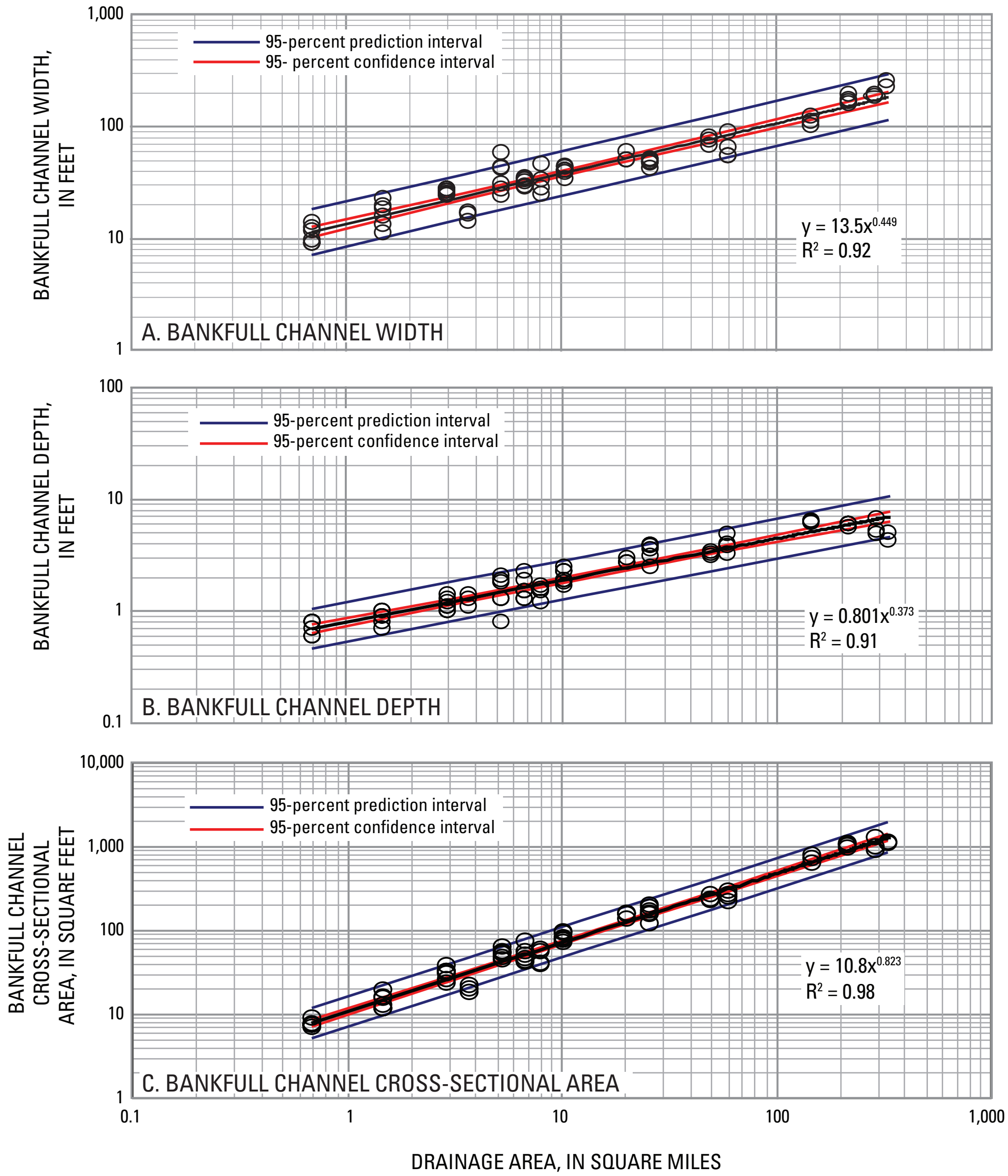

Figure 5. Graph showing mean channel dimensions as a function of drainage area size for streams in Region 5 in New York, with 95-percent prediction and confidence intervals: A. Bankfull channel width. B. Bankfull channel depth. C. Bankfull channel cross-sectional area.

to provide consistent, quantitative descriptions of stream condition (Harman and Jennings, 1999). The current study used the following criteria and measurements to classify streams; the values measured in this study are given 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

Table 2. Stream classification and bankfull channel-geometry data for cross-sections at the 16 streamflow-gaging stations surveyed in Region 5 in New York, 2001-02.

[mi^2, square miles; ft, feet; ft^2, square feet; mm, millimeters.]

Site name and station-identification number	Drainage area (mi^2)	Cross-section (XS) number and downstream stationing (ft)	Bankfull width (ft)	Bankfull depth (ft)	Bankfull cross-section area (ft^2)	Width of flood plain (ft)	Entrench-ment ratio[1]	Width-to-depth ratio	Water-surface slope	D50[2] (mm)	Sinuosity[3]	Cross-section stream type[4]
Sage Brook near South New Berlin (01501500) inactive	0.7	XS1 (4.4)	9.1	0.8	7.4	18	2.0	11.4	0.035	26.0	1.06	B4
		XS2 (27.5)	9.1	0.8	7.0	25	2.7	11.4	0.035	26.0		C4b
		XS3 (50)	14.0	0.6	7.7	na[5]	na[5]	23.3	0.035	26.0		na[5]
		XS4 (493)	11.9	0.6	7.6	42	3.5	19.8	0.035	31.4		C4b
		XS5 (512)	12.5	0.7	9.0	35	2.8	17.8	0.035	31.4		C4b
		XS6 (527)	9.7	0.8	7.5	29	3.0	12.1	0.035	31.4		C4b
Cold Spring Brook at China (01425500) inactive	1.49	XS1 (31)	11.4	1.0	11.7	22	1.9	11.4	0.020	40.0	1.16	B4
		XS2 (45)	13.5	0.9	11.6	54	4.0	15.0	0.020	40.0		C4
		XS3 (60)	15.9	0.8	12.9	33	2.1	19.9	0.020	40.0		C4
		XS4 (338)	19.8	1.0	19.7	72	3.6	19.8	0.020	34.2		C4
		XS5 (389)	18.4	0.9	15.8	22	1.2	20.4	0.020	34.2		F4b
		XS6 (443)	22.9	0.7	16.2	58	2.5	32.7	0.020	34.2		C4
Shackham Brook near Truxton (01508000) inactive	2.95	XS1 (0)	24.6	1.3	32.6	59	2.4	18.9	0.014	46.9	1.06	C4
		XS2 (32)	26.6	1.2	33.0	na[5]	na[5]	22.2	0.014	46.9		na[5]
		XS3 (61)	26.4	1.1	30.2	66	2.5	24.0	0.014	46.9		C4
		XS4 (89)	25.0	1.0	23.9	56	2.2	25.0	0.014	46.9		C4
		XS5 (237)	25.7	1.0	26.1	70	2.7	25.7	0.014	39.3		C4
		XS6 (273)	27.8	1.1	31.3	63	2.3	25.3	0.014	39.3		C4
		XS7 (326)	27.8	1.4	38.2	63	2.3	19.9	0.014	39.3		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 at each set of cross-sections.
[3] *Sinuosity*: ratio of stream length to valley length (Harman and Jennings, 1999).
[4] from Rosgen (1994): B3: moderately entrenched, riffle-dominated channel with cobbles; B3c: lower gradient B3-type stream; B4: moderately entrenched, riffle-dominated channel with gravel; B4c: lower gradient B4-type stream; C: low-gradient alluvial channel; C3: low-gradient alluvial channel with cobbles; C4: low-gradient alluvial channel with gravel; C4b: steeper gradient C4-type stream; F3: low-gradient, entrenched meandering channel with cobbles; F3b: steeper gradient F3-type stream; F4: low-gradient entrenched meandering channel with gravel; F4b: steeper gradient F4-type stream.
[5] not available.

Table 2. (Continued) Stream classification and bankfull channel-geometry data for cross-sections at the 16 streamflow-gaging stations surveyed in Region 5 in New York, 2001-02.

Site name and station-identification number	Drainage area (mi^2)	Cross-section (XS) number and downstream stationing (ft)	Bankfull width (ft)	Bankfull depth (ft)	Bankfull cross-section area (ft^2)	Width of flood plain (ft)	Entrench-ment ratio[1]	Width-to-depth ratio	Water-surface slope	D50[2] (mm)	Sinuosity[3]	Cross-section stream type[4]
Little Elk Creek at Westford (01497805) active	3.73	XS1 (LBF2)	16.7	1.1	18.6	24	1.4	15.2	0.022	57.9	1.10	F4
		XS2 (LBF4)	14.3	1.4	20.5	40	2.8	10.2	0.015	87.8		C3
		XS3 (HWM9a)	17.4	1.3	22.3	50	2.9	13.4	0.015	79.4		C3
Merrill Creek Tributary near Texas Valley (01510610) active	5.32	XS1 (24)	42.9	1.3	57.0	58	1.4	33.0	0.009	57.1	1.26	B4c
		XS2 (76)	43.7	1.3	54.8	57	1.3	33.6	0.009	57.1		B4c
		XS3 (161)	59.1	0.8	48.3	95	1.6	73.9	0.009	57.1		B4c
		XS5 (801)	24.7	1.8	44.3	42	1.7	13.7	0.015	69.4		B3c
		XS6 (840)	30.9	2.1	64.2	419	13.6	14.7	0.015	69.4		C3
		XS7 (898)	27.8	1.9	52.3	363	13.1	14.6	0.015	69.4		C3
Albright Creek at East Homer (01508500) inactive	6.81	XS1 (52)	29.8	1.9	56.7	85	2.9	15.7	0.018	62.6	1.05	C4
		XS2 (90)	33.4	2.3	75.2	146	4.4	14.5	0.018	62.6		C4
		XS3 (129)	32.3	1.3	41.7	112	3.5	24.8	0.018	62.6		C4
		XS4 (333)	35.3	1.5	51.4	56	1.6	23.5	0.005	79.5		B3c
		XS5 (356)	28.9	1.5	44.0	41	1.4	19.3	0.005	79.5		B3c
		XS6 (395)	34.8	1.3	46.7	37	1.1	26.8	0.005	79.5		F3
Dryden Brook near Granton (01423500) inactive	8.1	XS1 (67)	31.9	2.0	62.7	212	6.6	16.0	0.016	79.3	1.16	C3
		XS2 (149)	33.3	1.5	50.4	222	6.7	22.2	0.016	79.3		C3
		XS3 (238)	23.8	2.1	51.1	193	8.1	11.3	0.016	79.3		C3
		XS4 (726)	26.7	2.2	59.8	166	6.2	12.1	0.016	74.6		C3
		XS5 (763)	25.1	2.2	54.3	382	15.2	11.4	0.016	74.6		C3
		XS6 (807)	35.4	1.6	57.3	270	7.6	22.1	0.016	74.6		C3

Table 2. (Continued) Stream classification and bankfull channel-geometry data for cross-sections at the 16 streamflow-gaging stations surveyed in Region 5 in New York, 2001-02.

Site name and station-identification number	Drainage area (mi^2)	Cross-section (XS) number and downstream stationing (ft)	Bankfull width (ft)	Bankfull depth (ft)	Bankfull cross-section area (ft^2)	Width of flood plain (ft)	Entrench-ment ratio[1]	Width-to-depth ratio	Water-surface slope	D50[2] (mm)	Sinuosity[3]	Cross-section stream type[4]
Mink Creek at Richfield Springs (01496370) inactive	10.4	XS1 (110)	40.9	1.9	76.9	98	2.4	21.5	0.005	99.9	1.37	C3
		XS2 (141)	39.4	2.5	96.9	154	3.9	15.8	0.005	99.9		C3
		XS3 (171)	34.2	2.3	78.2	60	1.8	14.9	0.005	99.9		B3c
		XS4 (357)	40.9	2.3	92.7	275	6.7	17.8	0.005	99.9		C3
		XS5 (658)	41.3	1.7	71.7	295	7.1	24.3	0.002	1.7		C4
		XS6 (700)	43.9	1.9	82.7	356	8.1	23.1	0.002	1.7		C4
		XS7 (740)	44.4	1.8	80.0	308	6.9	24.7	0.002	1.7		C4
Trout Creek near Trout Creek (0142400103) active	20.2	XS1 (LBF3)	51.2	3.0	155	>500	>2.2	17.1	0.005	62.4	1.13	C4
		XS2A (LBF2a)	60.1	2.7	162	>500	>2.2	22.3	0.005	34.3		C4
		XS4	50.9	2.7	138	>500	>2.2	18.9	0.005	64.8		C4
Steele Creek at Ilion (01342730) inactive	26.2	XS1 (121)	51.7	3.9	202	930	18.0	13.3	0.011	35.2	1.19	C4
		XS2 (185)	48.1	2.5	122	256	5.3	19.2	0.011	35.2		C4
		XS3 (238)	47.6	3.9	187	495	10.4	12.2	0.011	35.2		C4
		XS4 (531)	50.6	3.1	158	468	9.2	16.3	0.011	62.6		C4
		XS5 (577)	48.5	3.6	173	347	7.2	13.5	0.011	62.6		C4
		XS6 (639)	42.4	3.8	161	257	6.1	11.2	0.011	62.6		C4
Little Delaware River near Delhi (01422500) active	49.8	XS1 (LBF5)	76.3	3.1	239	na[5]	na[5]	24.6	0.004	34.6	1.08	C4
		XS2 (LBF7)	68.7	3.4	232	na[5]	na[5]	20.2	0.004	10.7		C4
		XS4A (LBF12)[6]	80.9	3.3	268	na[5]	na[5]	24.5	0.004	16.0		C4

[6] XS4A data from pool.

Table 2. (Continued) Stream classification and bankfull channel-geometry data for cross-sections at the 16 streamflow-gaging stations surveyed in Region 5 in New York, 2001-02.

Site name and station-identification number	Drainage area (mi^2)	Cross-section (XS) number and downstream stationing (ft)	Bankfull width (ft)	Bankfull depth (ft)	Bankfull cross-section area (ft^2)	Width of flood plain (ft)	Entrench-ment ratio[1]	Width-to-depth ratio	Water-surface slope	D50[2] (mm)	Sinuosity[3]	Cross-section stream type[4]
Butternut Creek at Morris (01502000) inactive	59.7	XS1 (672)	89.9	3.3	298	1080	12.1	27.2	0.001	61.2	1.22	C4
		XS2 (784)	65.6	3.8	252	903	13.8	17.3	0.001	61.2		C4
		XS3 (852)	55.3	4.0	221	800	14.5	13.8	0.001	61.2		C4
		XS4 (980)	54.7	4.9	270	2340	42.8	11.2	0.001	61.2		C4
Otselic River at Cincinnatus [7] (01510000) active	147	XS1 (96)	112.1	6.4	720	2710	24.2	17.5	0.0006	na[5]	1.58	C
		XS2 (315)	126.0	6.3	799	na[5]	na[5]	20.0	0.0006	na[5]		na[5]
		XS3 (1042)	102.2	6.2	638	1210	11.8	16.5	0.0006	na[5]		C
Otselic River near Upper Lisle (01510500) inactive	217	XS1 (708)	160.2	6.0	958	221	1.4	26.7	0.002	58.7	1.25	B4c
		XS2 (1095)	196.7	5.6	1100	270	1.4	35.1	0.002	58.7		B4c
		XS3 (1303)	169.7	6.0	1020	322	1.9	28.3	0.002	58.7		B4c
		XS4 (1482)	175.2	6.0	1060	323	1.8	29.2	0.002	58.7		B4c
Tioughnioga River at Cortland (01509000) active	292	XS1 (521)	189.2	4.9	922	242	1.3	38.6	0.001	18.6	1.17	F4
		XS2 (751)	187.1	5.3	991	259	1.4	35.3	0.001	18.6		F4
		XS3 (891)	196.2	6.7	1310	268	1.4	29.3	0.001	18.6		F4
West Branch Delaware River at Walton (01423000) active	332	XS1 (RBF3)	261	4.3	1120	>800	>2.2	60.7	na[5]	47.0	1.38	C4
		XS2 (LBF6)	226	5.0	1130	>800	>2.2	45.2	na[5]	50.2		C4

[7]particle data unavailable for set of cross-sections.

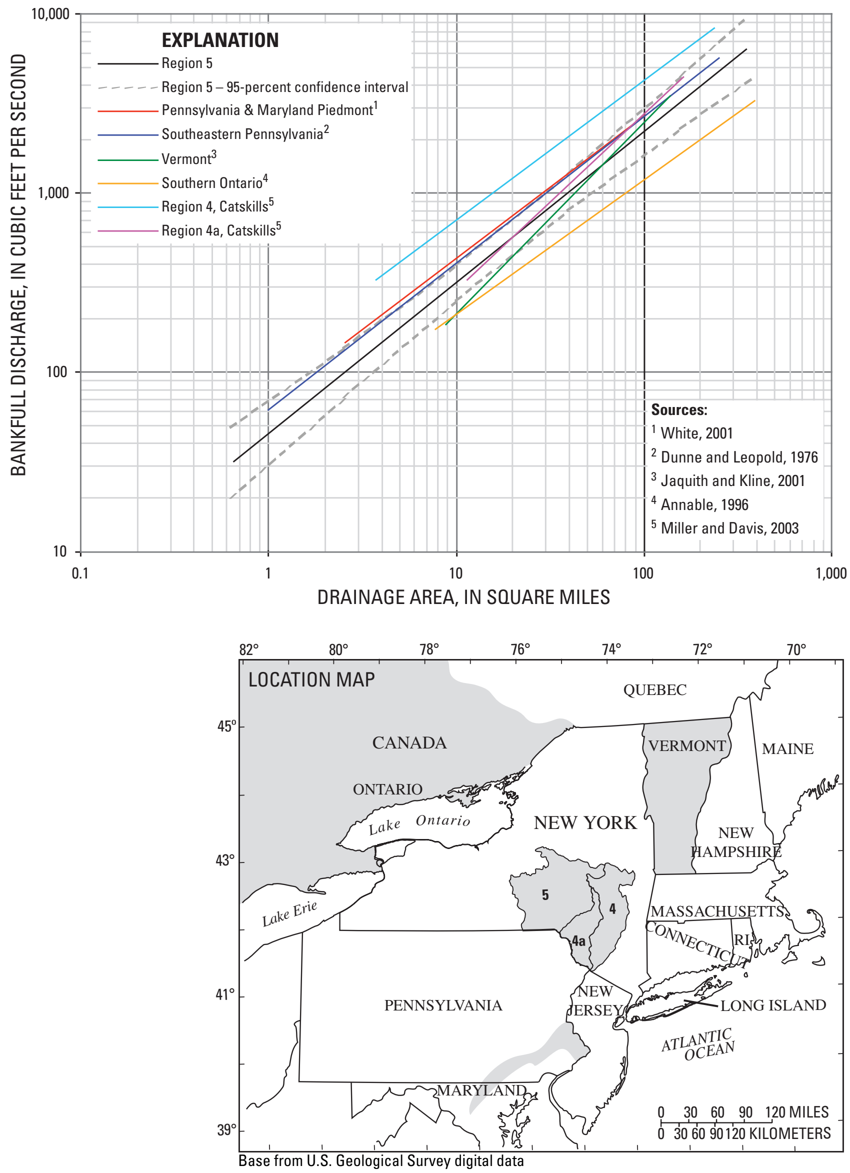

Figure 6. Graph showing bankfull discharge as a function of drainage area size for Region 5 in New York and published curves for six other regions in the Northeast.

values were obtained through a modified Wolman pebble count (Harrelson and others, 1994)

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

Each reach was classified by Rosgen stream type based on the average of stream channel metrics taken at each cross section (table 1). Each cross section was also separately classified by Rosgen stream type (table 2). Level I classification (types “A” through “G”) is based on entrenchment ratio and width-to-depth ratio, and level II classification (sub-types A1 to A6) is based on water-surface slope and median size of the bed material (Rosgen, 1996). At 6 of the 16 sites surveyed, the level I classification criteria resulted in the placement of some cross sections into different stream types within a single reach; most of these were due to the entrenchment ratios. At 5 of the 16 sites surveyed, level II classification for the reach differed from that of some of the cross sections; all of these were due to the median size of the bed material. At Merrill Creek tributary near Texas Valley, the reach was assigned to two different stream types (Bc and C) because of the large change in entrenchment ratio at the bottom of the reach.

Most of the streams surveyed were C-type reaches; the rest were types B and F (table 2). Both of the B reaches had slopes less than 0.02 and, therefore, were classified as Bc reaches (Rosgen 1998). The only F reach was at Tioughnioga River at Cortland; the streambed there was widened and flattened as a flood-control measure, but the effect on stream classification is uncertain because the years in which these alterations occurred are unknown. Three other streams – Cold Spring Brook at China, Little Elk Creek at Westford, and Albright Creek at East Homer – each had an F-type cross section, but at all three sites, the other cross sections were types B and C.

Comparison of Region 5 Equation to Those Developed for Other Areas

Six equations for the relation between bankfull discharge and drainage area size from other parts of the Northeast were compared with the Region 5 equation. The differences among these seven relations indicate a need to develop equations by region so they can be applied by water-resources managers to local planning and design efforts (fig. 6). For example, the statewide Vermont curve (Jaquith and Kline, 2001) and the New York Region 4a curve (Miller and Davis, 2003) have much steeper slopes than curves from other areas, possibly reflecting the steeper topography in these mountainous regions, which can cause greater bankfull flows than in flatter areas. The slope of the Region 5 curve is similar to that of the Pennsylvania – Maryland Piedmont relation (White, 2001); the New York Region 4 relation (Miller and Davis, 2003); the southern Ontario relation (Annable, 1996); and the southeast Pennsylvania relation (Dunne and Leopold, 1978). Only the southeastern Pennsylvania curve and the New York Region 4a curve, however, fall within the 95-percent confidence interval of Region 5. The New York Region 4 and the Pennsylvania – Maryland Piedmont curves lie above the upper bound of the 95-percent confidence interval for Region 5, although the Pennsylvania – Maryland Piedmont curve lies within the 95-percent confidence interval of Region 5 at larger drainage areas. The steeper slopes in these regions may cause larger magnitude bankfull flows than occur in comparable drainage areas in less mountainous regions. In contrast, the southern Ontario curve lies well below the lower bound of the 95-percent confidence interval for Region 5, possibly reflecting the lower mean annual precipitation, which can result in lower discharges in a given drainage basin.

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 found in other studies such as Harman and Jennings (1999) and Rosgen (1994). Channel dimensions associated with a 1- to 2-year recurrence interval were used to aid in the identification of bankfull indicators during initial site inspections, and if the bankfull recurrence interval at a site is longer or shorter than the predicted 1- to 2-year frequency, the bankfull channel may be incorrectly identified (White, 2001).

The small number of active USGS streamflow-gaging stations in Region 5 was a limiting factor in this investigation. The lack of recent data necessitated the following assumptions about inactive sites: (1) the recurrence interval of bankfull discharge had not changed since the site was last active (flood-frequency analysis was performed for active periods of each site), (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 last active, and (3) three to five low- to medium-flow discharge measurements were sufficient to define a stage-to-discharge relation that could reliably be extended to define a bankfull discharge.

Regional channel-geometry equations can be more reliable than those representing an entire state or larger area in the design of stream-restoration projects, enhancement of fish habitat, and adjustment of other in-stream and riparian structures (Castro and Jackson, 2001). Users of regional relations must recognize their limitations, however, and accept that these regression equations are designed to provide estimates of bankfull-channel dimensions and discharges only (White, 2001).

Summary and Conclusions

Equations relating the size of the drainage area to bankfull discharge and channel dimensions (width, depth, and cross-sectional area) are needed to predict bankfull discharge and channel dimensions at ungaged streams and to provide information for the design of stream-restoration projects. The USGS, with the NYSDEC, the NYSDOT, and the NYCDEP, undertook a study to develop these equations for streams in central New York (Region 5). Seven active and nine inactive sites were chosen according to set guidelines. Stream-survey data and discharge records from these sites were used in regression analyses to relate the size of the drainage area to bankfull discharge and bankfull channel width, depth, and cross-sectional area. The resulting equations were: bankfull discharge = 45.3 (drainage area)$^{0.856}$; bankfull channel width = 13.5 (drainage area)$^{0.449}$; bankfull channel depth = 0.801 (drainage area)$^{0.373}$; and bankfull channel cross-sectional area = 10.8 (drainage area)$^{0.823}$. The high correlation coefficients (R^2) for these four equations (0.96, 0.92, 0.91, 0.98, respectively) indicate that much of the variation in the variables is explained by the size of the drainage area.

Recurrence intervals were calculated for the estimated bankfull discharge of each stream, using regression equations relating measured discharges to known recurrence intervals. The recurrence intervals for bankfull discharge of surveyed streams in Region 5 ranged from 1.11 to 3.4 years, with a mean recurrence interval of 1.51 years. Streams were classified by Rosgen stream type on the basis of specific channel characteristics at each surveyed cross section. Most streams were C-type reaches, with occasional B- and F-type cross-sections in some reaches.

The Region 5 equation for the relation between bankfull discharge and size of drainage area was compared with equations developed for six other parts of the Northeast. The differences among these seven equations indicate a need to develop equations by region to improve their accuracy when they are applied to local planning and design efforts.

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References

Annable, W.K., 1996, Morphologic relationships of rural watercourses in southern Ontario and selected field methods in fluvial geomorphology: Toronto, Ontario Ministry of Natural Resources, 92 p.

Brunner, G.W., 1997, HEC-RAS River Analysis System user’s manual: U.S. Army Corps of Engineers CPD-68, 205 p.

Castro, J.M., and Jackson, P.L., 2001, Bankfull discharge recurrence intervals and regional hydraulic geometry relationships—patterns in the Pacific Northwest, USA: Journal of the American Water Resource Association, v. 37, no. 5, p. 1249-1262.

Dalrymple, Tate and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A2, 12 p.

Dunne, Thomas, and Leopold, L.B., 1978, Water in environmental planning: San Francisco, W.H. Freeman, 818 p.

Harman, W.A., and Jennings, G.D., 1999, River course—application of the Rosgen stream classification system to North Carolina: Raleigh, NC, North Carolina Cooperative extension service, (http://www.bae.ncsu.edu/programs/extension/wqg/sri/rv-crs2.pdf), accessed October 5, 2002.

Harrelson, C.C., Rawlins, C.L., and Potyondy, J.P., 1994, Stream channel reference sites: an illustrated guide to field technique: Ft. Collins, CO, U.S. Forest Service Rocky Mountain Research Station, General Technical Report RM-245, 61 p.

Jaquith, Shayne, and Kline, Michael, 2001, Vermont regional hydraulic geometry curves: Waterbury, VT, Vermont Water Quality Division, (http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_hydraulicgeocurves.pdf), accessed March 6, 2003.

Jarrett, R.D., and Petsch, H.E., 1985, Computer program NCALC user’s manual—verification of Manning’s Roughness Coefficient in channels: U.S. Geological Survey Water-Resources Investigations Report 85-4317, 27 p.

Kennedy, E.J., 1984, Discharge ratings at gaging stations: U.S. Geological Survey, Techniques of Water-Resource Investigations, Book 3, Chapter A10, 59 p.

Leopold, L.B., 1994, A view of the river: Cambridge, MA, Harvard University Press, 298 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, W.H. Freeman, 522 p.

Lumia, Richard, 1991, Regionalization of flood discharges for rural, unregulated streams in New York, excluding Long Island: U.S. Geological Survey Water-Resources Investigations Report 90-4197, 119 p.

Miller, S.J., and Davis, Daniel, 2003, Identifying and optimizing regional relationships for bankfull discharge and hydraulic geometry at USGS stream gage sites in the Catskill Mountains, NY: New York City Department of Environmental Protection Technical Report, 24 p.

Powell, R.O., Miller, S.J., Westergard, B.E., Mulvihill, C.I., Baldigo, B.P., Gallagher, A.S., and Starr, R.R., 2003, Guidelines for surveying bankfull-discharge geometry and developing regional hydraulic-geometry models for streams of New York State: U.S. Geological Survey Open-File Report 03-92, 26 p.

Rosgen, D.L., 1994, A classification of natural rivers: Catena, v. 22, no. 3, p. 169-199.

Rosgen, D.L., 1996, Applied river morphology: Pagosa Springs, CO, Wildland Hydrology, 388 p.

Thorne, C.R., Hey, R.D., and Newson, M.D., 1997, Applied fluvial geomorphology for river engineering and management: Chichester, England, John Wiley, 376 p.

White, K.E., 2001, Regional curve development and selection of a reference reach in the non-urban lowland sections of the Piedmont Physiographic Province, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigations Report 01-4146, 20 p.