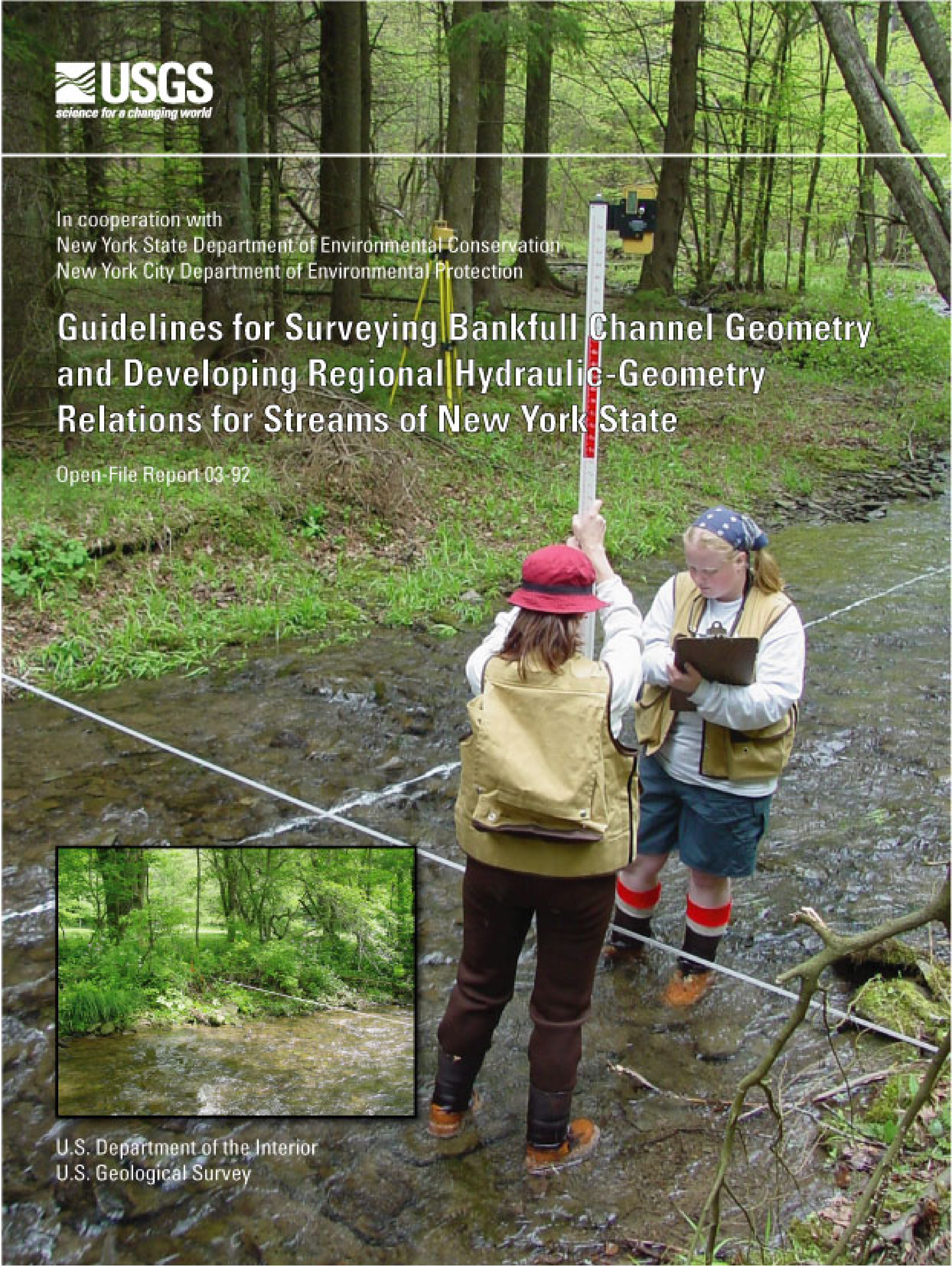

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In cooperation with
New York State Department of Environmental Conservation
New York City Department of Environmental Protection

Guidelines for Surveying Bankfull Channel Geometry and Developing Regional Hydraulic-Geometry Relations for Streams of New York State

Open-File Report 03-92

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

Cover. Surveying stream-bed elevations at a cross section in Cold Spring Brook, Town of China, Delaware County, New York
Photo by Barry P. Baldigo, USGS

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U.S. GEOLOGICAL SURVEY

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Troy, New York
2004

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.40483	hectare
square mile (mi^2)	2.59	square kilometer
	Flow	
cubic foot per second	0.02832	cubic meter per second (m^3/s)
	Velocity	
foot per second	0.3048	meter per second

Sea level: In this report "sea level" refers to the North American Vertical Datum of 1988 (NAVD88)

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ABSTRACT

Many disturbed streams within New York State are being restored in an effort to provide bank and bed stability and thereby decrease sedimentation and erosion. Efforts to identify and provide accurate indicators for stable-channel characteristics for ungaged streams have been hampered by the lack of regional equations or relations that relate drainage area to bankfull discharge and to channel depth, width, and cross-sectional area (bankfull hydraulic-geometry relations). Regional equations are needed to confirm bankfull hydraulic-geometry, assess stream stability, evaluate restoration needs, and verify restoration design for ungaged streams that lack stage-to-discharge ratings or historic peak-flow records.

This report presents guidelines for surveying bankfull channel geometry at USGS stream gages and developing regional hydraulic-geometry relations (equations) for wadeable streams in New York. It summarizes methods to (1) compile and assess existing hydrologic, geometric, photographic, and topographic data, (2) conduct stream-reconnaissance inspections, (3) identify channel-bankfull characteristics, (4) conduct longitudinal and cross-section surveys, (5) measure stream discharge, (6) develop and refine bankfull hydraulic-geometry equations, and (7) analyze and assure data completeness and quality. The techniques primarily address wadeable streams with either active or discontinued surface-water- and crest-stage gages. The relations can be applied to ungaged or actively gaged streams that are wadeable, and may be extended to non-wadeable streams (with some limitations) if they have drainage areas comparable to those used to develop the relations.

1. INTRODUCTION

Many disturbed stream channels throughout New York State are being restored in an effort to provide bank and bed stability and thereby decrease unusually high rates of erosion and sedimentation. Stream restorations have traditionally relied on straightening, widening, deepening, and hardening banks and channels, and imposing static stream geometry, to control erosion and protect private and public lands and related infrastructure. Recent restoration projects, in contrast, have begun to use a natural-channel approach that is based on models or equations that (1) relate hydraulic-geometry measurements, such as the channel's cross-sectional area, depth, and width at bankfull stage, to drainage-basin size in stable gaged streams, and (2) relate geomorphic characteristics such as channel dimensions, patterns, and profiles in unstable reaches to those in stable, undisturbed reaches. These relations are useful in confirming

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restoration designs that attempt to replicate geomorphically stable and nearly natural or functional ecosystems at unstable reaches in ungaged streams.

1.1 Need for Predictive Equations

Restoration designs commonly use hydraulic-geometry equations that are several decades old, based on a small number of localized streams, and ascribed to widespread regions, such as the equations for the eastern United States (Dunne and Leopold, 1978). The accuracy of hydraulic geometry predicted from these equations can be compromised because characteristics of individual streams typically reflect unique and localized conditions, such as precipitation, soils, and physiography, that also change through time. Therefore, hydraulic-geometry equations that do not reflect these local or regional conditions may be biased, and restoration designs based on these equations could be biased and ultimately result in project failure.

Efforts to predict, verify, and design stable-channel characteristics for ungaged streams of New York have been hampered by the lack of regional equations that define the relations between drainage-area size and (1) bankfull discharge, and (2) hydraulic-geometry variables such as mean depth, width, and cross-sectional area at bankfull discharge. These hydraulic-geometry relations are relatively constant at bankfull stage in stable streams of a given type and within a given hydrophysiographic region (Rosgen, 1996). Differences in precipitation and runoff rates, soil depth, elevation, surficial geology, and basin slopes typically produce different discharge hydrographs and channel geometry in streams from different hydrophysiographic regions (Lumia, 1991). Eight hydrologic regions have been established in New York to predict floodflows of unregulated streams (Lumia, 1991); their boundaries were used in this study and will be checked and redefined for bankfull flows after the completion of stream surveys across New York, excluding Long Island. Variability in predictive hydraulic-geometry equations can be further decreased through stratification of the relations by stream type within, and sometimes across, hydrophysiographic regions (Rosgen, 1996). Thus, regional hydraulic-geometry equations that use bankfull data from streams of a single Rosgen type (explained below) can improve the accuracy of predictive equations, but they are only applicable to streams of the same type. A statewide assessment of hydraulic-geometry relations, stratified by stream type (across regions), will be done after bankfull geometry surveys in target streams and reports from all regions of New York are completed.

1.2 Bankfull Discharge and Rosgen Stream Classification

Bankfull discharge is the flow that is most effective in transporting a stream’s bedload and corresponds to the instantaneous peak flow that occurs every 1 to 2 years or about every 1.5 years over the long term (Leopold, 1994). It may also be defined as the stage or flow at which a stream is about to overtop its bank onto the flood plain (Leopold and others, 1964; Leopold, 1994). Bankfull discharge represents a distinct and identifiable stage in many undisturbed streams and is considered to be the morphologic transition between the active stream channel and the flood plain (Leopold and others, 1964).

Rosgen’s stream-classification system, like many others, is intended to provide consistent, reproducible stream descriptions for evaluation of channel stability and (or) to calculate and design stable hydraulic conditions in ungaged streams. Several channel-geomorphology characteristics that correspond to bankfull stage are key indicators for Rosgen’s stream classification because they have relatively constant relations with drainage area in stable streams of a given hydrophysiographic region (Rosgen, 1994a, 1996). These indicators include the entrenchment ratio (width of flood-prone channel / width of bankfull channel), bankfull-channel width to depth ratio, streambed slope, channel sinuosity, and bed material (Rosgen, 1996). The system consists of 8 major stream types based mainly on the 4 bankfull channel-geometry characteristics, which are each further segregated into 3-to-6 subcategories based on the median bed material size (Rosgen, 1994a, 1996).

1.3 Approach

In 2001, the U.S. Geological Survey, in cooperation with the New York State Department of Environmental Conservation (NYSDEC), began a 5-year study to develop hydraulic-geometry relations for streams in each of the hydrophysiographic regions in New York (excluding Long Island). The study addresses wadeable streams of New York that are actively gaged, or have been gaged in the past, within 8 hydrophysiographic regions (fig. 1). These regions correspond to the flood regions of Lumia (1991).

The relations (equations) can be used to assess stream-channel stability, evaluate bank-restoration needs, and verify independent restoration designs at ungaged streams. The data may eventually be used to test whether streams in differing regions of New York show unique relations between drainage-area size and bankfull hydraulic-geometry characteristics and whether Rosgen stream types (Rosgen, 1996) can be used to stratify reach relations across regions accurately. Individual hydraulic-geometry equations for regions of New York can also be compared to hydraulic-geometry equations for the eastern United States developed by Dunne and Leopold (1978) and for adjacent regions, such as Pennsylvania (White, 2001), Vermont (Jaquith and Kline, 2001), and Ontario, Canada (Annable, 1996) to assess the underlying basis for any observed differences.

1.4 Purpose and Scope

This report presents guidelines for surveying bankfull-discharge channel geometry of wadeable streams in New York, and for developing regional hydraulic-geometry equations. It includes methods to (1) compile and assess existing hydrologic, geometric, photographic, and topographic data, (2) conduct stream-reconnaissance inspections, (3) identify channel-bankfull characteristics, (4) conduct longitudinal and cross-section surveys, (5) measure stream discharge, (6) develop and refine bankfull hydraulic-geometry equations, and (7) analyze and assure data completeness and quality. These guidelines are based primarily on the New York City Department of Environmental Protection (NYCDEP) protocol (Miller and Powell, 1999) and integrate standard

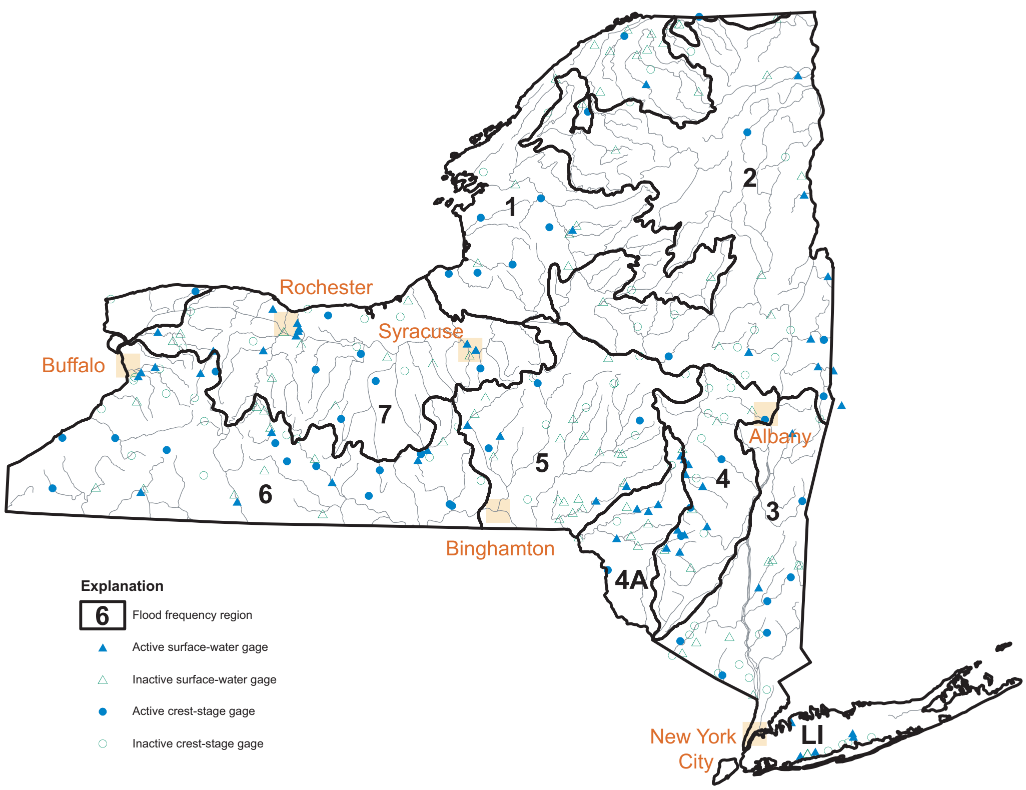

Figure 1. Hydrologic flood regions as defined by Lumia (1991) and active and inactive USGS stage-discharge gages for streams with more than 10 years of flow record in New York State.

USGS surveying methods (U.S. Geological Survey, 1966; Benson and Dalrymple, 1967; Dalrymple and Benson, 1967) with those developed by Rosgen, (1994b, 1996). These methods were used by NYCDEP to develop hydraulic-geometry equations that apply to streams in the Catskill Mountain Region in southeastern New York (Miller and Davis, in press). Several regions of New York have few active gages with 10 or more years of record; therefore, this report includes techniques used to develop regional equations for streams with discontinued surface-water and crest-stage gages as well as actively gaged streams.

1.5 Acknowledgments

Thanks are extended to Daniel Davis, Phillip Eskeli, Mark Vian, and Elizabeth Reichheld of the New York City Department of Environmental Protection; William VanDeValk and Scotty Gladstone of the Delaware County Soil and Water Conservation District; and Rene VanSchaack, Douglas Dekoskie, Joel Dubois, and Jake Buchanan of the Greene County Soil and Water Conservation District for training on survey techniques, use of survey data from several gages, and advice on data handling, analysis, interpretation, and presentation methods.

2. GUIDELINES FOR SURVEYING BANKFULL CHANNEL GEOMETRY AND DEVELOPING REGIONAL HYDRAULIC-GEOMETRY RELATIONS

These guidelines are presented in the following sections: preliminary procedures, field procedures, data-quality assurance and analysis, and administrative procedures.

2.1 Preliminary Procedures

Preliminary procedures consist of the collection of all information needed before field studies begin. These steps include selection of study sites, and assembling site data and tax map information.

2.1.1 Select study sites:

a. Select a range of active and discontinued stream gages that represent:
   - a single hydrophysiographic region,
   - a wide range of drainage-areas, and
   - major land-use categories (urban, suburban, or rural).

b. For each selected gage, ascertain that:
   - it has at least 10 years of record (minimum number of years statistically required for Log-Pearson Type III flood-frequency analysis),
   - its stage-to-discharge rating curve has been verified recently or still can be verified, and
   - the reach meets minimum requirements for slope-area calculation of discharge (Dalrymple and Benson, 1967), so that surveyed data can reliably be used in hydraulic analysis and calculation of bankfull discharge.

2.1.2 Obtain all necessary data from the agency monitoring the gage:

a. the most recent rating table (stage-to-discharge relation),
b. 9-207 Forms (streamflow-measurement summaries) that correspond to the most recent rating table and include moderate and high flows,
c. drainage area and land uses upstream of the study site (urban, suburban, or rural),
d. a recent Log-Pearson Type III flood-frequency analysis. If a Log-Pearson Type III flood-frequency analysis is unavailable, obtain a list of annual flood peaks (instantaneous maximum discharge Q), and conduct a Log-Pearson analysis following guidelines from the Interagency Advisory Committee on Water Data (1982), and
e. the gage description, including a road log and map, flood history, and the location and elevation of reference marks and reference points.

2.1.3 Obtain tax-map information on stream in vicinity of gage:

Estimate the approximate length of reach needed. If owners are not apparent, determine how much of the tax map information will be necessary. Notify all landowners with stream frontage on their property of the intended survey and leave a number they can call for further information. Obtain verbal or written permission as needed.

2.2 Field Procedures

Field procedures are essential to the study. They consist of a field reconnaissance and preliminary survey, detailed surveys of a longitudinal profile and at least one set of three cross sections, a discharge measurement taken at the same time as the survey is conducted, and an update of the stage-to-discharge rating at discontinued gages.

A field file for each study reach should be available that contains copies of the information stored within the master file. This information can be borrowed for use in the field.

Field-data-collection sheets and data-plotting spreadsheets should be standardized and have standard key words.

As the data are collected, the record keeper should continually verify that the measured values are consistent with the observed field conditions. All survey data should be plotted in the field to verify recording and measurement accuracy. Survey closure error larger than that allowable (Section 2.2.2, Step a) must result in a re-survey.

A field-data-collection checklist and a set of standard field-data-collection forms should be available to ensure that field personnel have completed the necessary tasks before leaving the site.

2.2.1 Conduct a field reconnaissance and a preliminary survey of the gage site:

See Field Form 1: Site Inspection and Field Form 2: Site Map in Appendix A. The same one or two people should conduct preliminary surveys for all sites to ensure consistency of methods and results.

a. Evaluate the gaged site for suitability for development of regional curve equations. Check the condition of the gage. If it is active, note whether the control is stable. If it has been discontinued, note whether reference marks and reference points are intact and whether elevations are recoverable. Identify the location of the gage intake. If possible, enter the gage house and compare the stage inside with the stage on the outside staff plate or wire weight. Note any channel alterations and previous survey markers. If the station is at or near a bridge or culvert, note whether backwater occurs at bankfull discharge. Evaluate the general stability of the channel and note whether an adequate length of single-thread channel (20 to 30 bankfull widths in length) is available for the survey. If the site is found to be suitable, proceed with the preliminary survey as noted below.

b. Select and mark the limits of the reach to be surveyed (upstream and downstream of the gage). The reach should include at least two meander wavelengths or a length equivalent to at least 20 bankfull widths, whichever is greater. The survey should start and end on the same type of feature boundary. Visually check for a change in stream type within the survey reach, especially at or near the gage. If stream type changes, the reach should extend far enough to allow identification of the type of each section of channel, and of the bankfull indicators in the stream type represented by the gage location.

c. Select and mark bankfull indicators with flagging tape and (or) stick flags along both banks of the reach; use similar morphological features to establish the estimated bankfull stage. Bankfull indicators include: (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 no trees to trees), (4) textural change in depositional sediment, and (5) elevation below which no fine debris (needles, leaves, cones, seeds) occurs (Castro and Jackson, 2001). Flag only those indicators that are clearest – do not struggle to find an indicator at a specific interval or at each break in stream features (top or bottom of pool, etc.) if no clear mark is present.

d. Measure the differences in elevation between clear bankfull indicators and the water surface close to the gage. Add the difference between water surface and bankfull indicators to the stage to obtain the approximate bankfull stage. This stage will be used in Section 2.3.7 to estimate the bankfull discharge from the stage-to-discharge rating table and the corresponding flood frequency from the Log-Pearson flood-frequency analysis.

e. If (1) the differences between surveyed bankfull-indicator and water surface elevations vary by more than a few tenths of a foot within the reach, (2) the channel widths vary greatly, or (3) the indicators are sparse or unclear, measure at least one test cross-sectional area (Field Form 2, Appendix A) and compare the value to the area for flows with a 1.1- to 3.0-year recurrence interval (Form 9-207). Follow steps outlined in Section 2.2.2, Step b for cross section measurement. Evaluate the height of the indicator and the cross-sectional area in relation to the estimated bankfull discharge, velocity, local channel roughness and slope, and any changes in morphology (such as channel width) that may account for an unusually high or low bankfull stage at a particular location. The height of the bankfull indicators above the current water surface may vary considerably throughout the reach and should be evaluated at each site in relation to local conditions. Always base bankfull elevation on physical indicators, not an estimated height above the current water surface.

f. Record the number and location of each bankfull flag. Each flag should be numbered and indexed on Field Form 2 (Appendix A) to indicate what feature the flag represents. Record each flagged location on the site map, Field Form 2 (Appendix A), and note what type of indicator was used to mark the location (such as breaks in slope or changes in sediment or vegetation), the difference in elevation between the indicator and the water surface, and any test cross sections or calculations used to identify the point.

g. Identify and flag locations for the cross-section surveys. Select areas at crossovers or riffles that are representative of the reach. Avoid areas that are unstable, affected by debris jams or other channel obstructions, wider than the rest of the channel, or extremely asymmetrical in cross section. Avoid areas where the plan form or profile changes abruptly. If a cableway or other identifiable discharge-measurement location is present, mark this location to be surveyed for comparisons with data on Form 9-207. All cross sections should begin and end above the estimated flood-prone level (flood-prone area elevation = bankfull elevation + maximum bankfull depth).

- For active gages, survey at least two cross sections in riffles and optionally one where moderate to high flows and stages are recorded or discharge measurements are made.
- For discontinued gages, survey one or two sets (depending on available length of suitable reach) of three cross sections in one or two riffles and optionally one cross section where moderate to high flows and stages were recorded or where discharge measurements were made.
- If using the computer program HEC-RAS (discussed in detail later), contiguous cross-sections should be 1-2 bankfull widths apart and cover a drop of at least 1 ft. in elevation.

2.2.2 Survey longitudinal profile and all cross sections in reach:

Follow general guidelines outlined by the U.S. Forest Service (Harrelson and others, 1994) using steps outlined below. The cross sections may be surveyed as part of the longitudinal-profile survey or independently; however, elevations for each cross-section survey need to be associated with local elevations measured during the longitudinal-profile survey described below.

a. Conduct a longitudinal-profile survey using the standardized longitudinal-profile Field Form 3 (Appendix A). All blanks on each sheet must be filled in to ensure that all data have been collected. Any spaces that are left blank should be marked with a dash to show that the omission was intentional. All abbreviated terms must be identified, and any reference to features must be labeled clearly and consistently on all pages of notes and from survey to survey. All reference points, rebar monuments, reference marks, or other features used to mark location and elevation must be described in detail to ensure that they are recoverable and that surveys are repeatable.

- Always begin the survey with a backsight to an assumed or known elevation (such as a reference mark or reference point) that is clearly described in the field notes. The survey reach must start and end at the same type of feature boundary to ensure accurate slope estimates for reach classification.
- Survey the longitudinal profile by marking station positions along the thalweg from the top to the bottom of the reach and shooting elevations of thalweg, water surface, and bankfull (top of bank is optional) at each flagged bankfull indicator. Add stations between flags to include the following key features, noting the station and elevation of each: gage-staff plate and intake pipe; cross-section rebar monuments on both banks; thalweg and water surface at top and bottom of riffles, pools, and steps; and deepest part of each pool.

  For each survey point, describe what is being surveyed, and clearly label all reference marks or turning points to distinguish them. Label all monuments by number, location, station, and bank, and copy all notations on flags to the survey notes.
- For field quality assurance/quality control (QA/QC), survey a reference mark at the gage, then

survey turning points up to the top of the reach. Conduct the complete survey from the top of the reach past the gage to the bottom, then survey turning points back to the starting reference mark to close the survey. The resurveyed USGS reference mark elevation and turning points must be within an allowable error, otherwise the survey must be repeated. The allowable error E is calculated from the following equation:

$$E = 0.007\,(TSD/100)^{1/2} \tag{1}$$

where *TSD* is the total survey distance, in feet. Survey closure error larger than that allowable (E) must result in a resurvey.

- Plot field data as they are collected and continually compare these data with the observed site condition to ensure accuracy. All survey calculations should use actual elevations. Calculate elevations as the measurements are taken, or at least before the end of the day. Pay special attention to variations in the difference between water surface and bankfull elevation to ensure that the measured bankfull elevations throughout the longitudinal profile are consistent or explainable.

b. Conduct a survey of each cross section using the standardized cross-section Field Form 4 (Appendix A). All spaces on each sheet must be filled in to ensure that all data have been collected. Any spaces that are left blank should be marked with a dash to show that the omission was intentional.

- If possible, conduct one cross-section survey at the location of current or historic USGS discharge measurements.
- For each cross-section, record the longitudinal-profile station number of the transect. Tie each cross-section survey into a reference mark or reference point surveyed in the longitudinal profile, and clearly identify the location.
- Each cross section surveyed must include the entire channel (bank to bank) and the adjacent flood plain and terraces on both sides of the channel up to and including the top of the bank. Include the width of the flood-prone area (flood-prone area elevation = bankfull elevation + maximum bankfull depth) in the cross-section survey so that the channel can be classified by the entrenchment ratio (the ratio of the width of the flood-prone area to the width of the bankfull channel) (Rosgen, 1998). Measure elevations and stationing of rebar monuments outside the active channel range.
- Verify that the two to six surveyed cross sections are representative of the overall reach that will be used to classify the reach by Rosgen stream type (Rosgen, 1994a, 1996, 1998).
- While the data are being recorded, the note taker should continually compare the measured data with the observed site condition to ensure accuracy, plot field data as they are collected, and watch for errors in recording or measurements.
- Photograph cross sections. Stretch a tape across the cross section(s) at or above bankfull elevation before taking pictures. Photograph the left and right banks and include upstream or downstream views through each cross section, or through each set of cross sections.

c. Calculate the particle-size distribution of the bed material by conducting a pebble count at each cross section or set of cross sections, and over the entire reach, using a standardized pebble-count Field Form 5 (Appendix A).

- Conduct the pebble counts according to the Modified Wolman Pebble Count procedure (Harrelson and others, 1994). Record the measurement (not the size class) of each pebble on the data sheet. All blanks on each sheet must be filled in to ensure that all data have been collected; mark with a dash any spaces in the survey notes that are left blank to show that the omission was intentional. In all pebble counts, distinguish bank particles from bed (active-channel) particles by an asterisk in the field notes so that analyses of materials in the active channel and in the bankfull channel can be done separately.
- For the reach pebble count, include at least 100 particles from the bed material collected from all bed features (riffles and pools) either (1) in proportion to the percentage of the total reach represented by each type of feature (Rosgen, 1996), or (2) from at least 10 cross sections uniformly spaced throughout the study reach.
- For the cross-section pebble count, include at least 100 particles in bed material of the riffle and (or) run where each cross section, or each set of three cross sections, is surveyed.

d. Draw a detailed sketch of the gaged study reach on a standardized site-map field sheet (Field Form 2, Appendix A) and follow general guidelines (Harrelson and others, 1994). Include:

- the boundaries of the study reach, including top- and bottom-of-reach markers,
- locations of the cross sections,
- locations of the bankfull flags,
- locations of the gage house, staff plate, intake pipe, and benchmarks,
- stream features (pools, riffles, bars, bedrock, high vertical banks, flood plains, terraces, vegetation),
- manmade features (dams, utilities, bridges, culverts, rip-rap),
- locations of photographed areas, and
- a map scale and clearly defined explanation of map symbols.

If the stream is large enough to be clearly visible on 1-meter-resolution aerial photographs, note the above features on a field copy of the aerial photograph in addition to the site map.

e. Photograph the reach, using as many frames as necessary to include the gage house, bankfull indicators, locations of cross sections, and any other key features.

2.2.3 Measure stream discharge during the survey of channel cross sections:

a. Record stream stage and estimate discharge at active gages from the most current stage-to-discharge rating table.

b. Measure discharge at discontinued gages in accordance with standard USGS procedures (Rantz, 1983).

2.2.4 Update the stage-to-discharge rating for discontinued gages (if present):

If discontinued (inactive) gages are to be used in regional or localized equations, obtain a copy of the gage's most recent stage-to-discharge rating curve from the USGS. Measure a range of discharges and plot the measurements on the old rating curve. Update the old stage-to-discharge rating curve, or calculate a new stage-discharge relation at the discontinued gage through standard USGS procedures (Rantz, 1983). High flows are difficult to measure with limited resources and time; therefore, stage and discharge at or near bankfull conditions will often need to be extrapolated manually or through USGS software that extends ratings beyond measured data.

2.3 Data-Quality Assurance and Analysis

Data-quality assurance and analysis entails checking field data for accuracy as well as analyzing of field data. These steps include quality assurance and quality control (QA/QC), plotting the longitudinal profile and cross sections, calculating particle D50 and D84 values (explained below), documenting reach meander geometry, and validating the bankfull estimate.

2.3.1 Check for Quality Assurance and Quality Control (QA/QC):

Once data have been collected and checked in the field, they should be further reviewed in the office to ensure that all required information was collected and is correct and done in accordance with the field protocol. This check should be done with a standardized QA/QC checklist (Appendix B). Any discrepancies, errors, or omissions should be corrected by the reviewer alone or in consultation with the leader of the survey team as needed, and so noted on the form. All changes should be initialed and dated. For legal purposes, cross out all mistakes in observed data with one line, and never erase. All mistakes in computed data should be erased and corrected. Any further discrepancies should be resolved through a field visit to verify accuracy of data.

2.3.2 Plot elevations of the longitudinal profile:

a. Enter the field data into a standardized longitudinal profile spreadsheet (Reference Reach Spreadsheet, Version 2.2L, D. Mecklenberg, Ohio Department of Natural Resources) and plot the longitudinal profile. Identify and label the thalweg, water surface, bankfull level(s), and top of bank. The bankfull line should be an average or visually "smoothed" line through the points, not a linear regression line or a best-fit straight line. Calculate the average bankfull slope of the reach from the top point to the bottom point (within one stream type) for stream-classification purposes.

b. Examine the profile to identify inconsistencies between the observed and the expected elevations. Note whether thalweg, water surface, and bankfull elevations vary with changes in bed features. For example, the water-surface profile should steepen in riffles and flatten in pools. Inconsistencies can be attributed to changes in channel features (debris or channel obstructions or changes in plan form or bed profile); check the data to decide whether a discrepancy results from the field notes or data entry, or reflects natural conditions. If the raw field data are corrected, only one person should be authorized to make the change. This person should be designated before the project begins.

c. Once the profile has been deemed correct, locate the bankfull profile where it intersects the gage staff plate. Calculate the elevation of the bankfull stage at the staff plate to establish the gage height associated with the bankfull stage. The profile in the vicinity of the gage is the section of greatest interest; if the bankfull indicators in this area are clear, they should take precedence over the calculated bankfull line.

d. Use the bankfull gage height to read the corresponding discharge from the current rating table for the gage.

e. Obtain the corresponding probability of exceedance and recurrence interval for this discharge from the Log Pearson Type III flood frequency analysis.

f. Calculate the slope of the riffle or run where each cross section (or set of cross-sections) was surveyed. This information will be used to develop bankfull discharge estimates for cross checking the discharge estimate developed from the gage data.

g. Calculate the water-surface slope of the entire reach for use in classifying the reach by Rosgen stream type.

2.3.3 Plot all cross sections:

a. Enter the data into a standardized cross-section spreadsheet and plot the cross sections. Identify and label each cross section on the profile and label water-surface, bankfull, and flood-prone elevations.

b. For each cross section, calculate the bankfull width, depth (mean and maximum), width-to-depth ratio, cross-sectional area, wetted perimeter, hydraulic radius (cross sectional area divided by wetted perimeter), width of the flood-prone area, and entrenchment ratio (Rosgen, 1998). These values are used to develop hydraulic-geometry relations and to classify the stream according to Rosgen stream type.

c. If inconsistencies are noted, indicate whether they can be attributed to changes in channel features (debris or channel obstructions or changes in plan form or bed profile) or are a result of error in the field notes or the data entry. If the raw field data warrant change, only one person (as designated in Section 2.3.2, Step b) should be authorized to make the change.

2.3.4 Calculate particle D50 and D84:

The D50 is the particle size that exceeds 50 percent of the sampled particles and is excluded by the other 50 percent (Rosgen, 1996). Likewise, the D84 is the particle size that exceeds 84 percent of the sampled particles (Rosgen, 1996).

a. Reach D50: Enter the pebble-count data from the reach-wide pebble count and plot the particle-size distribution of the bed material onto a standardized pebble-count spreadsheet (Rosgen, 1998). Use the cumulative frequency curve to calculate the D50 for the bed material in the reach. This information will help classify the reach by Rosgen stream type.

b. Cross section D84: Enter the pebble-count data from the riffle pebble counts at cross-section locations and plot the particle-size distribution of the bed material. Use the cumulative frequency curve to calculate the D84 of the bed material for the riffles and runs. This information will be used to evaluate bankfull discharge estimates.

2.3.5 Document reach-meander geometry from recent aerial photographs:

Use aerial photographs to calculate the sinuosity and, if needed, the meander wavelength and radius of curvature, for the gaged reach according to accepted methods (Rosgen, 1996). The sinuosity will be used to classify the reach by Rosgen stream type.

2.3.6 Finalize field data:

At this point, any outstanding discrepancies in the data should be resolved and any missing data collected, through another field visit.

2.3.7 Obtain estimates of bankfull discharge following several different methods, and compare these estimates:

a. Compare the field survey cross-sectional area to the cross-sectional areas for discharge measurements listed on USGS 9-207 forms. The 9-207 forms include actual discharge measurements made over a range of flows, as well as the gage height, cross-sectional area, and width associated with each discharge. If cross-sectional areas are listed in the 9-207s that are comparable to the field survey cross-sectional areas, note the associated discharge. This discharge can be compared with other bankfull discharge estimates.

b. Calculate the regional 2-year return interval discharge. The USGS has developed regional regression equations for estimating peak discharges that have recurrence intervals of 2 to 500 years (Lumia, 1991). This information can be used to provide rough estimates of the bankfull discharge (Q2, that discharge with an average 2-year recurrence interval) as well as for larger stormflows expected to occur along the flood-prone area (e.g., Q50). New York State (excluding Long Island) is divided into eight hydrophysiographic regions, and unique regression equations have been developed for each of the regions (Lumia, 1991).

Using the correct regression equation, calculate Q2 and compare this estimate to the discharge that corresponds to the 2-year recurrence interval (50 percent probability of exceedance) from the Log Pearson Type III flood-frequency analysis (Section 2.1.2, Step d).

c. Calculate the bankfull discharge through the cross sections using the following equation:

$$Q = \frac{1.486*A*R^{2/3}*S^{1/2}}{n} \qquad (2)$$

where Q = bankfull discharge, in cubic feet per second

A = bankfull cross-sectional area, in square feet

R = bankfull hydraulic radius, in feet

S = slope of riffle or run through cross section, in feet per foot

n = Manning's roughness coefficient

Calculate n (roughness coefficient) for the above equation using one or both of the following two methods.

- Hydraulic computations involving flow in open channels require an evaluation of the roughness characteristics of the channel (Coon, 1998; Jarrett and Petsch, 1985). The selection of roughness characteristics is subjective; therefore, a computer program for determining values of n has been written, called NCALC (Jarrett and Petsch, 1985).

  At discontinued gages only, enter the geomorphology data from each set of three cross sections and the discharge at the time of the survey into the USGS NCALC program to estimate n.

- At both active and discontinued gages, use the cross-section particle sizes to calculate the relative roughness (ratio of mean bankfull depth, d, to bed material size, D84). Use the curve describing the relations of bed particle size to hydraulic resistance (Rosgen, 1998) to obtain the friction factor (u/u*, or mean velocity divided by shear velocity) that corresponds to the calculated relative roughness (d/D84). Then use the curve that relates the friction factor to the roughness coefficient (Rosgen, 1998) to obtain the Manning's n that corresponds to the friction factor (u/u*).

The discharge calculated from the above equation can then be compared with other bankfull discharge estimates.

d. Use the stage-to-discharge rating curve to estimate bankfull discharge.

- For active gages, calculate the stage of bankfull discharge at the gaging station based on the field survey (Section 2.2.1, Step d). Use that stage and the current stage-to-discharge rating to find the discharge at bankfull stage, and validate by HEC-RAS analysis (see below).
- For discontinued gages, update and extend the rating to bankfull stage using Johnson's method (Kennedy, 1984), then extrapolate bankfull discharge from the stage calculated at the gaging station. Because the rating table at discontinued gages will likely be based on few (3-5 measurements), validate this estimate of bankfull discharge according to the following steps:

  1. Use NCALC to determine Manning's n at bankfull discharge, based on discharge from the extended rating, channel bed elevations across each cross section, bankfull water-surface elevation at each cross-section, and the distance along the thalweg between cross sections.
  2. Input Manning's n and cross-sectional geometry into the computer program HEC-RAS (Army Corps of Engineer's **H**ydraulic **E**ngineering **C**enter **R**iver **A**nalysis **S**ystem), and input a range of discharges close in value to the original estimate for bankfull discharge. Choose the discharge that produces the water surface slope closest to that measured in the field for bankfull slope.
  3. If any of these methods of estimating bankfull discharge does not fall within 10 percent of the others, examine the field data, input parameters, and rating. If all of these are correct, compare the recurrence intervals for the estimated bankfull discharges and choose the discharge that best fits the expected range of bankfull recurrence intervals (1-3 years).

2.3.8 Create regional curves

a. Once data have been collected from many streams within a given hydrophysiographic region, develop regional equations for that region using the following method:

1. Plot the bankfull discharge of each stream surveyed against its drainage area on a log-log scale.
2. Plot bankfull dimensions (width, depth, and cross-sectional area) against drainage area on a log-log scale.
3. Run power-function regressions for each data set to obtain the equations for each curve.

Additional gages may be surveyed and added to the data set if the equation for any curve has an R^2 value less than 0.9. Additionally, the range of drainage areas should be sufficiently large to cover the anticipated use of the curves for assessment or management. The curves cannot be extrapolated beyond the range of the data on which they are based.

b. Classify each gaged reach by Rosgen stream type (Rosgen, 1996), using the following variables calculated in Section 2.3:

1. Water surface slope (2.3.2)
2. Entrenchment ratio (2.3.3)
3. Width-to-depth ratio (2.3.3)
4. Particle size distribution (D50) (2.3.4)
5. Sinuosity (2.3.5)

Use the classification to separate hydraulic-geometry data by stream type, if appropriate.

c. Once preliminary equations have been calculated, evaluate the regional curves. Analyze data for outliers, reevaluate discharge estimates, and check all data and analyses for errors. If necessary, conduct a follow-up field visit and site inspection to reevaluate gage suitability and the validity of bankfull estimates and gage-calibration analyses. If circumstances are found that make the site unique, and if the site is not represented in the regional curves, identify it as such and describe these conditions in a separate list of gages not used for curve development

2.4 Administrative Guidelines

Use the following list of administrative items in developing regional curves and to ensure the reliability of the gage-calibration data.

- A master file should be kept for each study reach in a central location. The master file should contain all the gage data listed in Section 2.1, and all original field data, including plots and analysis. Only photocopies of the information in these files should be allowed to leave the building. A sign-out sheet should be provided for files removed from the master file.
- Once field data are collected, the original copies of the data sheets should immediately be placed in the master file and copies made for later quality assurance and quality control (QA/QC) and analysis.
- Only one person should be authorized to change field data. All changes should be initialed and dated.
- Field personnel should consult a field-equipment checklist before going to the field and again before leaving the study site each day.
- Equipment should be inventoried at the beginning and end of the field season and repairs and replacements addressed as necessary.

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APPENDIXES

A. Field Form 1: Site Inspection

Stream name ______________________________

at/near (location) ______________________________

USGS Station no. ______________________________

Date ______________________________

Field crew (initials) ______________________________

____

Gage: ☐ continuous record ☐ crest-stage

Rating table available? ☐ yes ☐ no

Active gage? ☐ yes ☐ no

Regulated? ☐ yes ☐ no

Reference marks? ☐ yes ☐ no

Staff gage ☐ yes ☐ no

Other reference marks ______________________________

____

____

SITE-RATING CRITERIA

0 = no or none **1** = slightly

2 = moderately **3** = yes or mostly

alluvial channel (bedrock negligible) ______

single channel ______

20 channel widths long ______

conforms to single stream type ______

channel in equilibrium ______

bankfull indicators present ______

gage in reach ______

TOTAL ______

NOTES

____

____

____

____

____

____

____

Preliminary Reach Sketch *

0 ______ FEET

* Include:

- North arrow
- staff
- intake
- structures
- crest-stage gages
- locations of reference marks and points
- direction of flow
- reach landmarks
- gage house
- other pertinent features

A. Field Form 2: Site Map

Stream name ____________________

at/near (location) ____________________

Date ____________________

Team member __________ task __________

__________ __________

__________ __________

__________ __________

__________ __________

Total number of bankfull flags: __________

Key to site map :

__________ ____________________

__________ ____________________

__________ ____________________

__________ ____________________

Test Cross Sections

	Test 1	Test 2	Test 3
Width:	______	______	______
Depth:	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
Mean depth	______	______	______
AREA	______	______	______

A. Field Form 3: Longitudinal Profile

Stream name at/near (location) ____

Date: ______________________________ Team member ____________ Task ______________

Level position number: __________________ Team member ____________ Task ______________

Notes ______________________________ Team member ____________ Task ______________

Station (feet from top of reach)	Backsight (+)	Height of instrument	Foresight (-)	Elevation (ft)	Description	Comments

LBF	left bankfull	RBF	right bankfull	LEW	left edge of water	LFP	left floodprone area
LBFH	left bankfull high	RBFH	right bankfull high	REW	right edge of water	RFP	right floodprone area
LBFM	left bankfull middle	RBFM	right bankfull middle	LTOB	left top bank	RM	reference mark
LBFL	left bankfull low	RBFL	right bankfull low	RTOB	right top bank	RP	reference point
TOR	top of riffle	BOR	bottom of riffle	R	rebar	TH	thalweg
TOP	top of pool	BOP	bottom of pool	TP	turning point	WS	water surface

p._____of_____

A. Field Form 4: Channel Cross Section

Stream name at/near (location) ____

Date:______________________________ Team member ____________ Task ______________

Cross section station:_______________________ Team member ____________ Task ______________

Level position number: ____________________ Team member ____________ Task ______________

Notes ____

Station (feet from tape)	Backsight (+)	Height of instrument	Foresight (-)	Elevation (ft)	Description	Comments

LBF	left bankfull	RBF	right bankfull	LEW	left edge of water	LFP	left floodprone area
LBFH	left bankfull high	RBFH	right bankfull high	REW	right edge of water	RFP	right floodprone area
LBFM	left bankfull middle	RBFM	right bankfull middle	LTOB	left top bank	RM	reference mark
LBFL	left bankfull low	RBFL	right bankfull low	RTOB	right top bank	RP	reference point
TOR	top of riffle	BOR	bottom of riffle	R	rebar	TH	thalweg
TOP	top of pool	BOP	bottom of pool	TP	turning point	WS	water surface

p. _____of_____

A. Field Form 5: Pebble Count

Stream name at/near (location) ______________________________

Date: ______________ Team member ______________ Task ______________

Notes ______________ Team member ______________ Task ______________

Enter intermediate axis (mm) for each field except as noted below:

F, fine (< 1 mm) C, clay or mud BR, bedrock * on bank

Riffle Count #1

Cross section (feet)

____

____

____

Riffle Count #2

Cross section (feet)

____

____

____

Longitudinal Profile

Station (feet)

____

____

____

____

____

____

____

____

____

____

B. QA/QC Checklist: Field Protocol

Reviewer: ______________________ Date: ______________________

Stream ______________________ USGS gage no. ______________________

Preliminary reconnaissance (Section 2.1.1 - 2.2.1):

Verify that all necessary data have been recorded or are filed in the site folder.

Site map (Field Form 2):

- The site map should include:
  - ☐ boundaries of study reach and locations of cross sections
  - ☐ location of gage house, staff plate, reference marks
  - ☐ locations of flagged features
  - ☐ locations of stream features (pools, riffles, bars, bedrock, high vertical banks, flood plains, terraces, vegetation, etc.)
  - ☐ manmade features (dams, utilities, bridges, culverts, rip-rap, etc.)
  - ☐ clear explanation of map symbols
  - ☐ distance scale and north arrow

NOTES

Longitudinal profile (Field Form 3):

- The longitudinal profile should:
  - ☐ start on USGS reference mark
  - ☐ be stationed along thalweg
  - ☐ include elevation of thalweg, water surface, and bankfull for all flagged bankfull indicators described on the site map (Field Form 2, Appendix A)

- Survey must:
  - ☐ start and and end at the same type of feature
  - ☐ include at least two meander wavelengths, or two sequences of pool/riffle features, or the surveyed channel segments should be at least 20 average bankfull widths in length

- All surveyed points should have an adequate description (Field Form 3, Appendix A)

B. QA/QC Checklist: Field Protocol (continued)

Longitudinal profile (Field Form 3-continued):

- Survey should include key features such as:
  - ☐ USGS reference mark with elevation
  - ☐ top and bottom of geomorphic features
  - ☐ maximum pool depths
  - ☐ staff plate
  - ☐ gage intake pipe
  - ☐ closeout point
  - ☐ cross-section reference mark
- Closeout survey must be within allowable error: $E = 0.007\,(\textit{total survey distance} / 100)^{1/2}$

NOTES

Channel cross section (Field Form 4):

1 2 3 4 5 6 7

☐☐☐☐☐☐☐ At least one cross section has been surveyed in riffle/run areas

☐☐☐☐☐☐☐ The cross section begins with a backsight to a reference mark or a point of known elevation

☐☐☐☐☐☐☐ The cross section includes the entire channel and the adjacent flood-prone area

☐☐☐☐☐☐☐ The cross section has been photographed (both banks; also from up- and downstream)

☐☐☐☐☐☐☐ All points have been described in Field Form 4

NOTES

Pebble counts (Field Form 5):

☐ One pebble count includes sampling of 100 particles from bed material collected from all bed features (riffles/pools) from at least 10 cross sections that are uniformly spaced throughout the study reach

☐☐ Other pebble counts include a sampling of 100 particles from bed material in riffles/runs where cross sections were surveyed.

NOTES