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Geomorphic Characteristics of Streams in the Eastern Mississippian Plateau Physiographic Region of Kentucky

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Executive Summary

Regional geomorphic relations, which describe average bankfull channel geometry and flow as a function of upstream drainage area for streams in a given region, provide a reliable point of reference for assessing stream conditions and evaluating channel dimensions and flow. Data collected from 16 out of 20 gauged and un-gauged sites were used to develop regional curves for bankfull channel depth, width, area, and discharge for rural, unregulated Eastern Mississippian Plateau (EMP) alluvial streams draining fewer than 47.8 mi^2. The bankfull discharge was also compared to the 1.01- and 1.5-year flows estimated from gauged streams in the EMP of similar drainage areas with at least 10 years of record of peak annual flow.

An extensive examination and collection of stream geomorphological characteristics in the EMP was conducted. Cross sections and longitudinal profiles were surveyed, and flow and bed sediment data were collected to compute bankfull parameters and to identify the channel type according to the Rosgen classification system. The effects of geology, historical land-use, and current land use on sediment loads and channel evolution were also considered in stream assessment and in development of the curves.

Bankfull regional curves were derived from collected data by using ordinary least-squares regression to relate bankfull channel dimensions and estimates of bankfull discharge to drainage area. The relationship between bankfull parameters and drainage area in the EMP region is described by curves that explain between 85% and 97% of the variation within the datasets for bankfull area, width, depth, and discharge. Standard errors are less than 28%. At each of the sites for which bankfull discharge was estimated, the bankfull discharge was found to be no more than 28% of the 1.5-year discharge at all of the gauged sites included in this study where bankfull parameters were measured. Therefore, use of the 1.5-year event for bankfull flow would represent a gross overestimate in most of the reaches examined in this study; estimates based on morphological features and/or the regional curves would be more accurate.

Geomorphic Characteristics of Streams in the Eastern Mississippian Plateau Physiographic Region of Kentucky

By William S. Vesely, Arthur C. Parola, Jr., Chandra Hansen,
and Margaret Swisher Jones

1. Introduction

The physical characteristics of stream channels strongly influence aquatic and riparian habitat, bank erosion, and sediment loads. Siltation, habitat modification, and flow alteration are the cause of nearly half of the identified stream impairments in the Commonwealth (KDOW 2008), with siltation cited most frequently. These primarily physical causes of stream impairment are all dependent on the presence of riparian vegetation; the entrainment, transport, and storage of sediment; and other geomorphic characteristics of stream channel networks. Changes in these characteristics are a product of complex watershed processes and human modification of the watershed and the stream channel network. Disturbance of streams due to land-use practices such as development, livestock grazing, land clearing, road construction, and channel modification or relocation tend to increase stream peak flow rates, disturb riparian vegetation, and alter stream channel characteristics. The response of many streams to disturbance can be excessive production of sediments through channel incision and subsequent severe bank erosion. The disturbances of streams and the associated erosion that continues for long periods can severely degrade stream and riparian habitat not only at the disturbed section of the stream but upstream and downstream as well.

To determine the implications of various physical impacts, specific geomorphic data are needed to evaluate flow stresses, sedimentation, and other physical habitat factors affecting biological communities. In assessing channel stability and habitat, estimates of bankfull flow conditions are particularly useful for

- Classification of the stream reach using the Rosgen (1996) method
- Determination of the degree to which the stream is incised
- Indication of relative bank stability
- Indication of some characteristics of channel pattern
- Indication of the capacity of the channel to transport its supplied load

Evaluation of channel stability is essential for the assessment of sediment loads, which may be needed for development of the sediment total daily maximum loads (TMDLs) required by recent US Environmental Protection Agency guidelines (USEPA 1999). Moreover, geomorphic data from a watershed's streams, including estimates of bankfull parameters, can be used as a basis for the design of stream restorations which physically alter disturbed stream channels in order to improve stream habitat, reduce bank erosion, and reduce sediment loads. In designing stream restorations, estimates of bankfull characteristics are useful for

- Initial estimation of channel geometry for planning of a restoration project prior to detailed morphological assessments required for final design
- Estimation of channel design parameters for sites where morphological characteristics are inconsistent or have not been developed
- Comparison of restoration designs developed using other methods
- Evaluation of restoration designs by permit agencies

Estimates of bankfull parameters may be obtained through direct measurement of similar channels in a watershed or region, or they may be obtained through analytical procedures such as the development of an effective discharge. They may also be obtained through the use of regional curves, which describe average bankfull width, depth, cross-sectional area, and discharge as a function of upstream drainage area for streams in a given region. Given the strong influence of local climate and geology on stream channel form, regional curves are typically developed with respect to physiographic region (e.g., Brush 1961; Harman et al. 1999; Kilpatrick and Barnes 1964; Leopold et al. 1964; McCandless and Everett 2002; Smith and Turrini-Smith 1999; Wolman 1955). While regional curves do not account for all sources of variability in channel characteristics, their formulation does include consideration of geologic conditions, land use, and valley use, and they provide a reliable point of reference for assessing stream conditions and evaluating channel dimensions and flow.

1.1 BACKGROUND

Quantitative geomorphology has been used for over half a century to support the assessment of channels and floodprone areas. Hydraulic geometry relations developed by Leopold and Maddock (1953) described the relationship between channel dimensions and mean annual discharge within specific drainage basins. In the next decade, hydraulic geometry relations, or at-a-station curves, were developed for several geographic regions in the eastern US (Brush 1961; Kilpatrick and Barnes 1964; Leopold et al. 1964; Wolman 1955). After the introduction and deliberation of the concept of a bankfull discharge, whose stage is just contained within the stream banks (Wolman and Leopold 1957; Wolman and Miller 1960), bankfull channel geometry and discharge data were also collected in the early 1970s (Emmett 2004). In the late 1970s, Dunne and Leopold (1978:614) noted the correlation between bankfull channel parameters and drainage area, and they introduced curves describing average bankfull channel dimensions and bankfull discharge as a function of drainage area in “hydrologically homogenous” regions. In the last decade, regional curves have been developed for physiographic regions across much of the US (e.g., NRCS 2007).

1.2 PROJECT PURPOSE AND SCOPE

Stream restoration efforts intended to improve stream habitat have been conducted in the Eastern Mississippian Plateau (EMP) region without general information on the geomorphic characteristics of its streams. The main purpose of this project was to provide quantitative descriptions (regional curves) that would represent expected values and variation of bankfull flow and channel cross-sectional area, width, and depth as a function of upstream drainage area in the EMP physiographic region of Kentucky.

Data used to develop the regional curves were collected from 20 sites on 12 gauged and ungauged EMP streams in March and April of 2008; bankfull discharge was estimated for 10 of these sites, 5 of which were sufficiently close to gauging stations with sufficient peak data that return periods for bankfull discharge could be computed. Criteria used to identify suitable stream channels for regional curve data collection included a wide range of drainage areas within the region and as many streams as possible having a channel environment that was predominantly alluvial and showed no signs of ongoing rapid morphological change (cf. McCandless and Everett 2002; Smith and Turrini-Smith 1999). Bankfull regional curves for cobble- and gravel-bed streams draining from 0.10 to 47.8 mi^2 were derived from the data for 16 alluvial study reaches by using ordinary least-squares regression to relate bankfull discharge and bankfull channel dimensions to drainage area.

2. The Eastern Mississippian Plateau Physiographic Region

The physiographic regions of Kentucky correspond to geologic regions of the state (Figures 2.1a and b), as the effects of surface weathering and erosion of different geologies produce landscapes and streams of dissimilar characteristics. The Eastern Mississippian Plateau (Figure 2.1c) is a sub-region of the more expansive Mississippian Plateau region, which extends from the Mississippi Embayment region in far western Kentucky to the Eastern Kentucky Coal Field region of far eastern Kentucky (Figure 2.1b). The EMP region has been delineated primarily by the extent and intensity of karst features common to some of the stratigraphy immediately east of Mammoth Cave. The Cumberland Escarpment defines the eastern boundary of the EMP region, and the Muldraugh Hills interface with the Knobs physiographic region defines the northern boundary.

The EMP encompasses all or part of 15 counties and covers roughly 3800 mi^2. Those counties that lie almost entirely within the region are Adair, Allen, Cumberland, Monroe, Russell, and Taylor. Portions of Barren, Casey, Clinton, Green, Lincoln, Metcalfe, Pulaski, Rockcastle, and Wayne Counties are also included. The major stream systems of the region include the Green and the Cumberland rivers.

2.1 STRUCTURAL GEOLOGY AND STRATIGRAPHY

The Eastern Mississippian Plateau physiographic region is located on a much larger geologic structure known as the Cincinnati Arch (Figure 2.1b), a north-south oriented structural feature extending northward from the Nashville Dome in central Tennessee into Ohio. Once the location of a rift basin when much of continental North America was inundated, the basin experienced a period of uplift beginning in the Cambrian Period (500-570 mya) and became an arched feature that is now relatively stable. In Kentucky, this area is bounded on the west by the Illinois Basin (containing the Western Kentucky Coal Field physiographic region), which extends throughout southeastern Illinois and southwestern Indiana, and on the east by the Appalachian Basin (containing the Eastern Kentucky Coal Field physiographic region), which extends northeasterly from central Tennessee into Pennsylvania.

(a)

(b)

(c)

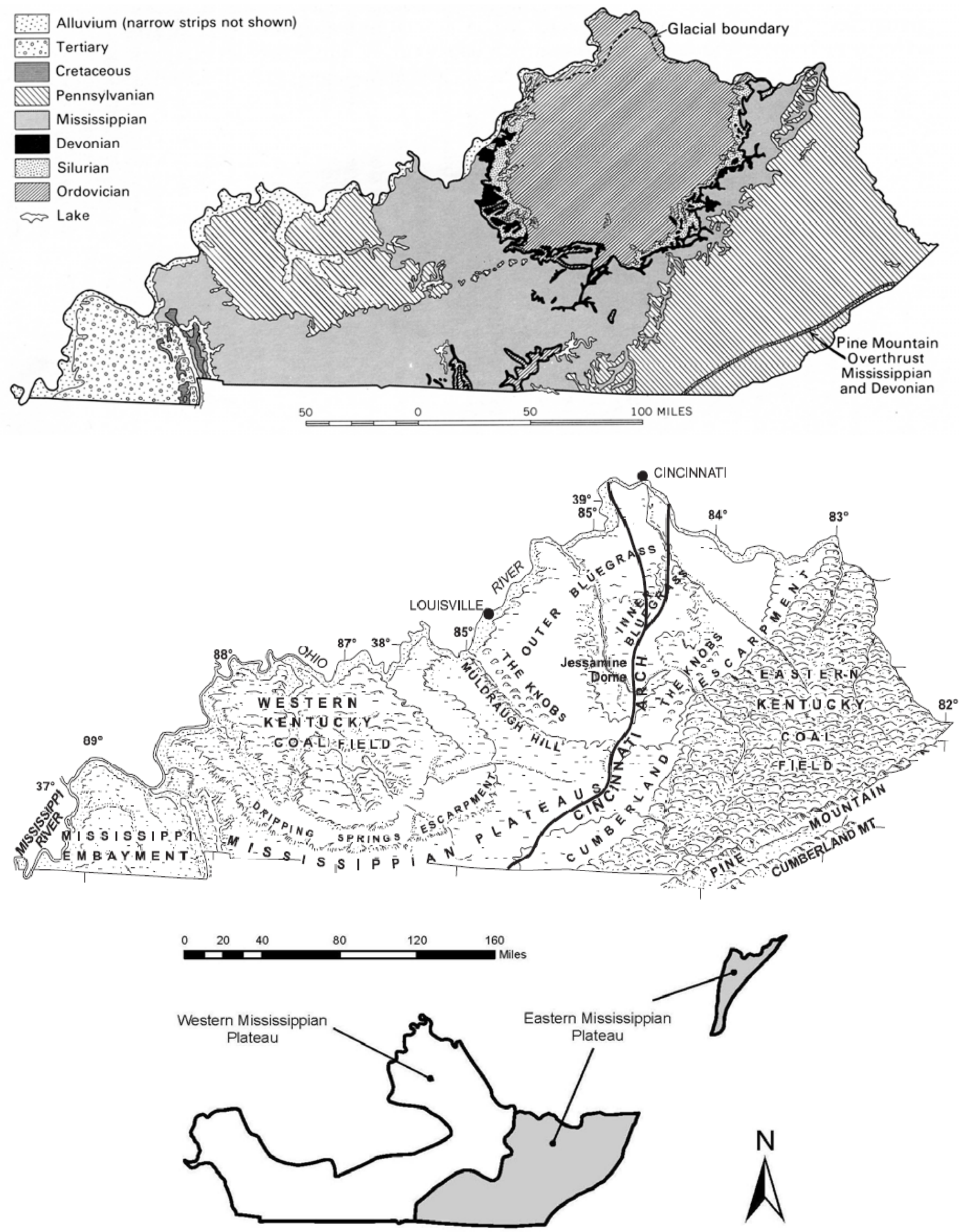

Figure 2.1 (a) Generalized geologic map of Kentucky (after McGrain 1983:12).
(b) Physiographic map of Kentucky (KGS 1980).
(c) Physiographic boundaries of the Eastern and Western Mississippian Plateau regions (KGS 2002).

The effects of the Cincinnati Arch (anticline) on the observed stratigraphy of the EMP region is a generally east-west dip in bedrock layers adjacent to the arch axis (on the order of 5 to 10 feet per mile), and the exposure of Lower Mississippian strata (and older strata that are adjacent to the Cumberland River) that have been subjected to erosion by rivers. The strata from the Mississippian Period (325-360 mya) are mostly marine sedimentary rocks (Figure 2.2 and Table 2.1). They are approximately 2000 feet thick in the EMP and represent the deposition in and shallowing of an expansive inland sea (Grabowski 2001). Though the strata are predominantly limestone, many contain significant amounts of shale, siltstone, dolomite, and sandstone. The Ste Genevieve and St. Louis Limestones are thinner in the EMP than in western portions of the Mississippian Plateau; therefore, EMP rivers and streams are less affected by sub-surface flow in carbonate strata solution cavities than those in the western portions. Minor exposures of Ordovician, Silurian, and Devonian strata are also present in this region (Figure 2.2).

2.2 PHYSIOGRAPHIC SETTING

The Green and Cumberland Rivers impart a significant influence on the geomorphic conditions of the EMP region. Periods of incision and aggradation along both rivers have sculpted the landscape of both the river bottoms and adjacent uplands. A major period of incision occurred more than 1.5 mya when the Ohio River was influenced by glaciation and sea-level changes. Some of the upland areas, however, have maintained erosion rates that are slower than estimated river incision rates (Granger et al 2001; Anthony and Granger 2006). As a result of these and later processes, the EMP may be described as three different physical subdivisions Sauer (1927): the Greenburg Area, the Mountain Margin, and the Cumberland Bends.

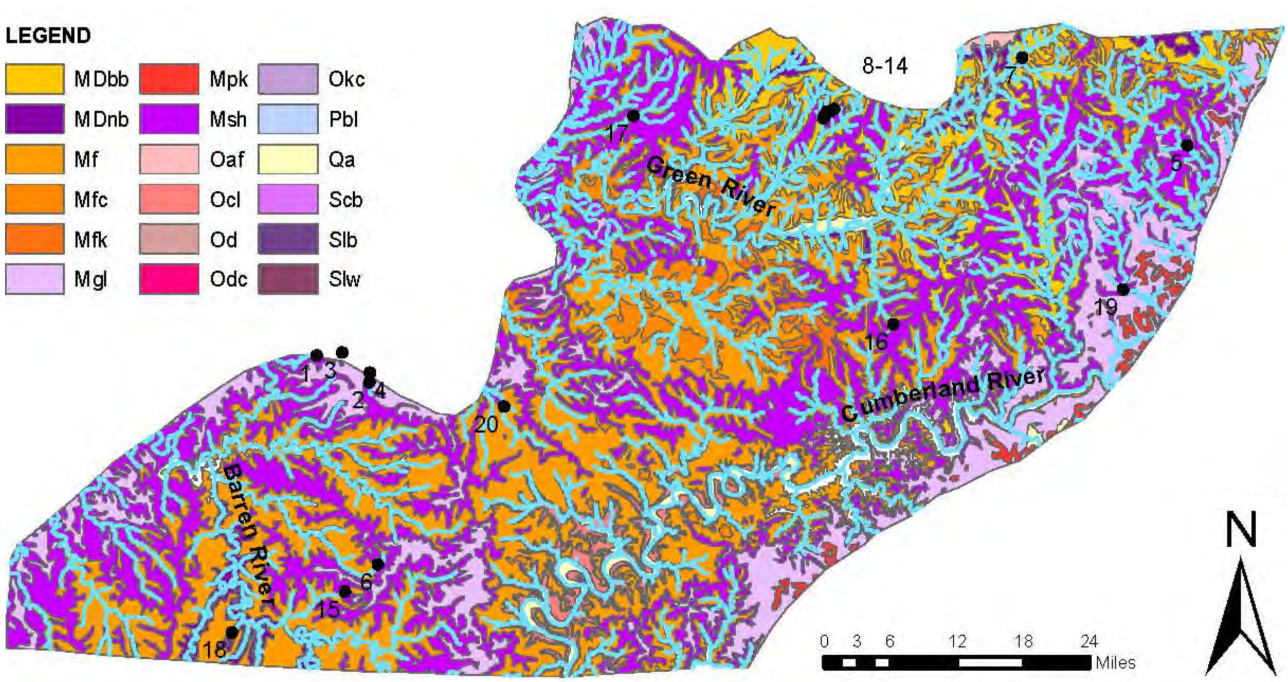

Figure 2.2 Geology of the EMP region (KGS 2002; KYDGI 2005b; Noger 2002).

Table 2.1 EMP Generalized Stratigraphy*

Period	Series		Formations and Descriptions
MISSISSIPPIAN	Upper Mississippian	Chester	Includes the Pennington, the Bangor Limestone, the Hartselle Formation, and the Kidder Limestone Member of the Monteagle Limestone (Mpk). The Pennington Formation is clay shale with minor amounts of sandstone and limestone and is up to 200 feet thick. The Bangor Limestone consists of argillaceous and arenitic skeletal limestone, typically 20-50 feet thick. The Hartselle Formation is largely a green clay shale up to 50 feet thick with minor amounts of sandstone except toward the KY/TN border where the sandstone content increases. The Kidder Limestone is up to 230 feet of oolitic limestone with some lime mudstones and minor siltstone and shale in the upper half.
		Meramec	Includes the lower portion of the Monteagle Limestone, the St. Louis Limestone (Mgl), and the Salem and Warsaw Formations (Msh). The Monteagle Limestone is represented by the Ste. Genevieve Limestone Member (Mgl), which is up to 90 feet of oolitic limestone with a thin zone of indistinct silicified breccias at the top. The St. Louis Limestone is up to 160 feet of very fine-grained limestone, dolomite, and fossiliferous siltstone. Many of the karst-prone areas are found in the above described limestone strata. The Salem and Warsaw Formations cannot everywhere be differentiated in the EMP and, thus, as a unit are described as argillaceous limestone and limey shale at the top and base and dolomitic siltstone and shale in the middle.
	Lower Mississippian	Osage	Includes the Fort Payne Formation (Mf/Mfc/Mfk) and the lower portions of the Borden Formation (MDbb), which is represented by Renfro, Wilde, Nada, Halls Gap, Holtsclaw Siltstone, Cowbell, Bedford, and Nancy Members. The Fort Payne Formation is a layer of dolomitic siltstone and cherty, dolomitic limestone. It is up to 660 feet thick but thins northward where it is more silty, shaly, and dolomitic and less siliceous. The Borden Formation members are a sequence of siltones, shales, and some sandstones having boundaries which often can only be approximately located. The sandstone members thicken toward the northeast in the EMP.
		Kinderhook	Represented by the Maury Formation equivalent, which is a greenish claystone typically of less than a foot thick, and upper portions of the New Albany, Chattanooga, and Ohio Shales (MDnb).

* The typical stratigraphy of the region provided by the US Geological Survey (Sable and Dever 1990; Grabowski 2001).

The Greenburg Area has long, relatively flat-topped ridges, between which lie streams in deep, wide valleys. Toward the northeast, nearest the Mountain Margin area in the upper Green River drainage, ridges become more rugged where remnant cap rock persists (Sauer 1927). These features are most readily observed in northern Green, Taylor, and Casey counties, and are less conspicuous along the Green and Cumberland rivers divide. Further south, for example in southern Taylor County, surficial erosion of the uplands is less prominent. Swales extend downward from the hill tops before defined stream channels begin, and slopes from the ridges to the valley bottoms may be flatter than in northern parts of the region (Figure 2.3). Further south still, drainage into the Cumberland River from the north is often steep and smaller streams have formed fluvial features well into the uplands. Near the middle and southern contact with the Mountain Margin are ridges underlain with karst-prone limestone. These have not completely eroded, due in part to the undulating rock structure in the area. Nearer the Cincinnati Arch the Green River and some of its tributaries have incised into weak lower Mississippian shales (Figure 2.4).

Figure 2.3 Flatter sloped hillsides between ridge tops and valley bottoms in central Taylor County (Little Pitman Creek).

Figure 2.4 Stream incision into lower Mississippian shales near the Cincinnati Arch in Lincoln County (McGills Creek of the Green River).

The Mountain Margin is a "piedmont" area adjacent to the Cumberland Escarpment, which Sauer (1927) broadly divided into three, north/south-oriented regions. The western region has a highly dissected topography, affected most strongly by the Cumberland River and having only margin influence by karst stratigraphy. Here the ridges are mostly narrow and dissected, while the larger rivers are often in wide valley (Figure 2.5). The central part is a rolling upland with areas having karst features, similar to those along the western boundary of the EMP, where solution cavity-forming limestone remains. The eastern portion along the escarpment consists of limestone valleys with ridges of sandstones, producing streams with higher sand loads than those in other portions of the EMP (Figure 2.6).

The Cumberland Bends (Cumberland Enclave) area is delineated by the lateral extents of the incised meander bends of the Cumberland River (Sauer 1927), beyond which the terrain is characterized by steep hills and rugged topography. A series of terraces and ridges marks recurring periods of the river's erosion and deposition of the Cumberland Bends and, upstream, areas of the Eastern Kentucky Coal Field region.

Figure 2.5 Broad valley and rugged hilltop terrain in the southern portion of the Cumberland River basin in Cumberland County (Bear Creek).

Figure 2.6 Stream of the Mountain Margin area draining valleys with sandstone and limestone (Bee Lick Creek).

3. Measurement and Analysis Methods

Bankfull channel characteristics were measured at 20 gauged and un-gauged sites throughout the EMP region. Channel cross section, longitudinal profile, and bed material data were used to calculate channel dimensions and parameters needed for classifying the channel, developing bankfull regional curves, and at 10 locations, estimating bankfull discharge. The bankfull discharge was also compared to the 1.01- and 1.5-year flows estimated for gauged locations in the EMP with at least 10 years of record of peak annual flow.

3.1 SITE SELECTION

Initial Screening of USGS Gauging Stations

When bankfull conditions can be identified at gauging stations, discharge can be related to the bankfull stage, and the frequency of bankfull flow events can be estimated. Therefore, USGS gauging stations with drainage areas of less than 50 mi^2 were initially considered in the selection of a sample to represent the EMP's population of streams. Gauge data, however, was not included as a screening factor when selecting potential study sites; gauged sites found to be suitable for measuring bankfull parameters would be included in the sample regardless of the utility of the gauge data. Fifteen stations were screened by examining aerial photographs of their locations and evaluating them according to two preliminary selection criteria:

1. Land use. Because streams in watersheds with a significant proportion of densely urbanized land tend to be undergoing rapid morphological change, watersheds that were more than 10% urbanized and those known to be undergoing urbanization were excluded.

2. Site characteristics. Sites known to have characteristics that would make them unsuitable for data collection (e.g., those that were known to be regulated, affected by waterway structures, or undergoing rapid morphological change) were excluded.

Two of the stations did not meet these criteria and were eliminated. Contour maps and aerial photographs were then reviewed to identify characteristics that could be relevant to field evaluation of the sites that had not been eliminated from consideration. The following tasks were completed in the review:

1. All stations were located on 1950s or later revisions of USGS 7.5-minute topographic quadrangle maps.
   a. Reaches likely to present consistent and reliable bankfull indicators were identified.
   b. Stream reaches in the vicinity of the gauges were examined for evidence of channel straightening, realignment, or other modifications.
   c. Any structures spanning or encroaching on the stream channel were identified.
   d. Valley constrictions, stream confluences, or sharp bends that could create backwater during high flows were recorded.
2. Aerial photographs were examined to identify land use changes and possible impacts to the stream channel and the floodplain that had occurred since the creation of the topographic and geologic maps.
3. The bedrock material underlying each site and its watershed were identified from Kentucky Geological Survey (KGS) 7.5-minute geologic quadrangle maps.
4. Surface drainage areas for each station were recorded from the total drainage areas provided with USGS gauge descriptions. Field reconnaissance was limited to streams in watersheds draining fewer than 50 mi^2.
5. The boundaries of the watershed of each station were identified using geospatial datasets (KGS 2002; Noger 2002). None of the streams draining fewer than 50 mi^2 had significant portions of their watersheds outside the EMP.

Initial Screening of Un-Gauged Sites

In order for the sample of selected sites to be optimal for the development of bankfull regional curves, it would ideally consist of sites on rural, unregulated, wadeable streams with active gauges and a wide distribution of drainage areas and geographic locations. The limited number of gauged sites, however, necessitated that un-gauged sites be included in the sample selected to represent the region's population of streams.

Un-gauged candidate sites on active channels were identified on the USGS 7.5-minute quadrangle maps and screened according to the above-listed land use and site characteristics. The un-gauged sites' drainage areas and geographic locations were also included as factors in screening and selection to produce a distribution broadly representative of the regional stream population. Because streams draining fewer than 10 mi^2 are the focus of the majority of natural channel design efforts (i.e., those that would make use of regional curves), their representation in the sample was considered a priority. About 25 un-gauged sites were selected for further evaluation.

Field Reconnaissance

An initial reconnaissance visit was made to photograph and evaluate each potential gauged and un-gauged site. Channel conditions throughout the region, as in other physiographic regions of Kentucky (Parola, Skinner, et al. 2005; Parola, Vesely, et al. 2005), were frequently found to be characterized by reach-scale instability, a lack of consistent and unambiguous bankfull indicators in incised channels, and recently modified channel geometry. The field evaluation eliminated five of the remaining twelve gauged sites and all but thirteen un-gauged sites based on two criteria:

1. Access. To obtain morphological data, a stable reach had to be accessible. Sites on private land were only selected if landowners granted access.
2. Channel morphology. Sites that met the above criteria were given further consideration only if the channel showed no signs of ongoing rapid morphological change and the geomorphic characteristics of the reach were suitable for surveying of bankfull indicators.

The suitability of the channel for surveying of bankfull indicators was determined based on evaluation of the floodplain and channel morphology upstream and downstream of the gauge or within the un-gauged reach. At a minimum, the reach had to have (1) cross-sectional geometry with unambiguous indicators of the bankfull level and evidence of at least one bank having been formed by deposition, (2) channel geometry that was not controlled by a structure, and for gauged sites, (3) a drainage area that differed by no more that 10% from the drainage area at the gauge station.

The bankfull level was determined according to the definition of bankfull flow proposed by Dunne and Leopold (1978), who described it as the flow that completely fills the channel so that its surface is level with the active floodplain. The active floodplain is the flat depositional surface adjacent to the channel that is constructed by the present river in the present climate and is frequently inundated by the river (Dunne and Leopold 1978). Dunne and Leopold also reported an approximately 1.5-year average return interval for bankfull flow; in the identification of the active floodplain of EMP assessment reaches, however, no minimum or maximum bankfull return period was assumed.

The primary indicators used to identify the active or actively-forming floodplain were fine-grained depositional features (Dunne and Leopold 1978). The characteristics of these features varied depending on channel morphology. The primary indicator for incised channels was a low depositional bench, and the bankfull level was identified as the point at which the slope transitioned between steep and horizontal (Figure 3.1). In cases where smaller, indistinct channels were forming within an incised channel, a primarily flat, vegetated bench was the most consistently observed depositional feature (Figure 3.2). Other incised channels lacked flat terraces; instead, the region between the valley flat and the channel was only a gently sloped incline, often with active accretion of fine sediment, and the bankfull level was not identifiable. In streams that were not incised, the bankfull level coincided with the top of bank and valley flat (Figure 3.3).

Identification of the bankfull level was refined by comparing elevations of multiple indicators and evaluating secondary, non-morphological indicators. The elevations of bankfull indicators along the channel were compared to confirm that they were consistent relative to the water surface. Secondary indicators of the bankfull level included the size fraction of the depositional material and changes in vegetation above and below the level identified as bankfull.

Final Site Selection

A total of 20 reaches on 12 streams were selected as study sites (Table 3.1). Seven of these study sites had USGS gauges. The other 13 sites were un-gauged. Drainage areas ranged from 0.10 mi^2 to 47.84 mi^2. The locations of each study site within the EMP region are shown in Figure 3.4.

Figure 3.1 Little Pitman Creek in Taylor County. The bankfull level is represented by a narrow, horizontal depositional bench below and distinct from the higher valley flat.

Figure 3.2 Well-developed, flat, vegetated bench within a larger disturbed channel along Pitman Creek, Pulaski County.

Figure 3.3 Beaver Creek in Barren County. The bankfull level coincides with the valley flat.

3.2 DATA COLLECTION

At all sites, sufficient channel and overbank topographic data and bed sediment data were collected to calculate bankfull parameters and to identify the channel type according to the Rosgen (1996) classification system. At three gauged sites, measurements of water and atmospheric pressure were collected to estimate bankfull discharge.

Channel Geometry

During field reconnaissance on gauged and un-gauged streams, morphological data was photo-documented and surveyed for the development of regional curves. The geomorphic features that were photo-documented included bankfull indicators, bed configuration, bed material, bank condition, flow patterns, valley configuration, dominant vegetation, and any structures that might affect flow within the channel or over the valley bottom.

Field surveys recorded cross-sectional and, at some sites, longitudinal profile data. Survey data were collected according to the procedures described in Harrelson et al. (1994). Survey control points consisting of at least two wooden stakes or steel re-bar were installed at each cross section location. Where practical, cross sections and longitudinal profiles were surveyed using a Nikon DTM-352 total station; measurements were accurate to within 1 cm in both the horizontal and vertical directions. Collected survey data were stored on a hand-held data logger during field activities and then transferred to a spreadsheet software program for analysis. Where a total station survey was not practical due to the remoteness of the site location, no longitudinal profile was surveyed, and cross section data were collected with the use of a line level, station tape, and elevation rod according to the following procedures:

Table 3.1 Assessment Site Location Summary

	Stream Site	USGS Gauge	Drainage Area (mi^2)	County	Latitude	Longitude
1	Beaver Creek at Hwy 31 nr Glasgow, KY	03312765	47.84	Barren	N37.03476	W85.90877
2	Beaver Creek at Mount Pisgah Road	—	7.11	Barren	N37.00016	W85.82263
3	Beaver Creek at SR 740	—	42.75	Barren	N37.03881	W85.86695
4	Beaver Creek near Old US 81	—	29.72	Barren	N37.01250	W85.82144
5	Bee Lick near Randy, KY	—	11.2	Pulaski	N37.30308	W84.48199
6	Bethlehem Branch near Mud Lick, KY	—	0.63	Monroe	N36.76211	W85.80851
7	Green River near McKinney, KY	03305000	22.4	Lincoln	N37.42027	W84.75089
8	Gum Lick Creek Site 1	—	1.65	Casey	N37.35306	W85.06491
9	Gum Lick Creek Site 2	—	1.72	Casey	N37.35238	W85.06644
10	Gum Lick Creek Site 3	—	3.64	Casey	N37.34288	W85.07759
11	Gum Lick Creek Tributary at Gum Lick Road	—	0.10	Casey	N37.35176	W85.06874
12	Gum Lick Creek Tributary Site 1	—	0.49	Casey	N37.35510	W85.06086
13	Gum Lick Creek Tributary near Clementsville, KY	03305835	0.71	Casey	N37.35211	W85.07231
14	Gum Lick Creek Tributary Site 2	—	0.78	Casey	N37.34536	W85.07757
15	Indian Creek near Flippin, KY	—	4.4	Monroe	N36.72633	W85.86183
16	Irvin Branch near Salem, KY*	03305725	1.37	Russell	N37.07343	W84.96627
17	Little Pitman Creek near Campbellsville, KY	03307260	19.3	Taylor	N37.34738	W85.38925
18	Long Hungry Creek near Mt. Zion, KY	—	5.8	Allen	N36.67263	W86.04540
19	Pitman Creek at Somerset, KY	03412500	31.3	Pulaski	N37.11582	W84.59004
20	South Fork Little Barren River at Edmonton, KY	03307500	18.3	Metcalfe	N36.96843	W85.60256

* Only morphological data was used for this USGS gauged reach; gauge data was not used.

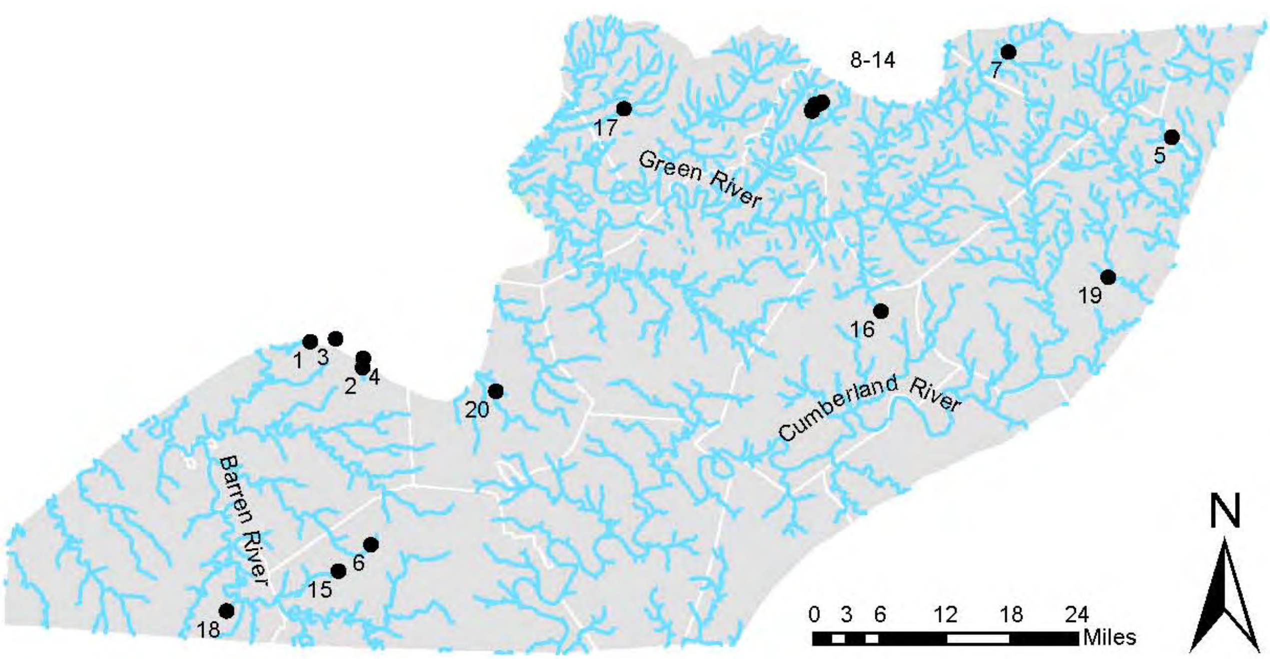

Figure 3.4 Locations of assessment sites. All fourth-order (Strahler 1957) or larger streams are shown (KGS 2002; KYDGI 2005a, 2005b; USEPA and USGS 2005).

1. A string line was pulled taut across the channel between the cross-section control points and set to a level horizontal plane using a line level. The taut line established a horizontal datum to which all elevation data were referenced.
2. A graduated survey tape was strung parallel to the datum line with zero set at the left bank (facing downstream).
3. The cross section was measured by noting the cross-channel station and measuring the vertical distance from the datum using a graduated tape. Distance, elevation, and point description data were recorded by a second survey crew member.

All cross sections were surveyed at locations that both coincided with a clear bankfull indicator and were representative of the reach morphology: at the crest of a riffle whenever possible or, at sites where no well-developed riffle was located in a reach with clear bankfull indicators, at a plane-bed section of the longitudinal profile. In reaches where multiple cross sections were taken, the cross section taken at the most clearly defined riffle crest was used to compute bankfull parameters. Selection of the most appropriate riffle crest for computing bankfull parameters was based on an extensive examination of the reach and its bankfull indicators. Where bankfull indicators suggested a number of possible bankfull levels, the level indicated by the lowest depositional features that were consistent relative to the water surface elevation was selected as bankfull. Only after the bankfull level was determined was the most appropriate riffle crest selected for surveying. Cross sections were surveyed to the width of the floodprone area or, when the floodprone width was clearly greater than four times the bankfull width, to a point at least one bankfull width from the top of each bank. Longitudinal profiles measured the elevations of the thalweg, water surface, bankfull indicators, and top of bank at several locations along the assessment reach.

The amount and extent of the survey data collection at each site depended largely on site accessibility. Where accessibility allowed for transport of conventional survey equipment to the site, multiple cross sections and the longitudinal profile were surveyed. At remote sites where a total station survey was not feasible, only cross sections were surveyed.

Bed Sediment Characteristics

The surface particle-size distribution was evaluated at each site on the riffle or plane-bed location surveyed to compute bankfull parameters. The Wolman (1954) pebble counting procedure was used at sites where bankfull discharge would be estimated and at several sites where only bankfull geometric parameters were evaluated. At most other sites, the size class corresponding to the median sediment size was visually estimated.

Bankfull Stage and Discharge

The gauge data for each of the seven gauged study sites was reviewed to determine which of the gauges would be useful for determination of bankfull discharge. The number of measurements of flows that were near (above and below) the bankfull level had to be sufficient for development of a stage-discharge relation (rating curve). Data from gauges that recorded only higher flows could not be used.

Three gauged sites had sufficient stage-discharge data for use in determining bankfull discharge: Beaver Creek near Glasgow, Green River, and Little Pitman Creek. At these sites, measurements of water and atmospheric pressure were logged to correlate the bankfull stage at the study site with the corresponding stage at the gauging station. Three pressure transducers from Solinst Canada, Ltd., were deployed at each study site where this method was employed:

- One submerged Gold Series model F15 Levelogger® anchored to the streambed at the study riffle.
- One submerged Gold Series model F15 Levelogger® near the low-flow water surface elevation at the gauging station (typically attached to a bridge pier or abutment).
- One Barologger® attached to a tree above the highest possible water level at the site.

The submerged loggers measured the total pressure (water depth and atmospheric pressure), while the Barologger® measured and logged the atmospheric pressure at the same times and intervals as the submerged loggers. The instruments have an accuracy of 0.05% of full scale (±0.01 feet for the Levelogger® and ±0.003 feet for the Barologger®). They can store 40,000 readings, allowing for extended deployment for obtaining high-flow data. Logging intervals were set (using the Solinst software) to five minutes at all sites; at these sites' drainage areas, this interval was short enough that the water surface change would typically be less than 0.2 feet between readings. The loggers were removed from the field once a rainfall event had occurred that was of sufficient magnitude to cause the water level at the study site to reach or exceed the bankfull elevation.

3.3 DATA ANALYSIS

Bed Sediment

Substrate Classification

Study reaches were classified as either alluvial or bedrock. A reach was classified as alluvial if deposits of coarse sediment (b-axis greater than 2 mm) were sufficient to form stable riffles, irrespective of the influence of bedrock on other channel bed conditions (e.g., limiting pool depth). Reaches classified as bedrock were typically but not strictly devoid of sediment deposition; deposits were limited, however, to lateral bars with no observed stable riffle features.

Particle Sizes

A cumulative frequency distribution was computed and plotted from the particle sizes recorded in the pebble counts, and grain sizes were classified according to the Wentworth (1922) scale. From the distribution curve and data, the particle sizes that equaled or exceeded 50 percent (D_{50}) and 84 percent (D_{84}) of the sampled material were determined for use in classifying the reach (Rosgen 1996) and computing bankfull discharge, respectively. For classification purposes, the measured or visually estimated D_{50} of the study riffle was considered to be representative of the dominant particle size throughout the reach.

Cross Sections and Profiles

Survey data were reduced using AutoCad. Cross section and longitudinal profile data were then extracted from AutoCad and plotted using Microsoft Excel. Each surveyed cross section at each site was plotted at a 1:1 horizontal-to-vertical scale so that breaks in slope could be clearly identified. Based on each cross section plot, multiple parameters were analyzed as follows:

- Bankfull indicators on both banks were identified and evaluated on each cross section plot to confirm that they corresponded to the active floodplain. Where unincised reaches exhibited natural (or manmade) levee formation, bankfull dimensions were calculated with reference to the consistent valley flat elevation beyond the levees.

- The cross section taken at the most clearly defined riffle crest or plane-bed reach at each site was used to compute bankfull parameters needed for
  - Developing regional curves: bankfull cross-sectional area (A_{BKF}); bankfull width (W_{BKF}); and mean bankfull depth ($D_{BKF} = A_{BKF} / W_{BKF}$).
  - Estimating bankfull discharge: bankfull wetted perimeter (WP_{BKF}), and bankfull hydraulic radius ($R_{h\ BKF} = A_{BKF} / WP_{BKF}$).
  - Classifying each assessment reach according to the Rosgen (1996) Level II classification system: maximum bankfull depth (D_{MAX}); floodprone width (W_{FP}); entrenchment ratio ($ER = W_{FP} / W_{BKF}$); and width-to-depth ratio (W_{BKF} / D_{BKF}).
- Cross section plots were compared to photographs of the same locations. Banks and depositional features in each cross section plot were examined in the photographs to evaluate their stability.

The longitudinal profile of each surveyed channel thalweg, water surface, bankfull indicators, and top-of-bank elevation were plotted with an exaggerated vertical scale so that breaks in slope could be clearly identified. The locations of cross sections were also plotted on each longitudinal profile. Based on each profile plot, bankfull levels at each cross section location were verified. A regression line was plotted through elevations of all bankfull indicators that were consistent relative to the water surface elevation. Where bankfull indicators suggested a number of possible bankfull levels, the level indicated by the lowest depositional features that were consistent relative to the water surface elevation was selected as bankfull. The regression line represented the average bankfull level through the reach. The bankfull level indicated by the regression line was then used to re-evaluate cross section plots: where a residual for a bankfull level point at a cross section was large, or where no bankfull indicator elevation was plotted, the corresponding cross section plot was examined to determine whether a bankfull indicator could be identified close to the level indicated by the regression line.

Based on each longitudinal profile and bankfull indicators, slopes needed for estimating bankfull discharge were calculated:

- The slope between riffle crests was calculated at sites where the maximum bankfull depth and the longitudinal spacing between riffle crests would result in backwater from the next downstream riffle crest up to the riffle crest of the study riffle if the flow were at the bankfull level.
- The riffle bed slope was calculated where backwater at bankfull flow would not extend up to the riffle crest of the study riffle.

Bankfull Discharge

Bankfull discharge was estimated at 10 of the selected study sites: the 7 gauged sites and 3 of the un-gauged sites. At the three gauged sites where pressure transducers (loggers) had been deployed, bankfull discharge was estimated from gauge and logger data. At the other four gauged sites and the three un-gauged sites, bankfull discharge was estimated using the Manning Equation.

Estimation of Bankfull Discharge from Gauge Data

Rating curves were derived from gauging information (Form 9-207 or the expanded rating table) obtained from the USGS Kentucky Water Science Center for the three gauged sites where loggers were used. The gauge rating table or Form 9-207 measurement data were used to determine bankfull discharge based on the water depth data obtained from the loggers.

For each submerged logger, a hydrograph was produced using Solinst software (Levelogger Gold 3.4.0). The software compensates the data of the submerged logger using the barologger data, providing actual water depth data, which was exported to Excel for further analysis as follows:

1. The water depths of the study site logger hydrograph were converted to relative elevations corresponding to the previously collected study site survey data.
2. The water depths of the gauging station logger hydrograph were converted to gauge heights using previously collected survey data of gauging station reference and bench marks.
3. The date and time that the water surface was at the bankfull level at the study site were determined. In some cases, this required interpolation between logged data.
4. The date and time at the gauging station for the corresponding bankfull event at the study site were estimated based on the computed travel time between the two submerged loggers. An estimated average velocity of three feet per second (typical for gravel-bed streams flowing at/near the bankfull level) was used.
5. The gauge height for the bankfull occurrence was determined using the gauging station hydrograph.

The bankfull discharge was determined using the gauge stage-discharge table/curve. The bankfull discharge was then checked by computing the mean bankfull velocity and comparing it to values for other sites in the region and streams in the Bluegrass (Parola et al. 2007) and Eastern Kentucky Coal Field (Vesely et al. 2008) regions of KY.

Estimation of Bankfull Discharge from the Manning Equation

Bankfull flow was estimated from the Manning resistance equation (Henderson 1966):

$$\mathrm{Q} = \frac{1.49}{n}\, \mathrm{A}\, \mathrm{R_h}^{2/3}\, \mathrm{S_f}^{1/2} \tag{3.1}$$

where Q is the flow in cubic feet per second (ft^3/s), *n* is the Manning roughness coefficient, A is the bankfull cross-sectional area in square feet (ft^2), R_h is the hydraulic radius in feet, and S_f is the friction slope (approximated as bankfull slope) in feet/feet. The bankfull area and hydraulic radius were derived from the cross-sectional data, and the friction (bankfull) slope was derived from the longitudinal profile and bankfull indicators, as described above. The channel roughness (*n* value) along the study riffles at the bankfull flow level was assumed to be dominated by the grain roughness of the riffle bed, which comprised the majority of the channel boundary. Because the resistance could be attributed primarily to the bed, the *n* value was obtained from the Limerinos (1970) relation:

$$n = \mathrm{R_h}^{1/6}\, \frac{0.0926}{1.6 + 2\,\mathrm{Log}\frac{\mathrm{R_h}}{\mathrm{D_{84R}}}} \tag{3.2}$$

where R_h is the hydraulic radius (ft), and D_{84R} (ft) is the particle size that equals or exceeds the diameter of 84% of the particles based on the pebble count of the riffle surface.

Flood Flow Frequency at Gauging Stations

For each of the seven gauged study sites and the six gauged sites eliminated during field reconnaissance, annual maximum series data were obtained from the USGS Kentucky Water Science Center or from their online datasets. The data was reviewed to determine which of the 13 gauges would be useful for flood frequency analysis. At least 10 years of data had to be available, spanning a period where the only breaks in the record were those unrelated to flood magnitude (USIACWD 1982:15).

Eleven gauges had 10 or more years of record and were used for flood flow frequency analysis. These included five of the study sites and the six other gauged sites in the region that had been eliminated for geomorphic analysis during field reconnaissance (Table 3.2). Using the log-Pearson Type III distribution (McCuen 1998) as described by USIACWD (1982), frequency analysis was conducted for each of the stations. From the frequency distribution, flows corresponding to the 1.01- and the 1.5-year events were estimated for each station. The return period of the bankfull flow was also computed for the five study sites included in the frequency analysis.

Table 3.2 USGS Gauging Stations Used for Flood Frequency Analysis

	USGS Site Name	Gauge ID	County	No. Yrs. Q_{peak} Data*	Drainage Area (mi^2)	Latitude	Longitude
1	Beaver Creek at Hwy 31 nr Glasgow, KY	03312765	Barren	11	47.84	N37.03472	W85.90361
7	Green River near McKinney, KY	03305000	Lincoln	32	22.4	N37.42194	W84.75028
13	Gum Lick Creek Tributary near Clementsville, KY	03305835	Casey	11	0.71	N37.35083	W85.07139
19	Pitman Creek at Somerset, KY	03412500	Pulaski	30	31.3	N37.11694	W84.59194
20	South Fork Little Barren River at Edmonton, KY	03307500	Metcalfe	42	18.3	N36.97417	W85.60306
—	Bear Creek near Burkesville, KY	03414102	Cumberland	11	3.52	N36.77060	W85.26750
—	Green River near Mount Salem, KY	03305500	Lincoln	30	36.3	N37.41110	W84.75030
—	Little Beaver Creek near Glasgow, KY	03312795	Barren	10	0.89	N37.00999	W86.01670
—	McGills Creek near McKinney, KY	03304500	Lincoln	28	2.14	N37.44390	W84.68479
—	Solomon Creek Trib near Scottsville, KY	03313020	Allen	10	0.24	N36.83110	W86.10119
—	West Bays Fork at Scottsville, KY	03313500	Allen	33	7.47	N36.74810	W86.18460

* The number of years (through water-year 2008 or, in the case of discontinued gauges, the last year of recorded data) for which (1) peak data was available online from the USGS and (2) the only breaks in the record were those unrelated to flood magnitude.

4. Bankfull Characteristics of Eastern Mississippian Plateau Channels

Bankfull channel parameters calculated for each assessment reach (Table 4.1) were used to classify each reach. Classification of each reach according to Rosgen (1996) Type II classification parameters identified 3 B1c-, 1 B3c-, 10 B4c-, 1 C4-, 4 E4-, and 1 F1-type channels; the channel type was consistent for the entire length of each reach.

Data from the 16 alluvial assessment reaches were used to develop regional curves for alluvial streams within the EMP. The curves describe the relationships between drainage area and bankfull channel geometry and bankfull discharge.

Table 4.1 Bankfull Geometry, Classification, and Discharge Data for Streams of the EMP Region

	Stream Site	USGS Gauge ID	Total DA (mi^2)	A_{bkf} (ft^2)	W_{bkf} (ft)	D_{bkf} (ft)	ER*	W/D Ratio	Slope (%)	D_{50} (mm)	Rosgen Stream Type†	$Q_{1.5}$ (cfs)	Q_{bkf} (cfs)	Q_{bkf}/ $Q_{1.5}$	RI (yrs)	Q_{bkf} Method	Gauge Ht (ft)
1	Beaver Creek at Hwy 31 nr Glasgow, KY	03312765	47.84	155.6	47.8	3.26	>3.7	14.7	0.12‡	18	E4	2284	580	0.25	1.02	Gauge	6.63
2	Beaver Creek at Mount Pisgah Road	—	7.11	49.4	33.7	1.47	1.3	22.9	—	12	B4c	—	—	—	—	—	—
3	Beaver Creek at SR 740	—	42.75	157.4	47.3	3.33	>3.2	14.2	—	Gravel	E4	—	—	—	—	—	—
4	Beaver Creek near Old US 81	—	29.72	164.7	48.0	3.43	3.1	14	—	15	C4	—	—	—	—	—	—
5	Bee Lick near Randy, KY	—	11.2	37.8	30.6	1.24	1.5	24.7	—	29	B4c	—	—	—	—	—	—
6	Bethlehem Branch near Mud Lick, KY	—	0.63	3.7	8.2	0.45	1.9	18.2	—	29	B4c	—	—	—	—	—	—
7	Green River near McKinney, KY	03305000	22.4	109.4	58.7	1.86	1.8	31.6	0.20§	BDR	B1c	2773	362	0.13	<1.01	Gauge	3.56
8	Gum Lick Creek Site 1	—	1.65	7.6	11.2	0.68	2.2	16.5	—	Gravel	B4c	—	—	—	—	—	—
9	Gum Lick Creek Site 2	—	1.72	11.5	16.2	0.71	1.4	22.9	0.75	19	B4c	—	33.3	—	—	Eq. 3.1	—
10	Gum Lick Creek Site 3	—	3.64	14.9	18.1	0.82	1.3	22.1	0.62	21	B4c	—	45.3	—	—	Eq. 3.1	—
11	Gum Lick Creek Trib. at Gum Lick Rd	—	0.10	1.7	3.2	0.52	2.5	6.2	—	Gravel	E4	—	—	—	—	—	—
12	Gum Lick Creek Trib. Site 1	—	0.49	3.6	5.2	0.70	2.9	7.4	—	Gravel	E4	—	—	—	—	—	—
13	Gum Lick Creek Tributary near Clementsville, KY	03305835	0.71	6.5	8.8	0.74	1.3	11.9	1.20	18	B4c	199	24.5	0.12	<1.01	Eq. 3.1	—
14	Gum Lick Creek Trib. Site 2	—	0.78	5.3	8.3	0.64	1.5	13	0.84	12	B4c	—	16.7	—	—	Eq. 3.1	—
15	Indian Creek near Flippin, KY	—	4.4	13.9	15.4	0.90	1.6	17.1	—	BDR	B1c	—	—	—	—	—	—
16	Irvin Branch near Salem, KY	03305725	1.37	11.6	14.2	0.81	1.6	17.5	1.10	41	B4c	—	31	—	—	Eq. 3.1	—
17	Little Pitman Creek near Campbellsville, KY	03307260	19.3	66.8	45.0	1.49	1.4	30.2	0.35**	BDR	B1c	—	330	—	—	Gauge	4.40
18	Long Hungry Creek near Mt. Zion, KY	—	5.8	26.6	19.0	1.40	2.1	13.6	—	Gravel	B4c	—	—	—	—	—	—
19	Pitman Creek at Somerset, KY	03412500	31.3	137	79.4	1.73	1.8	45.9	0.67	84	B3c	1793	505	0.28	<1.01	Eq. 3.1	3.22
20	South Fork Little Barren River at Edmonton, KY	03307500	18.3	60.5	56.8	1.06	1.1	53.6	0.15	BDR	F1	1517	164	0.11	<1.01	Eq. 3.1	2.69

* ER is entrenchment ratio (dimensionless).
† Visually estimated slopes were used for classification purposes.
‡ Estimated using Manning equation.
§ Estimated using Manning equation and *n*-value estimate for bedrock channel. Resulting slope is approximately equal to riffle bed slope.
** Estimated using Manning equation and *n*-value estimate for bedrock channel. Resulting slope is approximately equal to regression line through site's bankfull indicators.

4.1 BANKFULL REGIONAL CURVES

Bankfull regional curves were derived using ordinary least-squares regression. Bankfull channel geometry and discharge data were plotted as a function of drainage area on a log-log scale (Figures 4.1–4.3). A best-fit line was regressed for each plot in the form of a simple power function:

$$Y_{bkf} = a\,DA^{\,b} \tag{4.1}$$

where a and b are empirically-derived constants, DA is drainage area (mi^2), and Y_{bkf} represents a bankfull channel parameter: cross-sectional area, A_{bkf} (ft^2); width, W_{bkf} (ft); mean depth, D_{bkf} (ft); or discharge, Q_{bkf} (cfs). The resulting regression equations are provided in Table 4.2 along with calculated coefficients of determination and standard errors.

Table 4.2 Bankfull Regression Equations for Alluvial Streams of the EMP Physiographic Region

Regression Equation	n	Coefficient of Determination, R^2	Standard Error*, S_e (%)
$A_{bkf} = 7.24\ DA^{0.81}$	16	0.97	27.0
$W_{bkf} = 9.87\ DA^{0.48}$	16	0.95	21.8
$D_{bkf} = 0.73\ DA^{0.33}$	16	0.85	27.2
$Q_{bkf} = 22.9\ DA^{0.84}$	7	0.97	26.9

* Transformed from the log10 domain as a percentage of the mean according to Tasker (1978).

Coefficient of determination (R^2) values show that drainage area accounts for over 84% of the variation in the relationships between drainage area and channel bankfull parameters. Variation unaccounted for by drainage area may be attributed to other influences such as variability in sediment load caliber and quantity, hydrology, and the effects of local controls (Knighton 1987).

Bedrock Reaches

Bankfull depths, widths, and areas for bedrock assessment reaches (n = 4) were examined in relation to plots of the regional curves for bankfull geometry of alluvial streams to determine whether systematic bias was observed. Each of the four bedrock study sites had bankfull depths less than that of the mean value of the alluvial streams represented by the regression line. This indicates that bedrock streams may be biased toward having smaller bankfull depths than alluvial streams of the same drainage area. Although bedrock stream data indicates that, on average, bedrock streams may be shallower, three of the four bedrock stream depths were within the 95% prediction limit of the alluvial reach data. The depth of the fourth bedrock stream was less than the depth associated with the 95% prediction limit by only 0.008 ft (0.24 cm), which is within the margin of error of the field measurement method.

Three of the four bedrock study sites had bankfull widths greater than that of the mean value of the alluvial reaches represented by the regression line. This indicates that bedrock streams may be biased toward having greater bankfull widths, especially for the larger drainage area study sites included. Although bedrock stream data indicate that, on average, bedrock streams may be wider, none of the bedrock stream widths were outside the 95% prediction interval of the alluvial reach data.

Three of the four bedrock study sites had bankfull areas less than that of the mean value of the alluvial streams represented by the regression line. This indicates that bedrock streams may

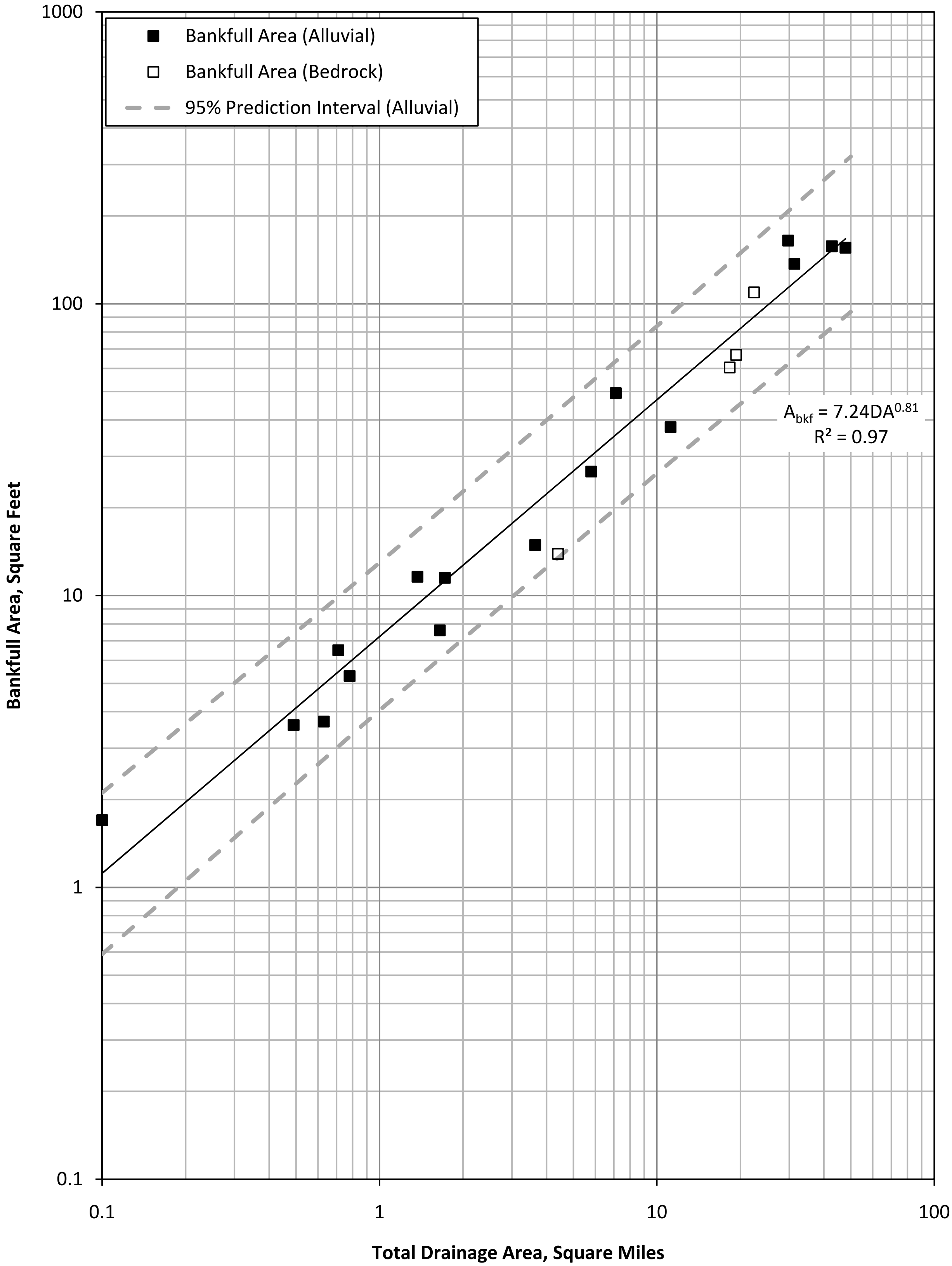

Figure 4.1 Bankfull cross-sectional characteristics as a function of drainage area for alluvial streams in the EMP region. Bedrock reaches are shown as hollow points for reference but were not included in the development of the regional curves.

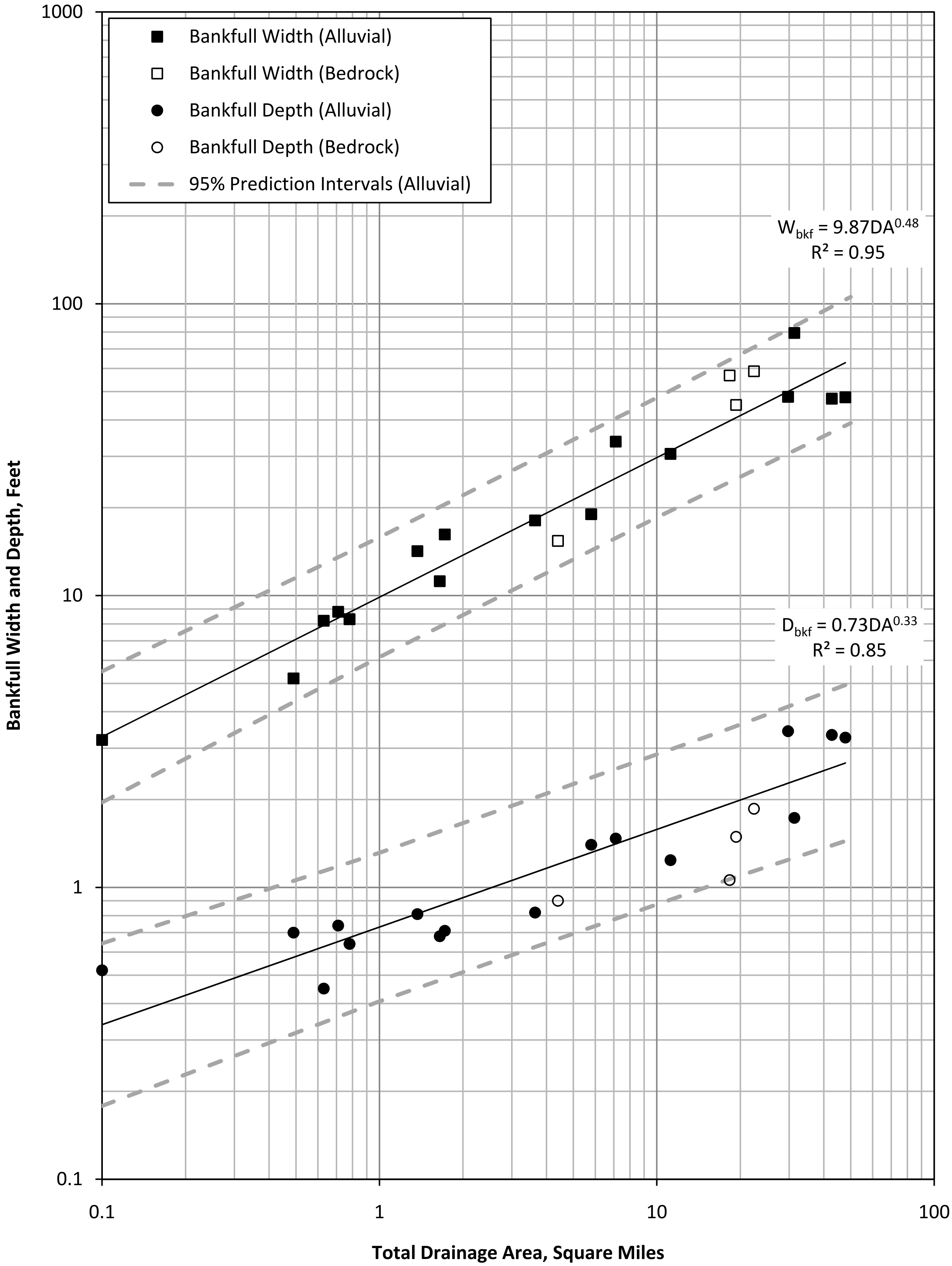

Figure 4.2 Bankfull cross-sectional characteristics as a function of drainage area for alluvial streams in the EMP region. Bedrock reaches are shown as hollow points for reference but were not included in the development of the regional curves.

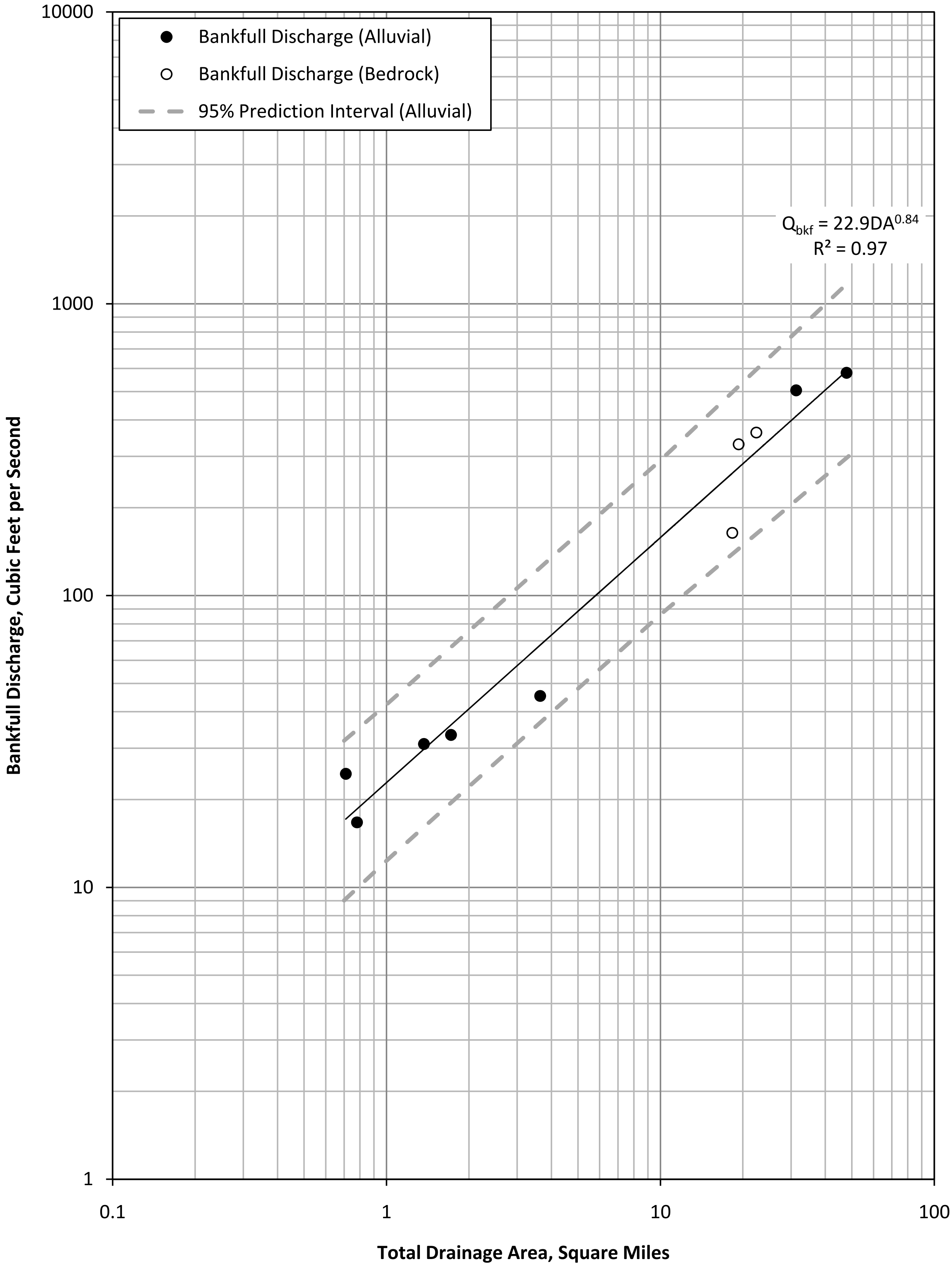

Figure 4.3 Bankfull discharge as a function of drainage area for alluvial streams in the EMP region. Bedrock reaches are shown as hollow points for reference but were not included in the development of the regional curves.

be biased toward having smaller bankfull areas than alluvial reaches of the same drainage area; the bias for bankfull area to be less than the regression line, however, is generally small and therefore not conclusive of significant bias. Although bedrock stream data indicates that, on average, bedrock streams may be wider, none of the bedrock stream widths were outside the 95% prediction interval of the alluvial reach data.

4.2 BANKFULL DISCHARGE RECURRENCE INTERVAL

Bankfull return periods were calculated for five of the seven gauged study sites (Table 4.1). Bankfull discharge of the un-gauged study sites were then compared to the regional 1.01- and the 1.5-year flows estimated from these five gauged study sites and six other gauging stations in the EMP region (Table 4.1) having a range of drainage areas similar to that of the study sites.

Regional curves for flows corresponding to the 1.01- and the 1.5-year events were derived using ordinary least-squares regression. Estimates of flows corresponding to the 1.01- and the 1.5-year events were plotted as a function of drainage area on a log-log scale for the eleven EMP gauge stations for which frequency analysis was conducted (Figure 4.4). Best-fit lines were regressed in the form of a simple power function:

$$Q_{t\text{-return}} = a\, DA^{b} \qquad (4.2)$$

where a and b are empirically-derived constants, DA is drainage area (mi^2), and $Q_{t\text{-return}}$ is the discharge with a return interval of t years. The resulting regression equations are provided in Table 4.3 along with calculated coefficients of determination and standard errors.

Table 4.3 Regression Equations for 1.01- and 1.5-Year Events Based on Gauge Data

Region	Regression Equation	N	Coefficient of Determination, R^2	Standard Error*, S_e (%)
EMP	$Q_{1.01} = 53.3\ DA^{0.73}$	11	0.82	72.6
	$Q_{1.5} = 189.7\ DA^{0.74}$	11	0.95	33.2

* Transformed from the log10 domain as a percentage of the mean according to Tasker (1978).

The bankfull discharges that were determined for 10 study sites were plotted to compare them to the regression lines. Bankfull discharge was less than the 1.01-year discharge computed for that site at all but one of the study sites. The difference between the bankfull discharge at each site and the 1.5-year discharge computed for that site was substantial: all five sites for which the values were compared had a Q_{bkf} less than or equal to 28% of the computed $Q_{1.5}$ (Table 4.1). Therefore, the regional 1.5-year discharge cannot be considered to be a reasonable representation or estimate of the bankfull discharge for EMP streams, and estimates derived from the regression equations for Q_{bkf} would likely be more accurate than those derived from assumed flood frequencies. Furthermore, given the substantial difference between the compared values, bankfull return periods for each of the study sites could be expected to be more frequent than the approximately 1.5-year average reported for streams in other regions of the US (Dunne and Leopold 1978; Leopold et al. 1964; McCandless and Everett 2002; Mulvihill et al. 2005; Rosgen 1996; Williams 1978).

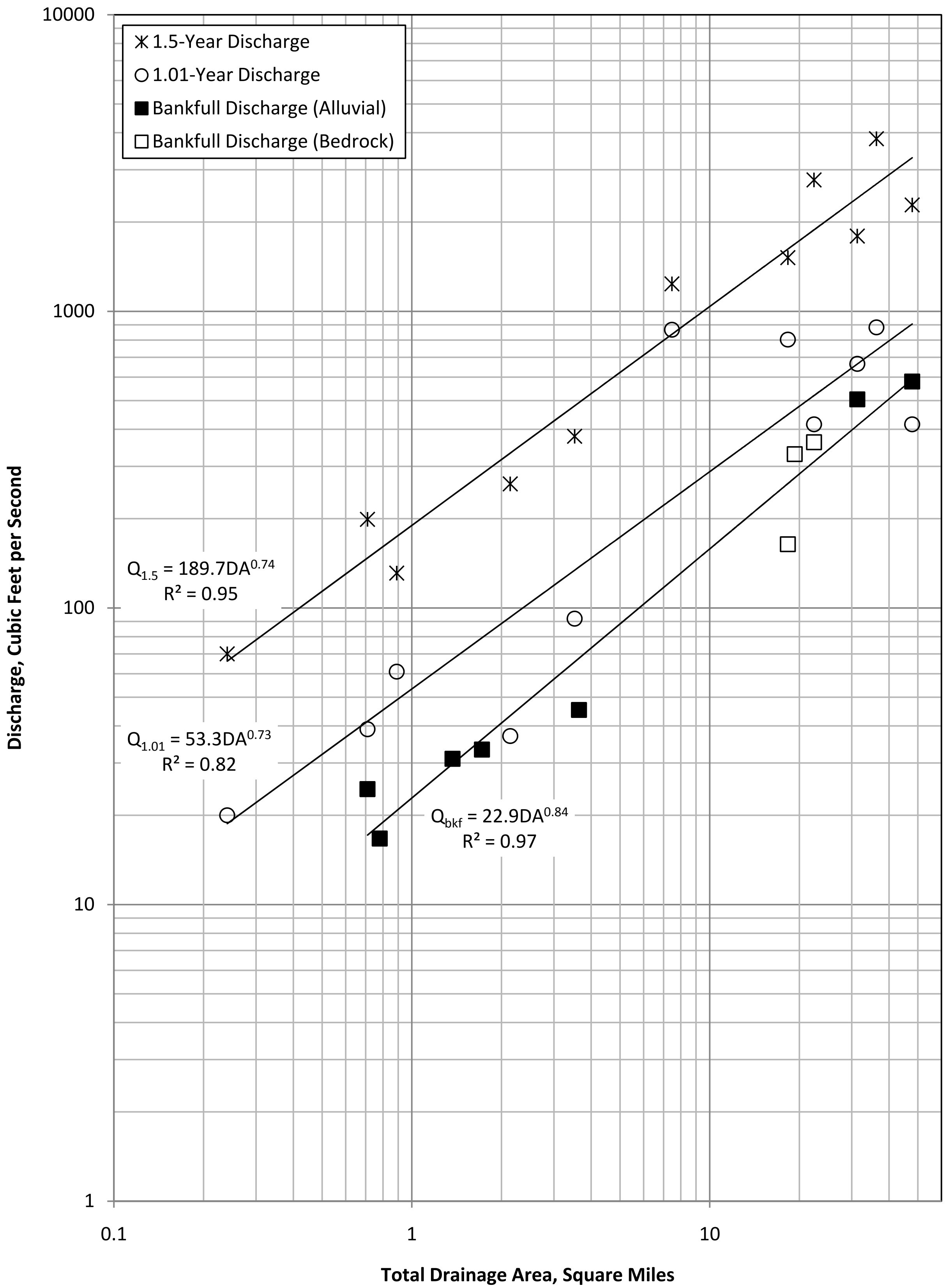

Figure 4.4 Regression curves for $Q_{1.01}$ and $Q_{1.5}$ derived from EMP gauges, and for bankfull flows estimated for alluvial study sites. Bedrock reaches are shown as hollow points for reference but were not included in the development of the regional curves.

5. Application of Bankfull Regional Relations

Regional curves describe characteristics that can generally be expected for streams of a given drainage area within a physiographic region. These descriptions are useful in the evaluation of stream stability, which includes the assessment of channel siltation, degradation, and bank erosion—factors that have substantial effects on aquatic habitat and sediment loads. They may be particularly useful in assessing channels undergoing rapid change, when bankfull indicators may be unapparent or ambiguous. Furthermore, these regional relations can be used as a basis for some restoration design methods (Rosgen 1998).

The regional curves for the EMP region were developed from sites with watersheds between 0.1 and 49.6 mi^2 where the channel appeared to be stable and had unambiguous bankfull indicators. The relationship between bankfull parameters and drainage area in the EMP region is described by curves that explain between 81% and 97% of the variation within the datasets for bankfull area, width, depth, and discharge. Standard errors are less than 29%. Bankfull discharge was found to be no more than 28% of the 1.5-year discharge at each of the five gauged sites having sufficient peak data for analysis. Therefore, use of the 1.5-year event for bankfull flow would represent a gross overestimate in all reaches examined in this project; estimates based on morphological features and/or the regional curves would be more accurate.

The curves developed in this project will be most applicable to streams having characteristics consistent with those criteria used to select the assessment reaches:

- Physiographic region. These curves apply to those streams with significant portions of their watersheds within the EMP region.
- Land use. Streams in watersheds that are less than 10% urbanized are represented.
- Flow regulation. Streams that are not subject to flow regulation are represented.
- Drainage area. The curves apply only to streams draining between 0.1 and 47.8 mi^2.
- Sediment size. Gravel- and cobble-bed streams are represented. The sample did not include sand-bed streams. The curves may also apply to bedrock reaches, although bedrock reach data suggest a bias toward shallower, wider bankfull channel configurations. This potential bias should be considered when evaluating bedrock reaches.
- Slope. The curves apply only to streams with slopes of up to 1.2%.

Streams affected by downstream confluences of large streams or locally high or large-caliber sediment supplies are not represented in the dataset used to develop these curves. Bankfull characteristics of channels formed under those conditions may be substantially different.

Because regional curves provide regional estimates of bankfull parameters that broadly describe stream conditions, they do not predict channel parameters for specific conditions that would form channels at specific sites. The cross-sectional dimensions of a channel are the product of many complex geomorphic processes, including the transport of sediment and channel evolution after repeated disturbance. A combination of geologic factors, the sequence and magnitude of land-use activities, and the sequence of channelization of the stream networks all have significant effects on sediment loads and channel evolution. Local watershed and channel conditions may cause channel bankfull flows and bankfull dimensions to differ significantly from those estimated from the equations produced by this project. Therefore, these equations should not be the only data used to evaluate or estimate bankfull characteristics in the assessment or design of EMP channels. Rather, they should only be used in conjunction with field-based geomorphic assessment of the stream and its watershed. The results of field examination of bankfull conditions on the stream of interest should be compared to the EMP regional curves. Channel dimensions that are more than one standard deviation greater or less than those dimensions estimated from the curves should be examined carefully to determine the cause of the variation. Likewise, designs that call for channel dimensions outside that range should provide sufficient data to justify the deviation from the curves.

Highly altered watershed conditions and direct manipulation of streams have changed watershed hydrology, sediment regimes, channel gradients, and base levels; ongoing maintenance continues to affect channel response and evolution. These altered reaches, from which the EMP regional curves were developed, represent the geometry of evolving contemporary channels; if the channels were to completely recover from disturbance, their floodplains, planform patterns, and profiles would change, and their channel cross section characteristics would likely differ from those described by these regional curves. Therefore, if a restoration project intends to create bankfull characteristics similar to those that could be expected in a completely recovered channel, the design may require smaller dimensions than those that would be estimated from these curves.

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Appendices

Financial and Administrative Closeout | A

TO BE INSERTED AFTER CLOSEOUT IS COMPLETE AND APPROVED.

Quality Assurance Project Plan | B

Prepared by: Arthur C. Parola, Jr., Ph.D.
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Group A: Project Management Elements

A3 Distribution List

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A4 Project /Task Organization

The stream geomorphic data collected in this project will be used by individuals assessing stream stability in the specific region characterized by the stream geomorphic data. The data will also be used by designers of stream restorations to determine the likely range of stream characteristics of the proposed stream restoration.

The project QA manager will be Dr. Parola. A research associate with training in applied geomorphology will collect all field data with the assistance of graduate students and professional staff. Dr. Parola, the project director, will maintain the official, approved QA Project Plan.

Figure B.1 illustrates the relationships and lines of communication between all project participants.

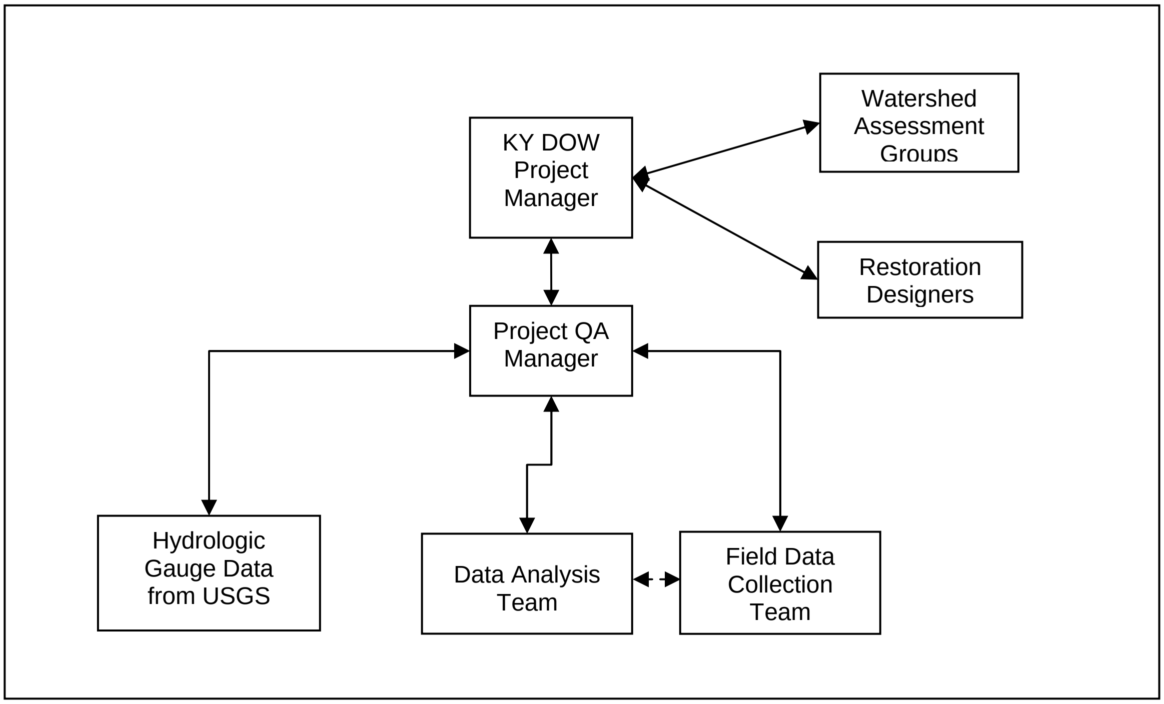

Figure B.1 Organizational Chart Showing Lines of Communication.

A5 Problem Definition and Background

Stream physical habitat, stream stability, bank erosion and total sediment loads are affected by the physical characteristics or stream channel networks of a watershed. Land-use practices in Kentucky, such as land development, livestock grazing, land clearing, channel relocation and modifications for flood protection, roadway construction and mining tend to increase stream peak flow rates, disturb riparian vegetation and alter stream channel characteristics. The response of many streams to disturbance can be excessive production of sediments through channel incision followed by severe bank erosion. In many cases in Kentucky, channels have incised into bedrock and have continued to widen through bank erosion for decades after disturbances have occurred. The direct disturbances to streams and the associated indirect erosion that continues for long periods can severely degrade stream habitat upstream, downstream and at the disturbed section of the stream. Physical alterations of stream channels are a significant source of stream habitat degradation and a major source of non-point source pollution in Kentucky's watersheds.

Methods of stream restoration and bioengineering techniques have been developed to improve stream habitat, reduce bank erosion and reduce sediment loads through physical alteration of disturbed stream channels. Determination of the necessity for stream restoration and restoration design requires that stream physical characteristics be compared to data from stable reference reaches in the same climactic and geophysical regions. Regional data on geomorphologic characteristics of streams are an important source for information necessary for stream evaluation and restoration design. At present, stream restoration in Kentucky is being conducted without the benefit of regional information on geomorphic parameters, although data collection in one River Basin Management Unit (RBMU) has been completed and the data has been analyzed. Data of bankfull characteristics for streams in the Tennessee/Cumberland/Mississippi RBMU were collected in 2000 (FFY 1999). The project will extend the collection, analysis and development of regional geomorphic stream characteristic curves to physiographic regions in which data have not been collected.

A6 Project Task Description

Collect Available Site Information

Information on all stream gauge stations in the selected physiographic region will be obtained to determine the possible locations of assessment sites. This information will be used to develop a list of potential sites for data collection.

Select Assessment Reaches

Each of the stream gauge stations selected as possible data collection sites will be visited. A preliminary classification of the stream type (Rosgen 1996) will be made. Sites that have ambiguous bankfull characteristics or other characteristics that make them unsuitable for use as assessment sites will be eliminated. The remaining stream gauge station sites will be considered for further analysis.

Experience in collection of data in the Tennessee/Mississippi/Cumberland RBMU has shown that channel conditions at stream gauge stations are typically significantly different than those upstream or downstream of stream gauge stations where channels have developed bankfull indicators. Debris collection, channel maintenance and bridge construction at or near stream gauge stations obscure or prevent the formation of a stable channel configuration; consequently, the information from the stream-gauge stations may not be valuable at most or all stream gauges. If similar problems are found at stream gauge stations in this project area, assessment reaches away from stream gauge stations will be selected. Extensive reconnaissance will be required to locate stable channels without stream gauge stations.

Complete Analysis of Assessment Site Station Frequency

Analysis of peak flow frequency will be conducted to develop a flood frequency curve from which the 1-to-2-year flow event and water surface elevation can be determined.

Collect Data of Assessment Reaches for Geomorphic Parameters

The site data required to characterize the bankfull conditions will be collected at each assessment site. The information will be collected to describe channel geomorphic characteristics over riffle sections as described in Rosgen (1996) for characterization of assessment reaches. Data sheets and photographs of each site will be developed to be useful to others conducting restoration work in the area of the assessment sites. The information will be stored and made available as part of a spreadsheet database. The Nonpoint Source Section of the Kentucky Division of Water will receive an electronic copy of the data. The information will be stored in a format that will be transferable to the Kentucky Division of Water for conducting watershed evaluation, restoration, or TMDL projects.

Where assessment reach information must be collected at sites without stream gauge station information, cross section data will be collected over riffle zones to the extent necessary to develop and run models of flow (using HEC-RAS) to approximate a range of channel formative discharges.

Analyze Bankfull Characteristics of Assessment Reaches

The geomorphic data collected from each assessment site will be analyzed. A definitive stream classification based on the site measurements will be made. Bankfull flow rates will be extracted or modeled from bankfull elevation measurements and compared with frequency analysis information. Roughness coefficients will be computed from the cross section, bankfull field information, and stream gauged flow rates where stream gauge information is available. Average velocities, depths, boundary stresses and stream power of bankfull flow will be computed.

Develop Regional Data and Curves of Bankfull Geomorphologic Characteristics

Data representing bankfull geomorphologic characteristics and variability will be developed for each physiographic region. Data for each assessment reach will be displayed according to stream type. The information will be presented in a clear and simple format.

Submit Annual, Final and Closeout Reports

An annual report will be submitted. The University of Louisville Research Foundation will request current final project and closeout report guidelines from the Kentucky Division of Water no less than six months prior to the project end date. The final project report will present the data and analysis of each assessment site in a clear and standard format. The data from each of the assessment sites will be stored in a database. The Nonpoint Source Section of the Kentucky Division of Water will receive an electronic copy of the database. The report will also present and describe the regional data that represent bankfull geomorphic characteristics. A closeout report will be prepared and submitted as required by the US Environmental Protection Agency.

A7 Quality Objectives and Criteria

The objective of this project is to develop reliable regional bankfull characteristics of stream channels in a specific physiographic region of Kentucky. Two basic groups of data will be collected: sediment samples and stream geometric characteristics. In addition, hydrologic data from USGS gauging stations will be used to associate flows with specific recurrence intervals.

Surveying techniques that provide accuracy of about 1 cm in all directions will be used with the total station equipment that will be employed for stream geometric data collection. Also standard sieve analysis procedures employed by the geomechanics laboratory using standard ASTM techniques for fine and coarse aggregates will provide data for sediment size gradation to high precision. Large variations in geometric characteristics (typically on the order of 0.3 m) are associated with the subjective selection of bankfull elevations based on field indicators; therefore all bankfull indicators will be measured and flow levels associated with each indicator will be reported. These indicators include tops of coarse bar deposits, tops of fine bar deposits, low vegetation lines, tops of banks and floodplain elevations.

Sediment sampling in coarse bed channels is limited by the ability to only sample a very small portion of the streambed. Four techniques may be used to assess sediment in gravel and cobble bed streams:

1. Pebble counts on each riffle studied
2. Riffle subsurface bulk samples
3. Bar bulk samples
4. 30 largest particles on the bar

Amounts of gravel required to characterize the active streambed will be determined according to Bunte and Abt (2001), Rosgen (1996) and Kappesser (2002).

To ensure consistency in the selection of sampling locations for bankfull indicators, for collection of geometric stream characteristics, and for sampling of bar materials, the QA manager will conduct on-site quality checks.

The USGS maintains well-established quality control procedures for the gauge data flows. The quality of each measurement is recorded. Only good or excellent measures of flow will be used in the assessment of bankfull flow conditions.

A8 Special Training and Certification

The QA manager and project team have acedemic as well as professional training in applied morphology and the techniques necessary to collect and analyze the required geomorphic data. This training includes extensive academic and professional training in surveying, sediment sampling, hydraulic and hydrologic modeling, and geomorphic assessment.

A9 Documents and Records

The QA manager will be responsible for ensuring that the data collection team and all others on the distribution list have the most current QA project plan through email distribution. However, we do not anticipate significant changes to the QAPP. The data report will include the items described in Table B.1.

A final report that documents the procedures used to collect the data, difficulties in the data collection process and factors that influenced data quality will be produced. The final report will include the raw field data in a database. The final report will also include the analysis and products derived from the analysis such as regional curves of stream geomorphic characteristics and any other relations derived from these analyses. The database will be submitted to the Kentucky Division of Water project manager.

Group B: Data Generation and Acquisition Elements

B1 Sampling Process Design (Experimental Design)

Regional curves have been developed using USGS stream gauge station information. Stream geometric properties near the gauge stations have been used to determine bankfull characteristics, flow rates and flow frequency. Ideally, bankfull curves can be developed solely from information at USGS gauge stations within a physiographic region of Kentucky.

Previous work at gauge stations in the Cumberland and Tennessee RBMU demonstrated that most sites lacked consistent and reliable bankfull indicators because of the frequent disturbance near the gauge station. Gauge stations were typically located on or near bridges that frequently accumulated debris and severe bank erosion occurred around the bridge. Alternatively, channels were heavily straightened and lacked benches or other well-defined bankfull features. In these watersheds and on streams with slopes greater than 0.5%, reference reaches were found with reliable bankfull indicators and sufficient geometric data were obtained to model flows through relatively straight riffle sections. Modeling was considered unreliable on streams with smaller slopes and only cross section geometric data were obtained.

Table B.1 Final Report Data

Type of Data	Source Data	Analysis
Site location, geology and topographic data	USGS topo maps, KY geologic maps, state GIS database	None
Bankfull stream characteristics	Geometric data collected by field team	Use of HEC-RAS flow model and AutoCad
Sediment gradation characteristics	Sediment data collected by field team	Grain size analysis
Streamflow and frequency distribution	USGS streamflow gauge data	Peak flow frequency modeling techniques

In consideration of the above information, one or a combination of the following methods will be used:

1. Obtain stable and reliable bankfull indicators at gauge station;
2. Model flows on streams with sufficient slope (greater than 0.5%); and
3. Obtain only geomotric characteristics of channel on low-gradient streams.

The procedures for these methods are outlined in Rosgen (1996); the flow modeling is included in Brunner (2001).

B2 Sampling Methods

Sampling for this project can be grouped into two categories: (1) surveying for channel geometric characteristics and (2) sediment sampling. Table B.2 describes the types of data to be sampled and the method used to sample.

Survey data will be checked during the surveying process by intermittently checking elevations at monumented locations. Any error in survey information will be apparent by following standard professional surveying procedures. A resurvey will be initiated when errors occur.

Total sediment weight before and after sieve analysis will be used to determine the error in sieve analysis procedures. Samples with an error greater than 8% will not be used, and the reasons for the errors will be determined and corrective action will be taken. The QA manager will be responsible for reviewing the sediment grain size distribution error analysis to determine the need to repeat the analysis.

Survey errors are most often apparent in the field when control points are recorded. Maximum errors at control points will be recorded. Surveys will be repeated where the errors at monuments are greater than 2 cm. The QA manager will review survey error measures at each site to ensure that inaccurate surveys are repeated.

B3 Sample Handeling and Custody

Total station survey data will be collected in electronic format on data loggers and downloaded each day to a laptop computer. Pebble count and other sediment data will be recorded on data forms and typed into a database.

Sediment samples will be labeled in the field and transported directly to the geomechanics laboratory. Grain size analysis will be conducted in the laboratory within one month of sample collection. Grain size analysis will be completed and data will be directly entered into a computer database. The data will be archived by the project QA manager.

Table B.2 Sampling Methods

Type of Data	Method	Reference
Channel cross section	Total station survey	Rosgen 1996
Channel profile	Total station survey	Rosgen 1996
Channel planform	Total station survey	Rosgen 1996
Riffle surface sediment grain size distribution	Wolman pebble counting	Bunte and Abt 2001
Subsurface sediment grain size distribution	Fine and coarse sieve analysis	Bunte and Abt 2001
Bar sediment grain size distribution	Fine and coarse sieve analysis	Rosgen 1996; Bunte and Abt 2001
Largest particles on bar size distribution	Field measured using ruler	Kappesser 2002

B4 Analytical Methods

Survey data will be analyzed and reduced using AutoCad. Cross section and stream profile characteristics will be extracted from the AutoCad data for further analysis using Microsoft Excel. The data will be entered into a Microsoft Access database following quality control checks during data processing and confirmation of satisfactory quality through spreadsheet analysis.

Gauge data frequency analysis will be conducted using several hydrologic modeling techniques. Peak flow estimates of flow frequency are unreliable at the level of channel formative and bankfull flow conditions. Alternative methods for quantifying flow frequency are being investigated.

The open channel flow model HEC-RAS will be used to obtained bankfull flow rates.

Linear regression techniques will be used to obtain regional relations for bankfull geomorphic parameters.

B5 Quality Control

Bulk sediment sample weights will be compared before and after sieve analysis to determine the percentage lost in the sieving processes. A loss of less that 8 % will be considered adequate for the sampling required for characterizing the bed sediments.

Standard surveying practices will be employed to ensure that survey location error is less than 1 cm.

B6 Instrument and Equipment Testing, Inspection, and Maintenance

Survey equipment and scales will be maintained to ensure proper function. This equipment will be tested against standards before and after field reconnaissance. The equipment will be sent to a local survey company for recalibration if found to be inaccurate or out of calibration

Sieves are cleaned after each use. Damaged sieves will be replaced.

B7 Instrument and Equipment Calibration and Frequency

Survey equipment is calibrated every six months, although it may be calibrated more frequently if found to be out of calibration during testing.

B8 Inspection and Acceptance of Supplies and Consumables

This does not apply to geomorphic data collection.

B9 Non-direct Measurements

Annual peak flows and gauge station rating curves will be obtained from the USGS. Strict and rigouous QA and QC has been established by the USGS to ensure the quality of these data. Ratings are given to flow data such that measurements of rating less than good will not be accepted for use in this project.

B10 Data Management

The data will be archived in paper format and entered into an Excel spreadsheet and archived.

Group C: Assessment and Oversight Elements

C1 Assessment and Response Actions

Assessment of data quality will be conducted at several levels. Survey equipment will be examined to determine its accuracy by laying out a known measurement distance and through repeat measurements each time the equipment is taken into the field.

The QA data manager will make visits to field sites during part of each field reconaissance to ensure that procedures described here are being followed. The project team will discuss procedures and assess errors in measurements at least biannually. Data collection will be repreated if necessary.

Accuracy of the surveying equipment is imperative for high quality field measurements. At least one backup instrument will be made available to ensure that a calibrated instrument is used.

C2 Reports to Management

Verbal reports on the status of projects will be made weekly. Data collecton procedures will be discussed, problems will be addressed and any necessary corrective actions will be taken on a weekly basis. The QA manager and field data collection team will meet to discuss QA and QC issues before each intenseve field data collection period.

Group D: Data Validation and Usability Elements

D1 Data Review, Verification and Validation

Spot checks of data using a simple level line and tape will be made to ensure that survey data are within an acceptable range for characterizing geomorphic parameters. Most problems with data error will be adrressed at the time of data collection.

D2 Verification and Validation Methods

The geomorphic data and regional relations for this project will be compared to those of other similar projects of regional geomorphic characteristics such as those by McCandless and Everett (2002). Data incorporated in the database will be reviewed and tested by the QA manager. Although large variationin geomorphic paramaters is anticipated; unusal deviation will be examined carefully to ensure that the they represents variation in geomorphic characteristics and not error of data collection and analysis procedures.

D3 Reconciliation and User Requirements

The antipated users of this data and the resulting regional relations developed from the data are individuals conducted stream assessments or designers of stream restoations. Large natural variations of sediment supply and stream geomorphic characteristics occur because of variation in current landues, landuse history, and direct modification of satream channels as well as variation in geology. Users of the information will be warned of that the data may be biased toward streams on which gauge stations have been installed (larger watersheds). In addition, users will be warned that local and basin conditions may cause substatial diffenences in stream characteristics. The database will provide information on the characteristics of streams and their watersheds, so that users have information available to make direct comparisons with specific site conditions.

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Eastern Mississippian Plateau Data | C

The data reported for each assessment site are provided on the enclosed CD-ROM.