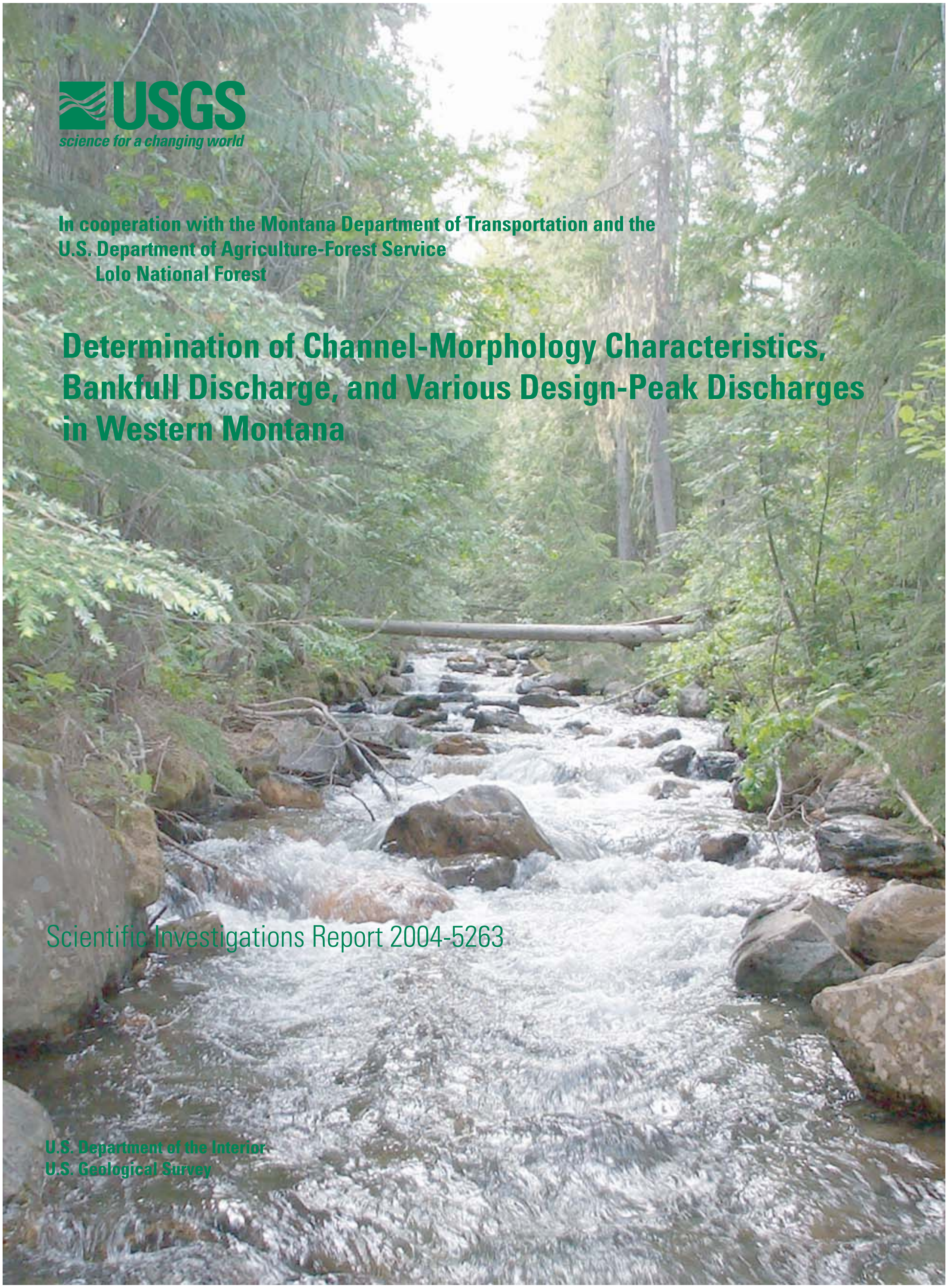

In cooperation with the Montana Department of Transportation and the U.S. Department of Agriculture-Forest Service
Lolo National Forest

Determination of Channel-Morphology Characteristics, Bankfull Discharge, and Various Design-Peak Discharges in Western Montana

Scientific Investigations Report 2004-5263

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

COVER PHOTOGRAPH: Flower Creek near Libby, Montana (station 12303100). Photograph by Sean M. Lawlor, U.S. Geological Survey, taken in 2002.

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Conversion Factors, Datum, and Acronyms

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
foot per foot (ft/ft)	1.0	meter per meter (m/m)
inch (in.)	25.4	millimeter (mm)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)

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

Acronyms used in this report:
OLS Ordinary Least Squares
SEP Standard error of prediction
USGS U.S. Geological Survey

Glossary

active-channel width The width of the active channel measured perpendicular to streamflow. The active-channel, a short-term geomorphic feature formed by prevailing stream discharges, is narrower than the bankfull channel and is defined by a break in bank slope that also typically is the edge of permanent vegetation.

bankfull cross-sectional area The cross-sectional area of a stream channel at bankfull stage measured perpendicular to streamflow.

bankfull discharge The stream discharge generally considered to be the single discharge that is most effective for moving sediment, forming or removing bars, and forming or changing bends and meanders, all of which result in the average morphological characteristics of channels (Dunne and Leopold, 1978).

bankfull-recurrence interval The average interval, in years, between annual peak discharges that exceed bankfull discharge.

bankfull stage The elevation above gage datum of the water surface corresponding to bankfull discharge.

bankfull-wetted perimeter The length, in feet, of the contact between the stream of flowing water and its containing channel, measured at a section perpendicular to streamflow at bankfull discharge.

bankfull width The width of the bankfull channel measured at a section perpendicular to streamflow at bankfull discharge.

D_{50} The median size of streambed particles as determined by measuring the intermediate axis of numerous particles on the streambed surface selected at random.

drainage area The horizontal projection of the area upstream from a specific location that has a common outlet at the site for its surface runoff from precipitation that normally drains by gravity into a stream.

entrenchment ratio The vertical containment of the river described as the ratio of the flood-prone width to the bankfull width (Rosgen, 1996).

flood-prone width The width across the flood plain, measured at a section perpendicular to the streamflow, at a water-surface elevation corresponding to twice the maximum depth of the bankfull channel (Rosgen, 1996).

Manning's roughness coefficient (*n*) A dimensionless measure of the frictional resistance to flow, or roughness, of a stream channel.

maximum bankfull depth The maximum depth of the bankfull channel measured at a section perpendicular to streamflow.

mean annual precipitation The basin average value for annual precipitation.

mean bankfull depth The mean depth of the bankfull channel measured at a section perpendicular to streamflow.

percent of basin covered by forest That portion of the drainage area of a stream shown in green on a 7.5-minute U.S. Geological Survey topographic map, divided by the total drainage area, and multiplied by 100.

recurrence interval The average interval, in years, between exceedances of a particular annual peak discharge.

Rosgen classification A system of describing river channels based on channel geometry, stream plan-view patterns, and streambed material (Rosgen, 1996).

sinuosity The ratio of the measured channel distance divided by the straight-line distance of the valley from the beginning of the channel reach to the end of the channel reach.

thalweg The lowest point in a stream channel.

width/depth ratio The ratio of bankfull width to mean bankfull depth measured at a section perpendicular to streamflow.

Determination of Channel-Morphology Characteristics, Bankfull Discharge, and Various Design-Peak Discharges in Western Montana

By Sean M. Lawlor

Abstract

Stream-restoration projects using natural stream designs typically are based on channel configurations that can accommodate a wide range of streamflow and sediment-transport conditions without excessive erosion or deposition. Bankfull discharge is an index of streamflow considered to be closely related to channel shape, size, and slope (channel morphology). Because of the need for more information about the relation between channel morphology and bankfull discharge, the U.S. Geological Survey (USGS), in cooperation with the Montana Department of Transportation and the U.S. Department of Agriculture-Lolo National Forest, conducted a study to collect channel-morphology and bankfull-discharge data at gaged sites and use these data to improve current (2004) methods of estimation of bankfull discharge and various design-peak discharges at ungaged sites. This report presents channel-morphology characteristics, bankfull discharge, and various design-peak discharges for 41 sites in western Montana.

Channel shape, size, and slope and bankfull discharge were determined at 41 active or discontinued USGS streamflow-gaging sites in western Montana. The recurrence interval for the bankfull discharge for this study ranged from 1.0 to 4.4 years with a median value of 1.5 years.

The relations between channel-morphology characteristics and various design-peak discharges were examined using regression analysis. The analyses showed that the only characteristics that were significant for all peak discharges were either bankfull width or bankfull cross-sectional area.

Bankfull discharge at ungaged sites in most of the study area can be estimated by application of a multiplier after determining the 2-year peak discharge at the ungaged site. The multiplier, which is the ratio of bankfull discharge to the 2-year peak discharge determined at the 41 sites, ranged from 0.21 to 3.7 with a median value of 0.84.

Regression relations between bankfull discharge and drainage area and between bankfull width and drainage area were examined for three ranges of mean annual precipitation. The results of the regression analyses indicated that both drainage area and mean annual precipitation were significantly related (p values less than 0.05) to bankfull discharge.

Introduction

Stream alterations in western Montana have resulted in adverse habitat changes for many fish and wildlife species and have contributed to declines in native fish populations (Peters, 1990). Projects to restore stream channels to their original and natural condition are increasingly being undertaken to reverse those declines. Successful restoration of altered stream channels to a more stable and natural condition requires information about the relation between channel morphology and streamflow under natural conditions.

Over the past 10 years, methods have been developed (Rosgen, 1996) that use channel morphology to assess relative stream stability and to design stable channel configurations. A key to proper use of these methods is the determination of bankfull discharge—an index of streamflow that is considered to be closely related to channel shape, size, and slope. Currently (2004), bankfull discharge at ungaged sites commonly is approximated using regression equations that relate peak discharge having a 2-year recurrence interval to various basin and climatic characteristics or using regression equations that relate a 2-year peak discharge to active-channel or bankfull width (Parrett and Johnson, 2004). Estimates from existing regression equations may have significant error, however, because the assumption that bankfull discharge is equal to peak discharge having a 2-year recurrence interval may not be valid for many sites. Previous studies have indicated that the recurrence interval for bankfull discharge at some sites is less than 2 years (Leopold and others, 1964; Rosgen, 1996; Moody and Odem, 1999).

A recent study in southwestern Montana (Bass, 1999) indicated that regression equations for estimation of 2-year peak discharge based on channel width might be improved by the inclusion of bankfull depth, cross-sectional area, or other channel-morphology characteristics as additional explanatory variables. Because the 2-year peak discharge generally is highly correlated with other annual peak discharges (flood discharges), results presented by Bass (1999) suggest that inclusion of other channel-morphology characteristics in a regression analysis might result in improved estimates of other annual peak discharges ranging from the 2-year flood to the 500-year flood.

Studies by Dunne and Leopold (1978), White (2001), and Cinotto (2003) showed a strong relation between bankfull discharge and drainage area. This relation was used on a reconnaissance level to infer some channel-morphology characteristics at sites not having onsite channel measurements within regions with similar runoff characteristics. Regional relations between other channel-morphology characteristics—such as bankfull width, mean bankfull depth, bankfull cross-sectional area—and drainage area also can be useful for reconnaissance-level studies.

Because of the need for more information about the relation between channel morphology and stream discharge, the U.S. Geological Survey (USGS), in cooperation with the Montana Department of Transportation and the U.S. Department of Agriculture Forest Service-Lolo National Forest, conducted a study to collect channel-morphology and bankfull-discharge data at gaged sites. These data then were used to try to improve methods for estimation of bankfull discharge and other flood discharges—annual peak discharges having recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years (various design-peak discharges)—at ungaged sites and to develop relations between bankfull discharge and drainage area and channel-morphology characteristics and drainage area.

Purpose and Scope

This report presents channel-morphology characteristics, bankfull discharge, and various design-peak discharges for 41 sites in western Montana. Specifically, the report describes: (1) determination of key channel-morphology characteristics at selected streamflow-gaging sites, (2) determination of bankfull discharge and its recurrence interval at each streamflow-gaging site, (3) development of a multiplier to apply to existing flood-frequency equations, (4) determination of the relation of various design-peak discharges for selected recurrence intervals to measured morphologic characteristics, and (5) analysis of regional relations between bankfull channel width, bankfull mean depth, bankfull cross-sectional area, and bankfull discharge to drainage area.

Channel-morphology data were collected at 41 sites in western Montana during 2001-03. At each site, a reach of stream was selected for detailed measurements of water-surface, streambed, and bankfull elevations. Within each reach, one to three cross sections were surveyed to estimate bankfull widths, mean bankfull depths, cross-sectional area, wetted perimeter, and flood-prone width. Stream discharge, particle-size distribution, and Manning's roughness coefficients (*n* values) were determined at each site (Barnes, 1967). These measurements also were used to estimate a Rosgen Level II stream classification (Rosgen, 1996) for each site. In some instances, stream reaches did not readily fit all parameters of the Rosgen stream classification. Stream profiles were surveyed and calculations made to determine bankfull discharge and its recurrence interval for each site. Regression analysis was used to determine whether relations between various peak discharges (recurrence intervals ranging from 2 to 500 years) and bankfull width might be improved by inclusion of channel-morphology data. Bankfull width, bankfull depth, bankfull cross-sectional area, and bankfull discharge were related to drainage area using regression analysis. The relations were developed for three ranges of mean annual precipitation.

Description of the Study Area

The study area consists of about 25,140 mi^2 in the Clark Fork and Kootenai River drainage basins in western Montana (fig. 1). In the northwestern part of the study area, mountain ranges typically are separated by narrow, steep-sided valleys that have little to no basin-fill deposits. These valleys primarily were the result of erosion by glaciers and streams. In contrast, much of the remainder of the study area consists of mountain ranges separated by larger valleys that are wide, deep, and can be filled with thousands of feet of basin-fill deposits (Kendy and Tresch, 1996).

Cold winters and mild summers characterize the climate of the study area. Winters are cold, and thick snow pack accumulates in the mountains. Summers generally are warm and dry in the valleys and cool in the surrounding mountains. The growing season typically extends from May to September or October, but in some basins is as short as July to August (National Oceanic and Atmospheric Administration, 1992). Following periods of extreme cold, mountainous areas commonly warm up more rapidly than valleys causing pronounced temperature inversions. The prevailing wind in most of the study area is from the west, and strong, gusty winds are common year round.

Precipitation in the study area primarily accompanies winter and spring frontal systems and summer convection storms. Annual precipitation can range from about 10 in. in the southwestern part of the study area to about 100 in. in the mountains of northwestern Montana (National Oceanic and Atmospheric Administration, 1992). Most of the valleys receive between 10 and 30 in. of precipitation per year, with more than one-half falling in winter and spring. Large winter snowpacks in the mountains gradually release their water content as snowmelt that helps maintain streamflow well into summer.

Determination of Channel-Morphology Characteristics

Channel-morphology data were collected at 41 sites near active or discontinued streamflow-gaging stations during 2000-03. All gaged sites in western Montana were initially considered for study. However, many sites were eliminated from further study because they were in urban areas or areas affected by dams, bridges, or other man-made structures; the annual peak-discharge record was less than 10 years; they were located in non-dynamic bedrock channels; or they were in areas with substantial recent land-use changes in the watershed. Other sites along large streams were eliminated from further study because their large widths and depths precluded efficient and economical data collection.

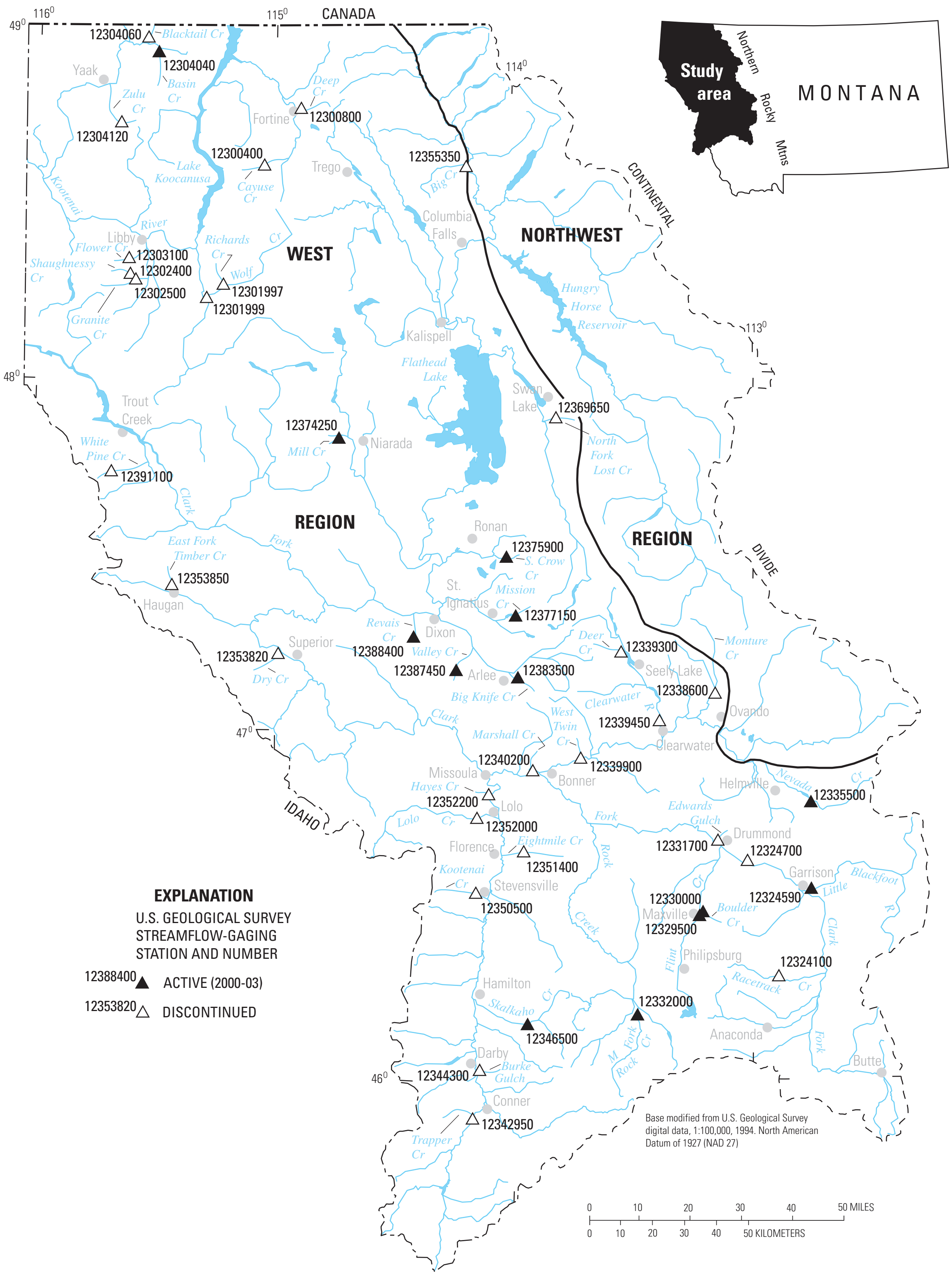

Figure 1. Location of the study area, measurement sites, and two flood regions (from Parrett and Johnson, 2004).

A suitable reach near the gaging station was identified at each site. In general, the selected reach was about 20 bankfull-channel widths in length and, whenever possible, the gaging station was located in the selected reach. Within the selected reach, water-surface, streambed (thalweg), and bankfull-channel elevations were measured at a minimum of seven locations along the channel using a survey level or an electronic-surveying instrument (total station). Reaches with flow obstructions such as bridge abutments, diversion structures, culverts, and bridges were avoided, if possible. Within each selected reach, one to three representative stream-channel (reference) cross sections were identified. Elevations and distances were measured at each cross section using a survey level and a fiberglass tape or a total station. The reference cross sections generally were located in stable subreaches between channel bends (fig. 2) as described by Parrett and others (1987), Leopold (1994), and Rosgen (1996). If a reach had more than one reference cross section, data from the cross sections were averaged to provide reach-representative values of bankfull width, mean bankfull depth, bankfull cross-sectional area, bankfull-wetted perimeter, width/depth ratio, and entrenchment ratio. Site and cross-section locations on South Crow Creek and Mill Creek in western Montana are shown on figure 3.

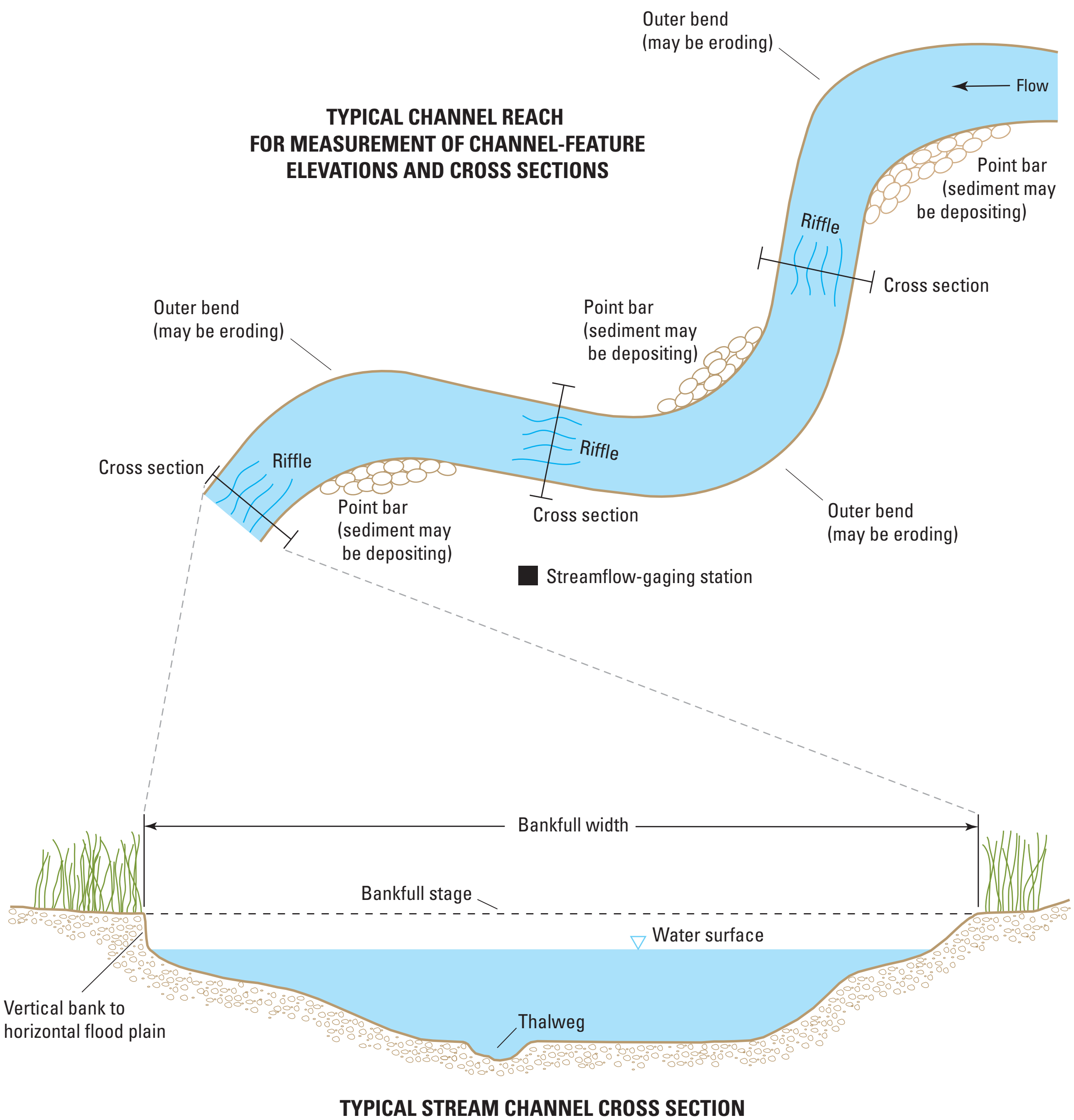

Figure 2. Typical channel reach and cross section for measurement of channel features.

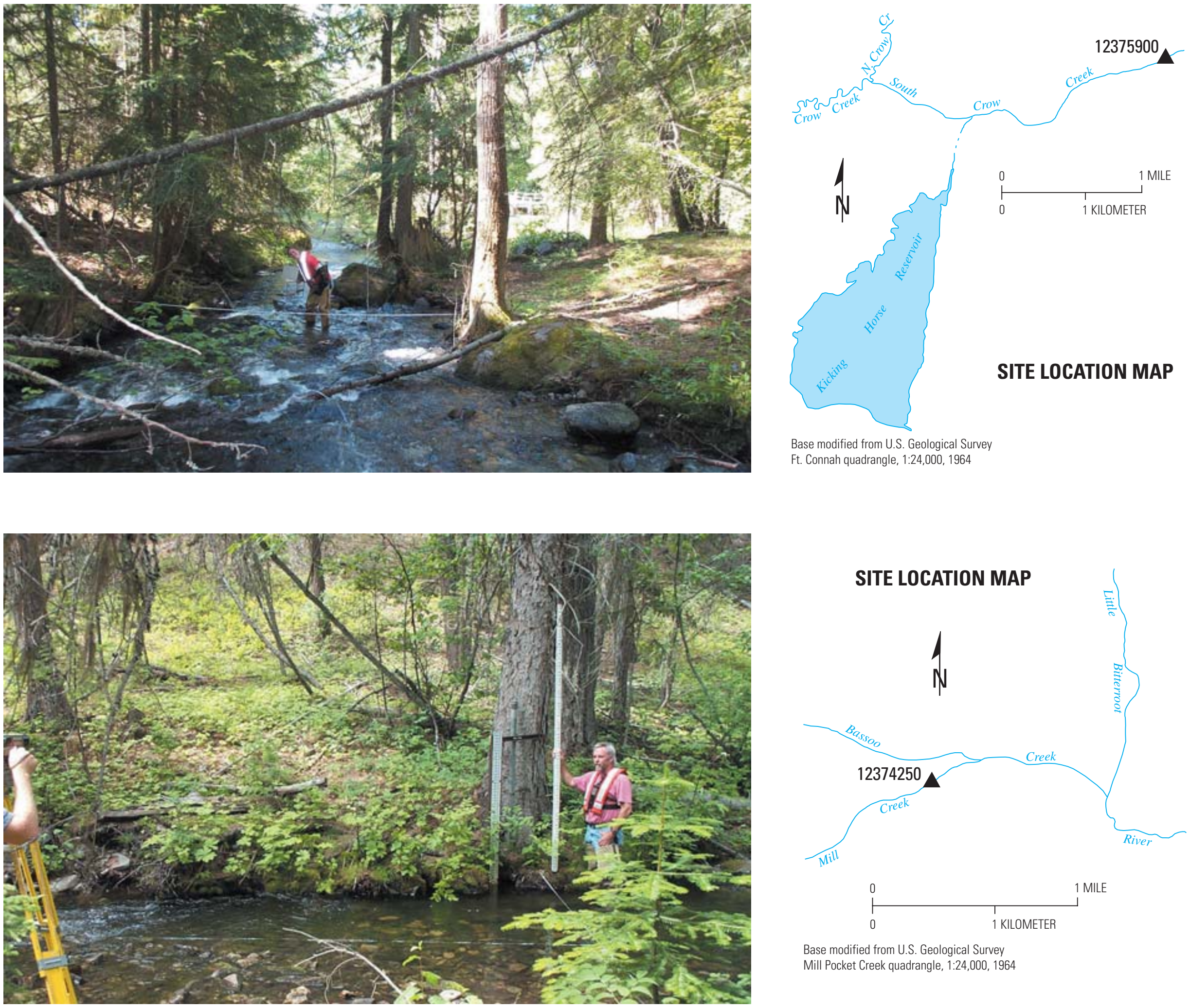

Figure 3. Site and cross-section locations on South Crow Creek (top) and Mill Creek (bottom), western Montana.

A survey level and fiberglass tape or total station were used to survey channel distance and elevation. Channel distance and elevation were used to construct longitudinal profiles of the water-surface, thalweg, and bankfull elevations. The USGS gaging-station datum at each site, referenced to NGVD 29, was used for vertical control during the surveys.

The bankfull stage was readily identified at most sites by topographic features (bankfull indicators), such as a change from a vertical bank to a horizontal flood plain (fig. 2). At many of the sites, bankfull stage also was marked by a change in the size distribution of materials along the bank. Occasionally, vegetation was used as an indicator; however, topographic features generally were more reliable indicators of bankfull stage.

Bankfull widths, bankfull depths, flood-prone widths, streambed-material sizes, and channel roughness were determined at each site; bankfull cross-sectional area, bankfull-wetted perimeters, entrenchment ratio, and sinuosity were then calculated. The flood-prone width was estimated by first determining the maximum depth of the bankfull channel at the cross section. Then a range-finder was set at the elevation corresponding to twice the maximum bankfull depth to measure the horizontal distance to the ground surface (perpendicular to the flow) on each side of the stream at that elevation, and the two distances were summed. The entrenchment ratio was calculated by dividing flood-prone width by bankfull width. In some instances, flood-prone width and sinuosity (needed to determine a Rosgen Level II stream classification; Rosgen, 1996) were difficult to measure because of thick vegetation on the flood plain. Aerial photographs and USGS 7.5-minute topographic maps were used in these instances to estimate flood-prone width and sinuosity. In instances where sinuosity was determined from the ratios of channel length to valley length from aerial photographs and topographic maps, and from the ratios of valley slope to channel slope, the sinuosity values shown in table 1 (at back of report) may not be consistent with sinuosity values determined by any one method.

Streambed particle-size distribution was determined from a pebble count through the selected stream reach using methods described by Wolman (1954). The Manning roughness coefficient (*n* value) at each cross section was estimated by visual inspection and comparison with *n* values from photographs (Barnes, 1967). Channel-morphology data together with various design-peak discharge data (Parrett and Johnson, 2004) for each site are shown in table 1; selected basin and climatic variables for each site are shown in table 2 (at back of report).

Additional data were collected during the site visit. Discharge was either determined from the most recent stage-discharge relation or measured with a current meter. Current-meter measurements were made in accordance with methods described by Rantz and others (1982).

Determination of Bankfull Discharge at Gaged Sites

Bankfull discharge and its associated recurrence interval were determined at each of the 41 gaged sites. For each study reach, the bankfull-stage, water-surface, and thalweg elevations, along with associated channel-distance data, were used to construct longitudinal profiles. Under the hydraulic condition of gradually varied flow, which is the most common hydraulic condition in natural streams (Jobson and Froehlich, 1988), bankfull-stage, water-surface, and thalweg profiles tend to be parallel. For example, figure 4 shows the longitudinal profiles and a best-fit line through the bankfull-stage data for two typical study reaches (Boulder Creek at Maxville and Eightmile Creek near Florence). In both examples, the left and right bankfull-stage profiles closely parallel the best-fit line with little point-to-point variability between the elevations and the line. In addition, the best-fit line through the left and right bankfull-stage profiles closely parallel the water-surface profiles. At some sites, both bankfull-stage profiles did not vary consistently (generally because of natural changes in streambed gradient) which caused both the bankfull-stage profiles to be segmented, rather than straight lines. In some instances, water-surface profiles were used as a guide in drawing the bankfull-stage profiles because the water-surface profiles were more uniform. The longitudinal profiles, together with the stage-discharge relation derived from data from the gaging station, were used to determine bankfull discharge if possible.

At 20 sites (table 1) where a gaging station was located within the selected reach, the bankfull discharge at the gage was determined from the bankfull stage-discharge relation. For 11 of the sites with active gages, the most recent stage-discharge relation was used to determine bankfull discharge (table 1). For seven of the sites with discontinued gages, the most recent stage-discharge relation was used to determine bankfull discharge. For two other sites with discontinued gages, the most recent stage-discharge relation did not provide reliable values for bankfull discharge, and the stage-discharge relation was adjusted on the basis of the discharge measured at the time of the site visit.

At 19 sites where the stage-discharge relation was not reliable (even after adjustment) or where the gage was not located within the study reach, a computer program for calculation of water-surface profiles (HEC-RAS version 3.0, U.S. Army Corps of Engineers, 2001a,b,c) based on the standard-step method (Davidian, 1984) was used to calculate a water-surface profile for bankfull discharge. The HEC-RAS model used cross-section and channel-distance data and estimated Manning's roughness coefficients to calculate water-surface elevation at each cross section for a selected discharge and an initial water-surface elevation at the most downstream cross section. For this analysis, the starting downstream water-surface elevation was the bankfull stage, and the discharge was varied until the simulated water-surface elevations at the remaining cross sections in the reach closely matched the surveyed bankfull-stage elevations. The discharge that resulted in the closest match of water-surface elevation to bankfull-stage elevation at all cross sections was determined to be the bankfull discharge (table 1).

At two sites, the stage-discharge relation and the simulations from HEC-RAS did not produce reliable information to determine bankfull discharge. In these two instances, the Manning equation for uniform flow (Henderson, 1966) was used to determine the bankfull discharge at one cross section for each site using cross-sectional area, average water-surface slope in the reach, and the Manning's roughness coefficient as input variables (table 1).

Finally, the bankfull discharge for each site was plotted on the most recent flood-frequency curve (Parrett and Johnson, 2004) to determine the recurrence interval for the bankfull discharge. The recurrence interval for bankfull discharge at the 41 sites in western Montana was somewhat variable from site to site and ranged from 1.0 to 4.4 years (table 1). The median value of recurrence interval was 1.5 years (fig. 5), which is similar to the recurrence interval for bankfull discharge determined in other studies (Rosgen, 1996; Moody and Odem, 1999; Castro and Jackson, 2001; White, 2001; and Cinotto, 2003).

Determination of Various Design-Peak Discharges at Ungaged Sites

One of the key goals of this study was to determine whether measured channel-morphology characteristics at gaged sites could be used to improve existing methods for estimation of bankfull discharge and various design-peak discharges at ungaged sites. Accordingly, regression analysis was used to examine the relation between various design-peak discharges and channel morphology at the 41 gaged sites in the current study.

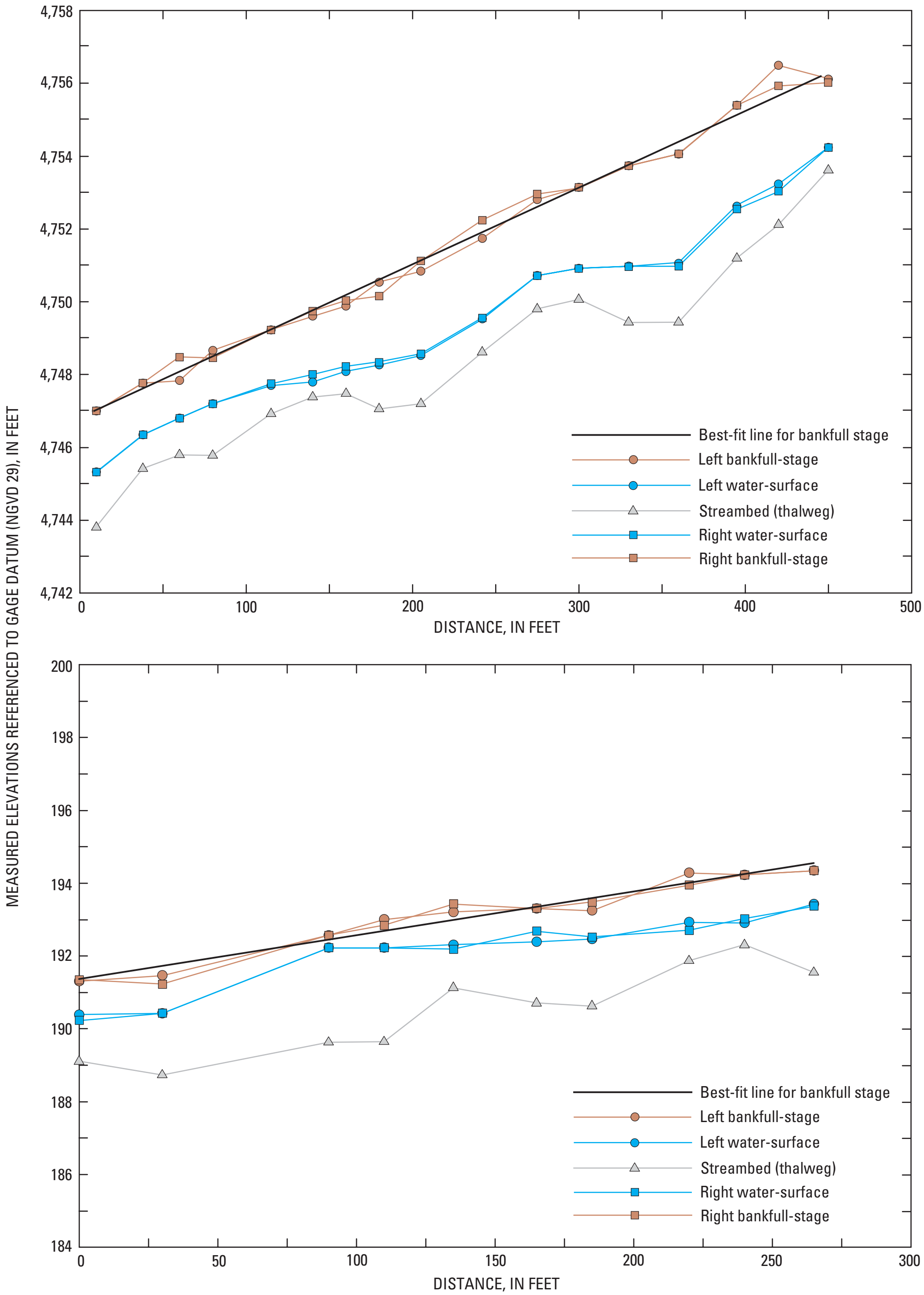

Figure 4. Longitudinal profiles for Boulder Creek at Maxville (station 12330000, top) and Eightmile Creek near Florence (station 12351400, bottom), Montana.

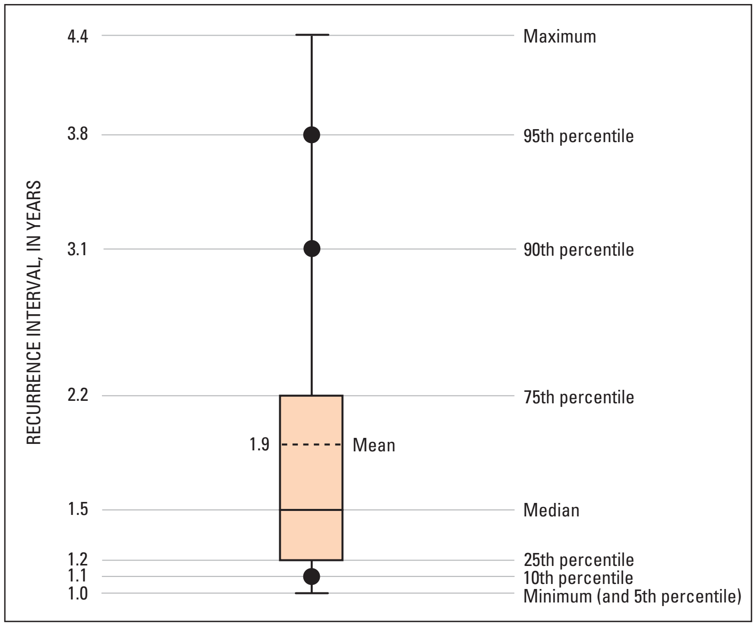

Figure 5. Variation in recurrence interval of bankfull discharge at 41 selected sites, western Montana.

Regression Relations between Various Design-Peak Discharges and Channel Morphology

Multiple regression analyses were performed to determine whether equations used to estimate design-peak discharges (based on bankfull width as the only explanatory variable, table 3, at back of report) might be improved by the inclusion of other measured channel-morphology characteristics. Regression analysis also was used to develop an estimation equation for bankfull discharge. To help ensure that relations between the various design-peak discharges and the channel-morphology characteristics would be linear, all variables were converted to base 10 logarithms (log), so that the regression equations were of the following linear form:

$$\log Q_{T \text{ or } BF} = \log K + a_1 \log x_1 + a_2 \log x_2 + \ldots a_p \log x_p, \quad (1)$$

where

$Q_{T \text{ or } BF}$	is the design-peak discharge or the bankfull (BF) discharge (in cubic feet per second), with a recurrence interval of T years,
K	is the regression constant,
a_1 through a_p	are regression coefficients, and
x_1 through x_p	are channel-morphology characteristics.

Equation 1 can be expressed without logarithms in the following non-linear form:

$$Q_{T \text{ or } BF} = K' \; x_1^{a_1} \; x_2^{a_2} \; \ldots \; x_p^{a_p} , \quad (2)$$

where

K'	is the anti log (10^K) of the linear regression constant K,

and all other terms are as previously defined.

Channel-morphology characteristics that were used as potential explanatory variables in the multiple regression analyses were bankfull width, mean bankfull depth, bankfull cross-sectional area, width/depth ratio, flood-prone width, entrenchment ratio, the D_{50} streambed-particle size, water-surface slope (determined from the water-surface profiles), and an index number ranging from 1 to 7, corresponding to the seven different values of the Rosgen stream classification of the 41 sites (table 1). Two additional variables, site latitude and site longitude, also were used in the regression analyses to determine whether regression results might vary by location within the study area (table 2).

An Ordinary Least Squares (OLS) stepwise-regression analysis using the method of all possible regressions was conducted using a computer program (Steppan and others, 1998). The regression analysis indicated that the only explanatory variables that were significant (p value less than 0.05) for all Q_T (2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals) and Q_{BF} were either bankfull width or bankfull cross-sectional area. For all Q_T and Q_{BF}, the equations based on bankfull cross-sectional area had slightly greater coefficients of determination (r^2) and slightly smaller standard errors of estimate than the equations based on bankfull width. Equations based on bankfull cross-sectional area thus can be considered to be slightly more reliable than those based on bankfull width, but field measurement of bankfull cross-sectional area is more complicated than measurement of bankfull width. Accordingly, equations for estimation of Q_T or Q_{BF} based on bankfull width might be considered preferable to those based on bankfull cross-sectional area.

Use of Existing Flood-Frequency Equations

Parrett and Johnson (2004) recently developed three sets of regression equations relating annual peak discharges (design-peak discharges) with recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years to various basin characteristics, active-channel width, and bankfull width for eight regions in Montana. As defined in the glossary, active-channel width is a measure of a geomorphic feature similar to, but narrower than, the bankfull channel. One of the regions (West Region) lies wholly within the study area of this report, and one (Northwest Region) lies partly within the study area (fig. 1). The regression equations and measures of their predictive reliability (standard error of prediction, SEP) for the West and Northwest Regions are shown in table 3. Parrett and Johnson (2004) also provided methods for weighting estimates from any two or more of the three sets of regression equations based on their standard error of prediction and degree of correlation.

The regression equations developed by Parrett and Johnson (2004) are based on data from 90 to 96 gaged sites in the West Region and 29 to 35 gaged sites in the Northwest Region (table 3). The regression equations relating the various design-peak discharges to bankfull width based on data from only the 41 gaged sites in this study are not necessarily consistent with or comparable to the regression equations based on more data developed by Parrett and Johnson (2004). Accordingly, the equations developed by Parrett and Johnson (2004) for estimation of design-peak discharges are considered to be more reliable than those developed for this study.

Although Parrett and Johnson (2004) did not develop a regression equation for estimation of bankfull discharge, a method was developed for estimation of bankfull discharge at ungaged sites based on data collected during this study that is consistent with the design-peak discharge equations developed by Parrett and Johnson (2004). The method is based on use of a multiplier applied to estimates of the 2-year peak discharge from equations from Parrett and Johnson (2004). The multiplier was calculated by using the median value of the ratios of bankfull discharge to the 2-year peak discharge at the 41 sites used in this study. The variability of the ratios of bankfull discharge to the 2-year peak discharge at the 41 sites is shown by the boxplot in figure 6. The values of the ratios ranged from 0.21 to 3.7,

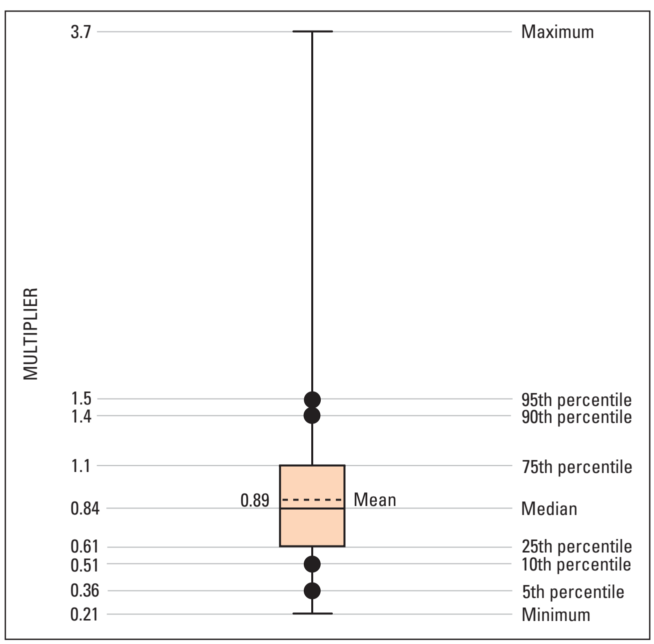

Figure 6. Variation of ratio of bankfull discharge to the 2-year design-peak discharge at 41 selected sites, western Montana.

with a median value of 0.84 and a mean value of 0.89. Thus, bankfull discharge at an ungaged site in western Montana can be calculated by first using one of the applicable equations, or a weighted combination of two or three of the applicable equations, developed by Parrett and Johnson (2004) for estimation of the 2-year peak discharge and then multiplying that estimate by 0.84. For example, if the equation from Parrett and Johnson (2004) for estimation of the 2-year peak discharge based on basin characteristics yields an estimate for 2-year peak discharge of 120 ft^3/s for an ungaged site in western Montana, the estimated bankfull discharge would be 120 ft^3/s x 0.84, or 101 ft^3/s. The reliability of estimates for bankfull discharge at ungaged sites based on use of the median multiplier together with estimated values of the 2-year peak discharge (table 3) is believed to be about the same as the reliability of the estimates for the 2-year peak discharge indicated by Parrett and Johnson (2004, table 2) for the West Region (Charles Parrett, U.S. Geological Survey, oral commun., 2003) because they are based on the same equations. The reliability of estimates for bankfull discharge based on use of the median multiplier for ungaged sites in the Northwest Region is unknown because none of the 41 sites used to develop the average multiplier were located in the Northwest Region.

Generally, the use of estimation equations based on regression has limitations because regression analyses do not define actual physical relations among variables; thus, regression equations might not provide reliable results when the bankfull widths are outside the range of values used to develop the equations. Meaningful relations between bankfull width and various design-peak discharges require stable conditions so that the channel is fully adjusted to the prevailing conditions of water and sediment discharge. Therefore, the equations in table 3 probably are not applicable to stream reaches having the following conditions:

1. Channels that are braided or unstable.
2. Channels largely composed of bedrock.
3. Channel reaches having long pools or steep slopes.
4. Channels altered by recent floods or human activities.
5. Small streams with poorly defined channels that are highly vegetated.
6. Streams with recent changes in streamflow regimen, such as those resulting from the construction of upstream diversion or regulation structures.

An additional constraint on the use of estimation equations based on bankfull width in table 3 is that the site needs to be visited and the width needs to be measured. Properly identifying bankfull width requires training and experience and, even among individuals experienced in making channel-geometry measurements, the variability in measured widths can be large. Both Wahl (1977) and Hammer (1981) reported that errors in geomorphic measurements could be as large as 30 percent even for experienced hydrographers. Equations based on bankfull and active-channel width (table 3) have measurement error described by Wahl (1977) included in the standard error of prediction (Parrett and Johnson, 2004).

Regression Relations between Channel Morphology and Drainage Area and Bankfull Discharge and Drainage Area

Studies by Emmett (1975) and Dunne and Leopold (1978) have shown that the bankfull-channel dimensions of width, mean depth, and cross-sectional area and bankfull discharge are related to the size of drainage area within regions where hydrologic processes and climate are similar. Regression analysis of the relation between these channel-morphology characteristics and drainage area and bankfull discharge and drainage area for gaged streams can provide a means of estimating channel morphology and bankfull discharge for ungaged streams when the drainage area is known. Plots of these relations have been termed regional curves (Dunne and Leopold, 1978); these curves can be used as a means of validating bankfull indicators observed in the field. However, according to Moody and Odem (1999), these curves should not be used as the primary means of estimating channel geometry or bankfull discharge.

To help ensure that climate would be similar for all sites used to develop regional relations between channel morphology and drainage area and between bankfull discharge and drainage area, mean annual precipitation was used as an additional potential explanatory variable in a regression analysis. To determine whether the relations might vary with location within the study area, site latitude and site longitude also were used as additional potential explanatory variables.

An OLS stepwise-regression analysis (Steppan and others, 1998) was used to relate the logarithms of bankfull width, mean bankfull depth, bankfull cross-sectional area, and bankfull discharge to the logarithms of drainage area, mean annual precipitation, and site latitude and longitude at all of the 41 gaged sites. The results of each of the four regression analyses indicated that both drainage area and mean annual precipitation were significant (p values less than 0.05) explanatory variables for estimation of bankfull discharge. However, the results of each of the four regression analyses also indicated that site latitude and site longitude were not significant (p values greater than 0.05) explanatory variables for estimation of bankfull discharge.

To ensure that regional curves relating channel morphology and bankfull discharge to drainage area alone would include the effects of mean annual precipitation, each gaged site was assigned an index number of 1, 2, or 3, depending upon the value of mean annual precipitation at the site. All gaged sites having a mean annual precipitation of less than 30 in. were given an index number of 1, all sites having mean annual precipitation between 30 to 45 in. were given an index number of 2, and all sites having mean annual precipitation greater than 45 in. were given an index number of 3. Regression analyses using drainage area and index number as the only explanatory variables were used to develop equations of the following form:

$$\log Y = \log K + a_1 \log DA + a_2 \log Index(i), \quad (3)$$

where

Y is either bankfull width (in feet), mean bankfull depth (in feet), bankfull cross-sectional area (in square feet), or bankfull discharge (in cubic feet per second),

K is the regression constant,

a_1 and a_2 are regression coefficients,

DA is drainage area (in square miles), and

$Index(i)$ is the index number (1, 2, or 3) for mean annual precipitation (in inches) at the site.

Because $a_2 \log Index(i)$ is a constant that can have only three values, depending upon whether $Index(i)$ = 1, 2, or 3, equation 3 can be simplified to:

$$\log Y = C_i + a_1 \log DA, \quad (4)$$

where

$$C_i = a_2 \log Index(i).$$

Using equation 4, three regional curves were drawn that relate Y to drainage area. Each curve has the same slope (a_1), but a different intercept (anti log C_i) depending upon the value of the $Index(i)$ for the mean annual precipitation. The resultant regional curves relating bankfull width, mean bankfull depth, bankfull cross-sectional area, and bankfull discharge to drainage area within the study area are shown in figure 7. The

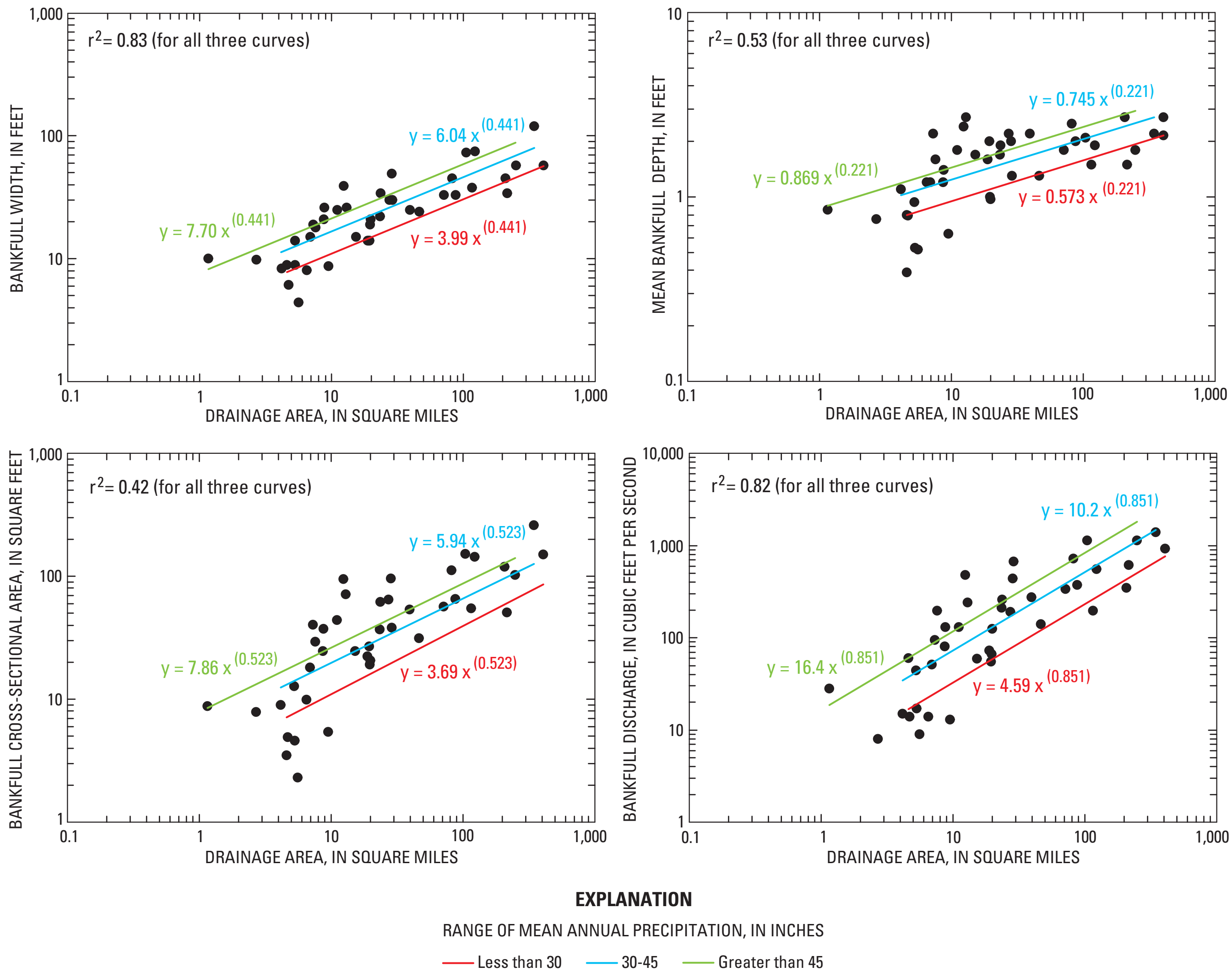

Figure 7. Regional relations of bankfull-channel dimensions and bankfull discharge to drainage area for different ranges of mean annual precipitation.

regional curves can be used on a reconnaissance level (without a site visit for measurement) to estimate channel morphology and bankfull discharge for ungaged sites in western Montana. Mean annual precipitation at an ungaged site in western Montana can be determined from Parrett and Johnson (2004).

The curves developed for this study are based on sparse, highly variable data. The relatively small number of streamflow-measurement stations used in the regression analysis limits the strength of the regional curves presented in this report. More detailed climatic data might further enhance the results from this study and possibly allow further stratification by climatic zones or ecoregions. For parts of Montana east of the Continental Divide with different basin and climatic characteristics, new data collection and analysis would be beneficial in estimating bankfull and other flood discharges.

Summary

Channel-morphology data were collected at 41 active or discontinued streamflow-gaging sites in western Montana. A suitable reach near the gaging station was identified at each site. In general, the selected reach was about 20 bankfull widths in length and, whenever possible, the gaging station was located within this reach. Within the selected reach, water-surface, streambed (thalweg), and bankfull-channel elevations were measured as well as bankfull widths and bankfull depths. Bankfull cross-sectional areas, bankfull-wetted perimeters, and width/depth ratio were determined from the elevation and location data. Furthermore, the flood-prone width, entrenchment ratio, sinuosity, streambed-material sizes, and channel roughness were determined at each site.

Bankfull discharge and its associated recurrence interval were determined at each of the 41 gaged sites. For each study reach, the bankfull-stage, water surface, and thalweg elevations, and associated channel-distance data were used to construct longitudinal profiles. At 11 sites with active gages, the recent stage-discharge relation was used to determine bankfull discharge. For seven sites with discontinued gages, the most recent stage-discharge relation was used to determine bankfull discharge. For two other sites with discontinued gages, the stage-discharge relation was adjusted on the basis of the discharge measured at the time of the site visit. At 19 sites, where the stage-discharge relation was not reliable or where the gage was not located within the study reach, a computer program for calculation of water-surface profiles was used to calculate a water-surface profile for bankfull discharge. At two sites, the Manning equation for uniform flow was used to determine the bankfull discharge at one cross section for each site. Finally, the bankfull discharge for each site was plotted on the most recent flood-frequency curve to determine the recurrence interval for the bankfull discharge. The recurrence interval for bankfull discharge ranged from 1.0 to 4.4 years. The median value of the recurrence interval was 1.5 years.

Regression analysis was used to examine the relation between various design-peak discharges and channel-morphology at the 41 gaged sites. Channel morphology characteristics that were used as potential explanatory variables in the multiple regression analyses were bankfull width, bankfull cross-sectional area, mean bankfull depth, the median streambed-particle size (D_{50}), water-surface slope, width/depth ratio, flood-prone width, entrenchment ratio, and an index number ranging from 1 to 7, corresponding to the seven different values of the Rosgen stream classification of the 41 sites. An Ordinary Least Squares (OLS) stepwise-regression analysis indicated that the only explanatory variables that were significant for all design-peak and bankfull discharges were either bankfull width or bankfull cross-sectional area. Equations for estimation of design-peak or bankfull discharge based on bankfull width might be considered preferable to those based on bankfull cross-sectional area, because bankfull width is less complicated to measure than bankfull cross-sectional area.

Bankfull discharge at ungaged sites in most of the study area can be estimated by application of a multiplier after determining the 2-year peak discharge at the ungaged site. The multiplier, which is the ratio of bankfull discharge to the 2-year peak discharge determined at the 41 sites, ranged from 0.21 to 3.7 with a median value of 0.84. The reliability of estimates for bankfull discharge at ungaged sites based on the multiplier of 0.84 together with estimated values of the 2-year peak discharge is believed to be about the same as the reliability of the estimates for the 2-year peak discharge for the West Region. The reliability of estimates for bankfull discharge based on the use of the multiplier for ungaged sites in the Northwest Region is unknown.

Regression analysis of the relation between channel-morphology characteristics and drainage area and bankfull discharge to drainage area can provide a means of estimating channel morphology and bankfull discharge for ungaged streams when the drainage area is known. An OLS stepwise-regression analysis was used to relate the logarithms of bankfull width, mean bankfull depth, bankfull cross-sectional area, and bankfull discharge to the logarithms of drainage area, mean annual precipitation, and site latitude and longitude for all 41 sites. The results of each of the four regression analyses indicated that both drainage area and mean annual precipitation were significant explanatory variables for estimation of bankfull discharge. To ensure that regional curves relating channel morphology and bankfull discharge to drainage area alone would include the effects of mean annual precipitation, each site was assigned an index number (equal to a specific range of the mean annual precipitation). The regional curves developed for the study area can be used on a reconnaissance level to estimate channel morphology and bankfull discharge for ungaged sites in western Montana.

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DATA

Table 1. Channel-morphology characteristics and design-peak-discharge data for selected streamflow-gaging stations, western Montana

[Location of streamflow-gaging stations shown in figure 1. All sites are in Montana. **Bold text** denotes only those stations that were active during data collection (2000-03). Drainage area, bankfull width, mean bankfull depth, maximum bankfull depth, bankfull cross-sectional area, width/depth ratio, flood-prone width, entrenchment ratio, sinuosity, D_{50}, recurrence interval, and Rosgen classification defined in the glossary; measured characteristics are averages except entrenchment ratio, valley and channel slope, and sinuosity. Abbreviations: ft, foot; ft/ft, foot per foot; ft^2, square foot; mm, millimeter; ft^3/s, cubic feet per second. Symbol: <, less than]

Station number (fig. 1)	Station name	Bankfull width (ft)	Mean bankfull depth (ft)	Maximum bankfull depth (ft)	Bankfull cross-sectional area (ft^2)	Width/depth ratio[1]	Flood-prone width (ft)	Entrenchment ratio	Valley slope (ft/ft)	Channel slope (ft/ft)
12300400	Cayuse Creek near Trego	8.9	0.53	0.86	4.6	18.7	19	2.2	0.036	0.035
12300800	Deep Creek near Fortine	14	1.6	2.4	22.2	8.8	26	1.9	.012	.011
12301997	Richards Creek near Libby	8.7	.63	.75	5.4	13.8	16	1.9	.035	.033
12301999	Wolf Creek near Libby	34	1.5	2.2	50.9	24.1	44	1.3	.011	.010
12302400	Shaughnessy Creek near Libby	10	.85	1.2	8.8	12.2	13	1.4	.052	.049
12302500	Granite Creek near Libby	34	1.9	2.6	61.6	19.7	50	1.5	.025	.024
12303100	Flower Creek near Libby	25	1.8	2.7	43.8	14.5	38	1.6	.047	.042
12304040	**Basin Creek near Yaak**	30	2.2	3.4	64.2	13.6	112	3.7	.014	.008
12304060	Blacktail Creek near Yaak	21	1.2	1.8	24.6	17.5	65	3.1	.030	.026
12304120	Zulu Creek near Yaak	14	.94	1.6	12.7	14.9	61	4.5	.023	.022
12324100	Racetrack Creek below Granite Creek, near Anaconda	25	2.2	2.9	53.4	11.4	57	2.3	.007	.007
12324590	**Little Blackfoot River near Garrison**	57	2.7	3.7	150	21.1	140	2.6	.004	.003
12324700	Clark Fork tributary near Drummond	8.9	.39	.59	3.5	22.8	20	2.2	.013	.012
12329500	**Flint Creek at Maxville**	45	2.7	3.9	119	17.5	110	2.4	.003	.003
12330000	**Boulder Creek at Maxville**	33	1.8	2.5	56.7	18.3	45	1.4	.022	.018
12331700	Edwards Gulch at Drummond	6.1	.79	1.5	4.9	9.9	23	3.9	.035	.031
12332000	**Middle Fork Rock Creek near Philipsburg**	75	1.9	2.7	144	38.5	100	1.3	.010	.010
12335500	**Nevada Creek above Reservoir, near Helmville**	38	1.5	2.2	55.0	26.0	90	2.4	.005	.004
12338600	Monture Creek at Lolo National Forest boundary, near Ovando	73	2.1	2.9	152	36.8	370	5.0	.005	.004
12339300	Deer Creek near Seely Lake	21	.97	1.5	20.6	22.4	61	2.7	.008	.008
12339450	Clearwater River near Clearwater	120	2.2	3.5	261	56.2	362	3.1	.003	.003
12339900	West Twin Creek near Bonner	19	2.2	3.1	40.2	8.5	36	2.0	.054	.050
12340200	Marshall Creek near Missoula	4.4	.52	.74	2.3	8.9	10	2.6	.060	.060
12342950	Trapper Creek near Conner	49	2.0	2.8	95.5	25.2	268	4.9	.015	.015
12344300	Burke Gulch near Darby	8.1	1.2	1.5	9.9	6.8	16	1.9	.050	.050
12346500	**Skalkaho Creek near Hamilton**	33	2.0	2.9	65.2	16.3	41	1.3	.021	.020
12350500	Kootenai Creek near Stevensville	30	1.3	2.6	38.1	25.1	42	1.5	.048	.047
12351400	Eightmile Creek near Florence	14	2.0	2.6	27.0	6.8	65	4.8	.013	.010
12352000	Lolo Creek above Sleeman Creek, near Lolo	57	1.8	2.7	103	31.9	77	1.4	.005	.004
12352200	Hayes Creek near Missoula	8.3	1.1	1.2	9.0	8.2	28	3.3	.053	.051
12353820	Dry Creek near Superior	24	1.3	2.0	31.4	18.8	37	1.6	.014	.013
12353850	East Fork Timber Creek near Haugan	9.8	.76	1.4	7.9	13.7	32	3.2	.014	.014
12355350	Big Creek at Big Creek Ranger Station, near Columbia Falls	45	2.5	3.1	112	18.3	70	1.6	.013	.012
12369650	North Fork Lost Creek near Swan Lake	26	2.7	3.9	71.5	9.6	55	2.1	.010	.010
12374250	**Mill Creek above Bassoo Creek, near Niarada**	19	1.0	1.7	19.2	18.2	50	2.7	.028	.028
12375900	**South Crow Creek near Ronan**	18	1.6	2.9	29.3	11.7	33	1.8	.057	.053
12377150	**Mission Creek above reservoir, near St. Ignatius**	39	2.4	3.7	94.7	16.8	59	1.5	.016	.016
12383500	**Big Knife Creek near Arlee**	15	1.2	2.6	18.1	13.0	33	2.2	.033	.028
12387450	**Valley Creek near Arlee**	15	1.7	20.5	24.6	9.0	36	2.4	.032	.030
12388400	**Revais Creek below West Fork, near Dixon**	22	1.7	2.6	37.0	12.8	46	2.1	.035	.035
12391100	White Pine Creek near Trout Creek	26	1.4	2.4	37.3	18.5	42	1.6	.029	.028

[1]Data from individual cross-section values are not averages of bankfull width and mean bankfull depth.
[2]From Parrett and Johnson (2004).
[3]Determined from stage-discharge relation.
[4]Determined from water-surface profile model (U.S. Army Corps of Engineers, 2001a,b,c).
[5]Determined from uniform-flow equation (Henderson, 1966).

Table 1. Channel-morphology characteristics and design-peak-discharge data for selected streamflow-gaging stations, western Montana—Continued

Station number (fig. 1)	Sinuosity (ft/ft)	D_{50} (mm)	Estimated Manning's roughness coefficient (n)	Recurrence interval (bankfull discharge, in years)	Rosgen classification	Bankfull discharge (ft^3/s)	Design-peak discharge[2] (Q), in cubic feet per second, for indicated recurrence interval (in years)							
							2	*5*	*10*	*25*	*50*	*100*	*200*	*500*
12300400	1.09	31.0	0.063	1.1	B4	[3]17	51	89	120	162	197	235	276	334
12300800	1.03	28.0	.040	1.1	C4	[3]73	130	169	197	233	261	291	321	365
12301997	1.06	60.0	.045	1.4	C4	[4]13	24	50	71	100	123	148	173	207
12301999	1.10	105	.075	1.3	B3	[4]617	617	1,270	1,750	2,390	2,860	3,320	3,780	4,350
12302400	1.06	14.0	.043	4.3	A4	[4]28	11	30	52	94	141	203	287	439
12302500	1.08	110	.075	2.0	B3	[4]260	250	1,100	1,320	1,800	2,120	2,660	3,500	5,070
12303100	1.10	100	.070	1.2	B3	[4]130	250	320	390	490	610	840	1,200	1,730
12304040	1.02	21.0	.045	1.2	C4	[3]191	260	369	443	537	607	677	748	844
12304060	1.15	70.0	.065	2.2	B3	[5]80	73	128	169	227	275	325	378	454
12304120	1.05	39.0	.055	2.1	C4	[5]44	42	72	98	137	173	214	262	337
12324100	1.03	5.2	.035	1.3	C4	[4]275	366	485	556	637	693	745	794	855
12324590	1.03	27.0	.035	1.5	C4	[3]917	1,250	2,540	3,620	5,230	6,600	8,100	9,740	12,100
12324700	1.04	<.062	.032	2.4	C6	[3]60	47	100	147	221	287	361	446	574
12329500	1.36	28.0	.050	1.4	B4	[4]345	451	691	862	1,090	1,270	1,450	1,650	1,910
12330000	1.22	105	.065	1.7	B3	[3]335	372	570	726	953	1,150	1,360	1,600	1,950
12331700	1.11	<.062	.030	1.6	C6	[4]14	20	63	113	209	311	443	610	897
12332000	1.05	65.0	.065	1.2	C3	[3]554	906	1,240	1,430	1,640	1,790	1,920	2,040	2,190
12335500	1.14	9.0	.035	1.4	C4	[4]195	504	937	1,270	1,720	2,080	2,440	2,830	3,350
12338600	1.19	40.0	.073	1.3	C4	[4]1,130	1,350	1,650	1,820	2,020	2,160	2,290	2,410	2,560
12339300	1.02	32.5	.036	1.0	C4	[3]124	244	321	372	438	487	537	588	657
12339450	1.27	50.0	.030	1.6	C4	[4]1,400	1,600	2,200	2,630	3,210	3,670	4,160	4,680	5,410
12339900	1.08	80.0	.055	1.9	B3	[4]95	97	167	223	304	372	446	527	646
12340200	1.00	45.0	.043	1.2	C4	[4]9	17	27	35	48	59	71	85	106
12342950	1.04	60.0	.046	2.0	B4	[4]440	450	589	688	824	931	1,050	1,170	1,340
12344300	1.27	6.0	.075	4.4	B4	[3]14	9	15	19	24	28	31	35	40
12346500	1.07	160	.073	1.1	B3	[3]375	672	872	986	1,120	1,200	1,280	1,350	1,440
12350500	1.02	165	.075	1.4	A4	[3]670	814	1,060	1,200	1,360	1,470	1,570	1,660	1,770
12351400	1.27	5.7	.075	2.3	E4	[4]55	50	73	89	110	126	142	159	181
12352000	1.20	80.0	.035	1.1	C3	[3]1,140	1,460	1,760	1,960	2,210	2,410	2,610	2,810	3,090
12352200	1.04	15.0	.040	2.4	B4	[4]15	11	26	40	62	82	104	129	166
12353820	1.05	52.0	.045	1.2	C2	[4]140	386	462	508	561	599	635	670	714
12353850	1.03	5.0	.035	1.1	C4	[4]8	39	60	74	91	104	117	130	147
12355350	1.05	89.0	.035	1.0	C3	[3]719	1,140	1,440	1,650	1,940	2,160	2,390	2,640	2,980
12369650	1.03	215	.070	1.5	B3	[3]240	260	310	344	386	417	448	480	523
12374250	1.14	58.0	.052	3.1	C4	[3]66	43	82	116	170	220	279	348	458
12375900	1.14	110	.065	2.5	B3	[3]197	168	251	303	367	413	456	498	552
12377150	1.04	35.0	.045	3.0	B4	[3]480	420	531	598	675	729	780	828	890
12383500	1.18	22.6	.055	3.7	B3	[3]51	38	55	67	82	94	106	118	135
12387450	1.07	60.0	.057	2.1	B4	[3]59	57	79	93	112	127	142	157	177
12388400	1.03	100	.070	3.8	B3	[3]210	156	224	272	336	386	439	493	570
12391100	1.04	58.0	.065	1.2	B4	[4]130	212	340	442	591	717	858	1,010	1,250

Table 2. Basin and climatic characteristics for selected streamflow-gaging stations, western Montana[1]

[Location of streamflow-gaging stations shown in figure 1. All sites are in Montana. Latitude and longitude reported in degrees, minutes, and seconds; North American Datum of 1927 (NAD 27). Drainage area, mean annual precipitation, and percentage of basin covered by forest defined in the glossary. Abbreviations: mi^2, square miles; in., inches]

Station number (fig. 1)	Station name	Latitude	Longitude	Drainage area (mi^2)	Mean annual precipitation (in.)	Percentage of basin covered by forest
12300400	Cayuse Creek near Trego	483633	1150142	5.29	28	95
12300800	Deep Creek near Fortine	484600	1145300	18.9	50	92
12301997	Richards Creek near Libby	481531	1151157	9.50	29	90
12301999	Wolf Creek near Libby	481401	1151702	216	27	100
12302400	Shaughnessy Creek near Libby	481800	1153600	1.16	60	97
12302500	Granite Creek near Libby	481807	1153529	23.6	67	88
12303100	Flower Creek near Libby	482041	1153620	11.1	67	96
12304040	Basin Creek near Yaak	485549	1152856	27.4	[2]35	[2]96
12304060	Blacktail Creek near Yaak	485703	1153227	8.66	35	93
12304120	Zulu Creek near Yaak	484349	1153830	5.27	34	94
12324100	Racetrack Creek below Granite Creek, near Anaconda	461644	1125507	39.5	35	95
12324590	Little Blackfoot River near Garrison	463111	1124733	407	20	65
12324700	Clark Fork tributary near Drummond	463700	1130200	4.61	15	15
12329500	Flint Creek at Maxville	462750	1131420	208	20	68
12330000	Boulder Creek at Maxville	462820	1131359	71.3	31	98
12331700	Edwards Gulch at Drummond	464025	1130831	4.69	16	35
12332000	Middle Fork Rock Creek near Philipsburg	461142	1133000	123	35	93
12335500	Nevada Creek above Reservoir, near Helmville	464642	1124600	116	23	74
12338600	Monture Creek at Lolo National Forest boundary, near Ovando	470537	1130910	105	41	75
12339300	Deer Creek near Seely Lake	471237	1133227	19.8	39	82
12339450	Clearwater River near Clearwater	470109	1132312	345	37	81
12339900	West Twin Creek near Bonner	465500	1134300	7.33	25	62
12340200	Marshall Creek near Missoula	465300	1135500	5.63	23	84
12342950	Trapper Creek near Conner	455343	1141051	28.5	66	67
12344300	Burke Gulch near Darby	460200	1140900	6.50	22	80
12346500	Skalkaho Creek near Hamilton	460940	1135652	87.8	36	99
12350500	Kootenai Creek near Stevensville	463214	1140931	28.9	64	69
12351400	Eightmile Creek near Florence	463910	1135730	19.5	21	87
12352000	Lolo Creek above Sleeman Creek, near Lolo	464500	1140900	250	52	98
12352200	Hayes Creek near Missoula	464900	1140600	4.16	33	79
12353820	Dry Creek near Superior	471317	1145819	46.3	[2]54	[2]80
12353850	East Fork Timber Creek near Haugan	472500	1152500	2.72	58	89
12355350	Big Creek at Big Creek Ranger Station, near Columbia Falls	483607	1140955	82.1	48	74
12369650	North Fork Lost Creek near Swan Lake	475306	1134753	13.0	[2]57	[2]88
12374250	Mill Creek above Bassoo Creek, near Niarada	474949	1144145	19.6	[2]25	[2]97
12375900	South Crow Creek near Ronan	472930	1140133	7.57	67	48
12377150	Mission Creek above reservoir, near St. Ignatius	471923	1135843	12.4	74	33
12383500	Big Knife Creek near Arlee	470851	1135824	6.88	[2]41	[2]95
12387450	Valley Creek near Arlee	471013	1141347	15.3	[2]32	[2]93
12388400	Revais Creek below West Fork, near Dixon	471559	1142421	23.4	[2]36	[2]88
12391100	White Pine Creek near Trout Creek	474419	1154027	8.75	58	86

[1]U.S. Geological Survey (2004).
[2]William Stotts (U.S. Geological Survey, written commun., 2004).

Table 3. Three sets of regression equations for estimation of design-peak discharge in western Montana[1]

[Abbreviations: n, number of stations used in the regression analysis; *SEP*, standard error of prediction; Q_T, annual peak discharge, in cubic feet per second, for recurrence interval *T*, in years; *A*, drainage area, in square miles; *P*, mean annual precipitation, in inches; *F*, percentage of basin covered by forest; W_{ac}, width of active channel, in feet; W_{bf}, width of bankfull channel, in feet]

Regression equation	Average *SEP*, in log units	Average *SEP*, in percent	Regression equation	Average *SEP*, in log units	Average *SEP*, in percent
(1) Based on basin characteristics					
West Region (n = 96)			**Northwest Region (n = 35)**		
$Q_2 = 0.268 A^{0.927} P^{1.60} (F+1)^{-0.508}$	0.242	60.5	$Q_2 = 0.128 A^{0.918} P^{1.33}$	0.202	49.2
$Q_5 = 1.54 A^{0.884} P^{1.36} (F+1)^{-0.577}$	.224	55.4	$Q_5 = 1.19 A^{0.846} P^{0.954}$	.164	39.2
$Q_{10} = 3.63 A^{0.86} P^{1.25} (F+1)^{-0.605}$	.221	54.3	$Q_{10} = 4.10 A^{0.807} P^{0.72}$	.161	38.4
$Q_{25} = 8.50 A^{0.835} P^{1.14} (F+1)^{-0.639}$	.222	54.6	$Q_{25} = 15.8 A^{0.76} P^{0.51}$	.161	38.4
$Q_{50} = 13.2 A^{0.823} P^{1.09} (F+1)^{-0.652}$	.227	56.0	$Q_{50} = 31.2 A^{0.733} P^{0.445}$	.157	37.4
$Q_{100} = 18.7 A^{0.812} P^{1.06} (F+1)^{-0.664}$	.235	58.5	$Q_{100} = 56.4 A^{0.71} P^{0.403}$	.168	40.2
$Q_{200} = 24.7 A^{0.804} P^{1.04} (F+1)^{-0.674}$	.248	62.2	$Q_{200} = 97.0 A^{0.694} P^{0.364}$	.190	46.0
$Q_{500} = 35.4 A^{0.792} P^{1.02} (F+1)^{-0.69}$	.267	67.9	$Q_{500} = 175 A^{0.674} P^{0.347}$	.230	56.9
(2) Based on active-channel width					
West Region (n = 93)			**Northwest Region (n = 29)**		
$Q_2 = 1.11 W_{ac}^{1.74}$	.252	63.5	$Q_2 = 1.57 W_{ac}^{1.67}$	.318	84.3
$Q_5 = 2.46 W_{ac}^{1.63}$	.244	61.1	$Q_5 = 5.04 W_{ac}^{1.50}$	.294	76.4
$Q_{10} = 3.75 W_{ac}^{1.58}$	.245	61.4	$Q_{10} = 9.68 W_{ac}^{1.40}$	.297	77.3
$Q_{25} = 5.81 W_{ac}^{1.51}$	.252	63.4	$Q_{25} = 21.3 W_{ac}^{1.30}$	.302	79.1
$Q_{50} = 7.61 W_{ac}^{1.48}$	.261	66.2	$Q_{50} = 36.1 W_{ac}^{1.24}$	.312	82.3
$Q_{100} = 9.57 W_{ac}^{1.45}$	.272	69.6	$Q_{100} = 60.0 W_{ac}^{1.19}$	.325	86.7
$Q_{200} = 11.8 W_{ac}^{1.43}$	.286	73.8	$Q_{200} = 92.7 W_{ac}^{1.16}$	.342	92.9
$Q_{500} = 15.0 W_{ac}^{1.41}$	.304	79.8	$Q_{500} = 164 W_{ac}^{1.12}$	.370	103.4
(3) Based on bankfull width					
West Region (n = 90)			**Northwest Region (n = 29)**		
$Q_2 = 0.281 W_{bf}^{1.98}$	.281	72.3	$Q_2 = 0.527 W_{bf}^{1.82}$	.348	95.1
$Q_5 = 0.678 W_{bf}^{1.86}$	.266	67.5	$Q_5 = 1.93 W_{bf}^{1.63}$	.324	86.6
$Q_{10} = 1.08 W_{bf}^{1.79}$	.263	66.6	$Q_{10} = 4.00 W_{bf}^{1.52}$	.326	87.3
$Q_{25} = 1.75 W_{bf}^{1.72}$	.266	67.5	$Q_{25} = 9.46 W_{bf}^{1.40}$	.329	88.0
$Q_{50} = 2.34 W_{bf}^{1.69}$	.272	69.5	$Q_{50} = 16.6 W_{bf}^{1.34}$	.334	90.1
$Q_{100} = 2.99 W_{bf}^{1.66}$	.281	72.3	$Q_{100} = 28.4 W_{bf}^{1.29}$	.345	94.1
$Q_{200} = 3.72 W_{bf}^{1.64}$	.293	76.1	$Q_{200} = 45.0 W_{bf}^{1.26}$	.360	99.6
$Q_{500} = 4.82 W_{bf}^{1.61}$	.310	81.7	$Q_{500} = 81.6 W_{bf}^{1.21}$	.386	109.9

[1]From Parrett and Johnson (2004).