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Geomorphic Characteristics of Streams in the Eastern Kentucky Coal Field 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 9 stream-flow gauge sites and 17 un-gauged sites were used to develop regional curves for bankfull channel depth, width, area, and discharge for rural, unregulated Eastern Kentucky Coal Field (EKCF) streams draining fewer than 242 mi^2. The return interval of the bankfull discharge was also estimated for each gauge site with at least 10 years of record of peak annual flow.

An extensive examination and collection of stream geomorphological characteristics in the EKCF 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 discharge and bankfull channel dimensions to drainage area. Bankfull flow return periods were estimated using a log-Pearson Type III distribution of annual maximum series data. The relationship between bankfull parameters and drainage area in the EKCF region is well described by the curves, which explain over 87% of the variation within the datasets for bankfull area, width, depth, and discharge. Standard errors are less than 38% for the bankfull geometry and 48% for bankfull discharge. On average, the bankfull discharge was found to be approximately 44% of the 1.5-year discharge, and no consistent frequency represented the computed return period of the bankfull flow. 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 Kentucky Coal Field 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 2007), 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. In many cases channels incise into bedrock and continue to widen through bank erosion for decades after disturbances have occurred. 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

At present, stream geomorphic assessment and restoration design in the Eastern Kentucky Coal Field (EKCF) physiographic region are being conducted without regional curves; stream restoration efforts intended to improve stream habitat have been conducted without general information on the geomorphic characteristics of streams in various regions of the state. 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 in riffles as a function of upstream drainage area in the EKCF physiographic region of Kentucky.

Bankfull channel geometry data were collected from 20 sites on 18 EKCF streams between March 2003 and March 2006; bankfull discharge data were collected at 9 gauged sites on 8 of those streams. Regional curves were developed from a combination of these data and data collected from 6 ungauged EKCF sites/streams between April and September 2000 (Parola, Skinner, et al. 2005). Drainage areas for all 26 sites ranged from 0.31 mi^2 to 242 mi^2. Criteria used to identify suitable stable stream channels for regional curve data collection included a wide range of drainage basin areas within the physiographic region; active stream-flow gauges with long-term hydrological records, preferred in order to determine discharge at the identified bankfull stage; and as many streams as possible having a channel environment that was alluvial, relatively stable, and showed no signs of ongoing rapid morphological change (cf. McCandless and Everett 2002; Smith and Turrini-Smith 1999). Bankfull regional curves for streams draining less than 242 mi^2 were derived from the data by using ordinary least-squares regression to relate bankfull discharge and bankfull channel dimensions to drainage area.

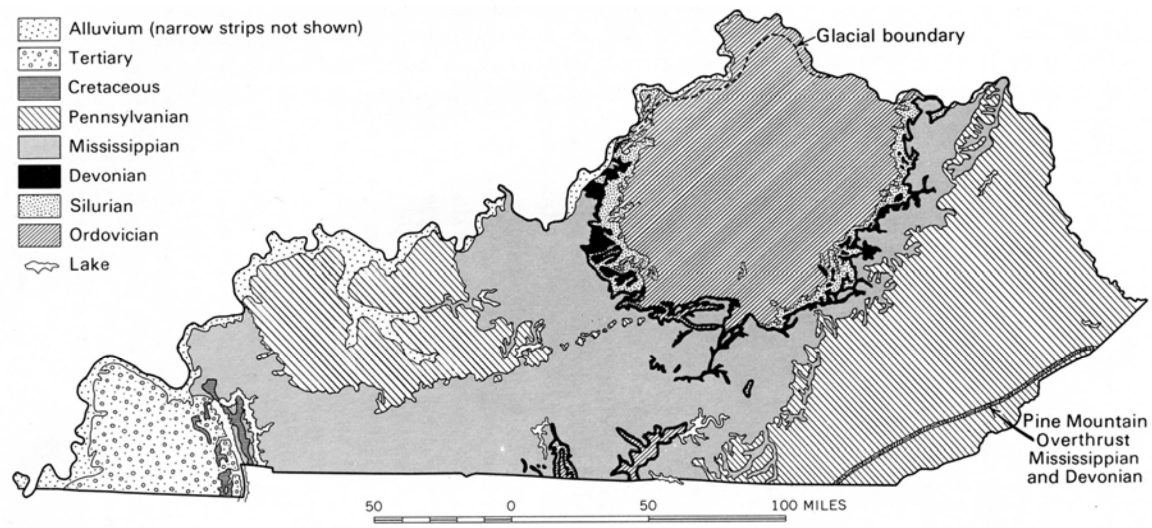
2. The Eastern Kentucky Coal Field Physiographic Region

The physiographic regions of Kentucky correspond to geologic regions of the state, as the effects of surface weathering and erosion of different geologies produce landscapes and streams of dissimilar characteristics. In the Eastern Kentucky Coal Field, gravel bed streams dissect the Cumberland Plateau. The major stream systems of the region include the Ohio, the Big Sandy, the Little Sandy, the Licking, the Kentucky, and the Cumberland rivers.

2.1 STRUCTURAL GEOLOGY

The EKCF physiographic region is part of a larger physiographic region known as the Cumberland Plateau, which extends from Pennsylvania south to Alabama. It is bounded on the west by the Pottsville or Cumberland Escarpment, formed from resistant sandstones and conglomerates in the lower part of the Pennsylvanian strata (Figures 2.1a and b). The Pennsylvanian stratigraphy of the Eastern Kentucky Coal Field includes the Breathitt and Lee formations (Table 2.1). During the Pennsylvanian period 250-300 million years ago, sediment eroding from the ancestral Appalachian Mountains was deposited in a large inland sea extending over a region known as the Appalachian Basin. Fluctuations in the level of this ancient sea, along with basin subsidence and changes in depositional environment, resulted in a cyclical layering of the region’s coal-bearing lithology, comprised predominantly of interbedded sandstone, shale, coal, and to a lesser extent, limestone. Orthoquartzitic sandstone, possibly deposited as channel fills or sandbars, is the primary constituent of the older Lee formation (Rice et al. and Horne et al., as cited in Outerbridge 1987). The erosion-resistant quality of this rock type is responsible for its presence in prominent cliff outcroppings and river knickpoints. Additionally, this resistant rock generally provides terrain that is not prone to landslides (Outerbridge 1987). Overlying the Lee formation is the Breathitt formation, consisting of less resistant subgraywacke sandstone interbedded with siltstone, shale, and coal.

(a)



(b)

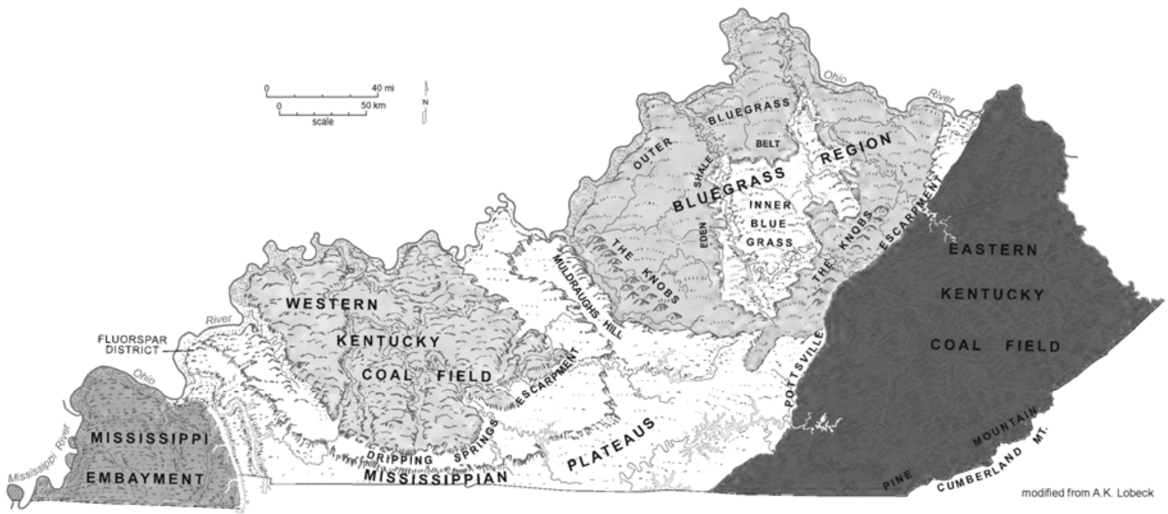


Figure 2.1 (a) Generalized geologic map of Kentucky (after McGrain 1983:12).
(b) Physiographic map of Kentucky (KGS 2001).

The EKCF region contains several major structural features: the Kentucky River fault system, the Irvine-Paint Creek fault system, the Pine Mountain thrust fault, and the Waverly arch of northeastern Kentucky. The Kentucky River fault system extends eastward into West Virginia, mostly as a concealed system within this region. The Irvine-Paint Creek fault system extends eastward from central Kentucky to a terminus near Paintsville. The Pine Mountain overthrust fault brings Devonian and younger rocks northwestward over Pennsylvanian rocks.

Due to relatively little deformation of the original layered lithology, the hills of the Eastern Kentucky Coal Field are a highly dissected upland plateau (Outerbridge 1987). With the exception of the Pine Mountain thrust fault, the structure of the region's geology remains in a relatively undisturbed state of limited dip, faults, or folding. The Appalachian Basin region was spared the rock-warping forces induced by continental collisions during the formation of Pangea. The flat-lying structure is only mildly deformed into a broad, shallow syncline spanning eastern Kentucky, southern West Virginia, Virginia, and Tennessee. Rocks dip gradually with existing localized anticlines.

Table 2.1 EKCF Generalized Stratigraphy*

System	Series	Formation	Facies	Description
PENNSYLVANIAN	Lower and Middle Pennsylvanian	Breathitt	Upper Delta Plain	Sandstone, siltstone, shale, and coal; sandstone, gray, weathers yellowish-brown, in locally large channel-fill deposits, interbedded with siltstone and shale; siltstone and shale, gray, weathers green to yellowish-brown; coal beds generally less than 1 m thick. Forms rounded to craggy hills with rockfalls and abundant debris flows and avalanches.
				Sandstone, siltstone, shale, and coal; sandstone, gray, weathers yellowish-brown, commonly in large channel-fill deposits which contain quartz-pebble conglomerate interbedded with siltstone and shale; siltstone and shale, medium-dark-gray weathers yellowish-brown; coal beds as much as 6 m thick. Forms very steep craggy hills with rockfalls and abundant debris flows and avalanches
			Lower Delta Plain	Sandstone, siltstone, shale, and coal; sandstone, gray, weathers yellowish-brown, commonly in channel-fill deposits, interbedded with siltstone and shale; siltstone and shale, medium-dark gray, weather yellowish-brown; coal beds generally less than 3 m thick. Forms steep craggy hills with rockfalls and abundant debris flows and debris avalanches. Thin limestone beds occur throughout the stratigraphic column above the top of the Lee Formation but aggregate less than 1% of the column; gray to black, weather gray; these rocks have no effect on topography or landslides. Orthoquartzites of the Lee Formation intertongue with adjacent formations.
			Lagoonal	Siltstone, shale, sandstone, and coal; siltstone and shale, dark-gray, weathers yellowish-brown, in units up to 20 m thick, commonly interbedded with sandstone laminae; sandstone, gray, weathers yellowish-brown, also in local channel fills; coal beds generally less than 2 m thick. Forms rounded hills with debris flows and debris avalanches.
		Lee	Barrier Bar	Sandstone, conglomerate, siltstone, shale, and coal; sandstone orthoquartzitic, light-gray to white, weather white to pink to brown, in thick channel-fill-like deposits commonly with basal quartz-pebble conglomerate as much as 3 m thick; interbedded with dark-gray siltstone and shale that weathers yellowish-brown; coal beds generally less than 2 m thick. Sandstone forms cliffs, as much as 90 m thick and mesas. Forms generally stable terrain and stabilizes overlying beds except at cliffs where rockfalls litter slopes below with boulders up to about 10 m across.
MISSISSIPPIAN	Upper Mississippian	Pennington	Lower Delta Plain	Sandstone, siltstone, shale, and limestone; sandstone, reddish-gray to gray, weathers yellowish-brown to red, in channel fills, interbedded with siltstone and shale; siltstone and shale, reddish-gray, weathers yellowish-brown to red, with interbedded thin gray, yellow-weathering limestone beds. Forms very abundant earth flows and debris flows.

* The typical stratigraphy of the region provided by the US Geological Survey (USGS) as presented by Outerbridge (1987).

In addition to these slight deformations, the geological structure of the Eastern Kentucky Coal Field includes abundant stress relief joints. As erosion dissects the uplifted Appalachian Basin, large amounts of sediment are removed from underlying rock. The newly exposed rock is relieved of the confining pressure of its overburden and subsequently expands. Due to the low tensile strength of rock, a network of stress relief joints forms. This network consists of vertical joints along valley walls and horizontal joints between bedding planes along valley floors. The interconnectedness of these joints provides a conduit for groundwater flow (Wyrick and Borchers, as cited in Outerbridge 1987).

2.2 PHYSIOGRAPHIC SETTING

The EKCF region encompasses all or part of 37 counties and covers roughly 11,650 mi^2 in the easternmost portion of Kentucky (Figure 2.1b). While no sub-regions have been defined for the EKCF, the region encompasses three topographically distinct areas: the eastern mountains; the western one-third of the region near the Pottsville or Cumberland Escarpment; and the area between these two limits. East of the Pine Mountain overthrust fault are the Pine and Cumberland mountains. These are true mountains with highly inclined strata. The other two areas, while commonly referred to as mountains, are ridges and valleys produced by the erosional processes of stream dissection.

The western third of the EKCF was termed the Ridge Top and Limestone Valley Settlements area by the Kentucky Geological Survey in the early twentieth century (Davis 1924). This area corresponds to an outcrop of the basal members of the coal measures strata, delineating the area along a meandering line roughly bisecting Whitley, Clay, Owsley, and Lee counties and terminating at the northwestern corner of Greenup County. Along much of the western portion of the Ridge Top and Limestone Valley Settlements area, the ridges are relatively narrow and the valleys wide. Streams of the Kentucky and Cumberland river networks have excavated valleys to the underlying limestone layers, in which sinkholes and subsurface channels have formed. Soils in these valleys are alluvial. In the rest of the Ridge Top and Limestone Valley Settlements area, the ridges are wide and level (Figure 2.2), and valley bottom areas are narrow. Streams are deeply entrenched and valley walls are steep or precipitous (Figure 2.3). Soils tend to be sandy, with gravels present in many places.

In the remaining portion of the EKCF region, termed the Creek Bottom Settlements area by Davis (1924), ridges are much narrower (Figure 2.4) and more uneven than in the Ridge Top area, and valleys are wider (Figure 2.5). The valley wall slopes in the Creek Bottom Settlements, while steep, are generally not precipitous and thus were better suited for agricultural production during the early settlement period. Soils are generally loams and silty loams but are thin on the hill slopes and subject to erosion when cultivated.

3. Measurement and Analysis Methods

Bankfull channel characteristics were measured at sites near stream-flow gauging stations operated by the US Geological Survey (USGS) Kentucky Water Science Center and at ungauged sites. Channel geometric and longitudinal profile data and bed material properties were used to calculate channel dimensions and parameters needed for estimating bankfull discharge, classifying the channel, and developing bankfull regional curves. Where discharge was estimated for a gauged location with at least 10 years of record of peak annual flow, the bankfull discharge return interval was also estimated.

Figure 2.2 Headwaters of Middle Fork Red River near Torrent, Kentucky, above a knickpoint reach.

Figure 2.3 Salt Lick of South Fork Red River in the Ridge Top Settlements area near Slade, Kentucky.

Figure 2.4 Narrow ridge top in Lilley Cornett Woods in the Creek Bottom Settlements area.

Figure 2.5 Troublesome Creek at Noble, Kentucky, in the Creek Bottoms Settlements area.

3.1 SITE SELECTION

Initial Screening of USGS Gauging Stations

All USGS gauging stations within the EKCF were considered in the selection of a sample to represent the population of EKCF streams. In order for the sample to be representative of regional stream conditions, it would ideally consist of sites on rural, unregulated, wadeable streams with active gauges and a wide distribution of drainage areas and geographic locations. Prior data collection in other physiographic regions of Kentucky, however, had shown that the number of gauge sites suitable for assessment is typically limited and unlikely to comprise a sample that meets all of the ideal criteria; channel conditions at stream gauge stations tend to be characterized by reach-scale instability, a lack of consistent and unambiguous bankfull indicators in incised channels, and recently modified channel geometry (Parola, Skinner, et al. 2005; Parola, Vesely, et al. 2005). Therefore, while geographic locations and drainage areas were identified and recorded, their distributions were not factors in site selection.

Each station was screened according to three preliminary selection criteria prior to field reconnaissance:

1. Recording frequency and duration of available discharge data. Stream flow records were available for a large number of EKCF streams and rivers. Discontinued gauge sites were excluded unless the record of annual maximum series data was suitable 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). Active gauge sites with fewer than 10 years of annual maximum series data were excluded unless they had real-time discharge data for estimating bankfull flow.
2. 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. Logging has occurred in all of the watersheds in the region, and mining has occurred in most of the watersheds; therefore, these land uses were not used as a basis for exclusion of sites.
3. 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.

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 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 such as excavation for old mill races.
   c. Any structures spanning or encroaching on the stream channel were identified.
   d. Valley constrictions 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. Maps indicating karst-prone areas (KGS 2006; KYWSC 2007) at scales of 1:500,000 were checked for karst-prone strata that might affect the relative proportion of surface and sub-surface flow. Much of the Ridge Top and Limestone Valley area of the EKCF is underlain by carbonate rock, and stream flow at many prospective sites was therefore potentially susceptible to karst effects. At present, karst influences cannot be reliably predicted. Topographic maps provide clear evidence of karst surface features where present (Currens 2002), but the drainage patterns of karst aquifers may differ significantly from surface drainage patterns, and the apparent surface drainage area, especially in small basins, may not reflect the extent of groundwater conveyance. Similarly, maps of some groundwater karst basins relative to surface drainage boundaries are available (KGS 2005), but their information is currently insufficient to predict the influence of karst on the quantity of runoff at a particular site. Because methods for identifying karst flow (e.g., dye-trace tests) were beyond the scope of the project, and because karst strata in the EKCF may be overlain by non-karst layers and therefore do not present features readily identifiable under visual inspection (e.g., seep holes), the map review served only to identify whether sites were potentially influenced by karst. Those sites were noted but not eliminated from consideration.
4. The bedrock material underlying each site and its watershed were identified from Kentucky Geological Survey (KGS) 7.5-minute geologic quadrangle maps.
5. 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 250 mi^2.
6. The boundaries of the watershed of each station were identified using geospatial datasets (KGS 2002; Noger 2002).
   a. None of the streams draining fewer than 250 mi^2 had significant portions of their watersheds outside the EKCF region.
   b. Stations east of the Pine Mountain overthrust fault (Figure 2.1a) were eliminated as potential study areas because their geology differed significantly from that of the rest of the EKCF region.

Field Reconnaissance

An initial reconnaissance visit was made to photograph and evaluate each potential site. The field evaluation was based on three additional criteria:

1. Access. To obtain morphological data, a stable reach near the gauging station had to be accessible. Sites on private land were only selected if landowners granted access.
2. Channel pattern. Only single-thread channels were selected.
3. Channel morphology. Sites that met both of the above criteria were given further consideration only if the channel showed no signs of ongoing rapid morphological change and the geomorphic characteristics of a reach near the gauge 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. 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 (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 EKCF 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. Many incised channels had multiple depositional surfaces—low, flat terraces that had to be distinguished from the active floodplain. In those channels, the primary indicator 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. In streams that were not incised, the bankfull level coincided with the top of bank and valley flat (Figure 3.3).

Figure 3.1 Leatherwood Creek at Daisy, Kentucky. The bankfull level is represented by a narrow, horizontal depositional feature below and distinct from the higher valley flat.

Figure 3.2 Stable, well-developed active floodplain within a constructed flood conveyance channel along Road Fork, Pike County.

Figure 3.3 Tygarts River near Greenup, Kentucky. The bankfull level coincides with the valley flat.

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. When consistent indicators suggested a number of possible bankfull levels, the reach was nevertheless considered to be suitable for surveying. 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.

The second minimum requirement for selection of an assessment reach—channel geometry that was not controlled by a waterway structure—led to the elimination of several sites and necessitated that many of the reaches selected for assessment be located downstream or upstream of the gauge. Gauges typically were located at road bridges or culverts, which affect local channel geometry by altering flow velocity distributions, flow patterns, and sediment dynamics. Therefore, most of the gauge sites had cross-sectional geometries that had been affected by structural or other anthropogenic influences such as dredging or debris blockage removal. Some of these sites had to be eliminated because only inconsistent indicators of bankfull flow could be identified near the gauging station. Reaches selected for assessment were generally located downstream of the gauge to avoid the backwater influence of the bridge or culvert on floodplain and channel characteristics. Reaches upstream of the gauge were only chosen for assessment under two conditions: (1) when the configuration of the crossing structure associated with the gauge was considered to not significantly influence fine-grained sediment deposition required for floodplain formation, or (2) when the location of the upstream reach was considered to be beyond the backwater influence of the crossing structure associated with the gauge.

Final Site Selection

A total of 9 gauged sites on 8 streams met all of the above criteria; each of the gauges had at least 10 years of recorded annual maximum series data. Though the 9 gauged sites represented a wide range of drainage areas, the majority of selected gauged study reaches were located on large streams. Only one selected site had a drainage area of less than 10 mi^2, five drained between 20 and 100 mi^2, and three drained more than 100 mi^2.

After the 9 gauged sites had been identified, an additional 11 un-gauged sites on 10 streams were added; data collected from 6 un-gauged EKCF sites/streams and published by Parola, Skinner, et al. (2005) were also included in the sample. The inclusion of these 17 additional un-gauged sites increased the sample size, the representation of channels having smaller drainage areas, and the spatial extent of the sample within the region. 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. Other criteria for choosing ungauged assessment reaches were the same as those applied to gauged sites, omitting those criteria related to the gauges. Drainage areas for all 26 sites (Table 3.1 and Figure 3.4) on 24 streams ranged from 0.31 mi^2 to 242 mi^2.

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.

Table 3.1 Assessment Site Location Summary

	Stream Site	USGS Gauge	No. Yrs. Q_{peak} Data	Drainage Area (mi^2)	County	Latitude	Longitude
1	Bear Branch near Noble	3278000	28	2.21	Breathitt	N 37º 27.033'	W 83º 11.717'
2	Bear Hollow Tributary	—	—	0.55	Johnson	N 37º 44.717'	W 82º 47.850'
3	Cane Creek*	—	—	7.46	Laurel	N 37º 03.341'	W 84º 14.480'
4	Cat Creek	—	—	1.31	Powell	N 37º 46.533'	W 83º 48.500'
5	Cat Creek	—	—	7.81	Powell	N 37º 49.483'	W 83º 48.833'
6	Daniels Creek	—	—	0.80	Lawrence	N 37º 06.717'	W 82º 46.833'
7	Dog Slaughter Creek*	—	—	6.02	Whitley	N 36º 51.593'	W 84º 18.063'
8	Eagle Creek*	—	—	3.52	McCreary	N 36º 52.174'	W 84º 22.162'
9	Glade Branch	—	—	0.36	Johnson	N 37º 51.720'	W 82º 53.467'
10	Grapevine Creek	—	—	13.85	Perry	N 37º 21.150'	W 83º 20.933'
11	Horse Lick Creek*	—	—	55.75	Jackson	N 37º 20.149'	W 84º 08.229'
12	Jenny's Creek	—	—	35.6	Johnson	N 37º 48.800'	W 82º 50.283'
13	Leatherwood Creek at Daisy	3277400	26	40.9	Perry	N 37º 06.800'	W 83º 05.550'
14	Lick Fork	—	—	6.78	Johnson	N 37º 46.733'	W 82º 49.017'
15	Line Fork Tributary	—	—	0.31	Letcher	N 37º 04.679'	W 82º 59.566'
16	Lynn Camp Creek at Corbin	3404900	49	53.8	Whitley	N 37º 57.083'	W 84º 05.617'
17	Red Bird River near Big Creek	3281040	28	155	Clay	N 37º 10.717'	W 83º 35.583'
18	Red River near Hazel Green	3282500	53	65.8	Wolfe	N 37º 48.733'	W 83º 27.833'
19	Road Fork	—	—	2.82	Pike	N 37º 35.917'	W 82º 22.317'
20	Rock Creek*	—	—	18.79	McCreary	N 36º 35.997'	W 84º 44.708'
21	South Fork Dog Slaughter Creek*	—	—	3.48	Whitley	N 36º 51.516'	W 84º 17.939'
22	Stave Branch	—	—	0.49	Johnson	N 37º 50.100'	W 82º 50.200'
23	Stillwater Creek at Stillwater	3283000	29	24	Wolfe	N 37º 45.400'	W 83º 29.200'
24	Troublesome Creek at Noble	3278500	32	177	Breathitt	N 37º 26.600'	W 83º 13.100'
25	Tygarts Creek at Olive Hill	3216800	38	59.6	Carter	N 37º 17.950'	W 83º 10.417'
26	Tygarts Creek near Greenup	3217000	67	242	Greenup	N 37º 33.850'	W 82º 57.133'

* Site data incorporated from prior study of Upper Cumberland river basin management unit (Parola, Skinner, et al. 2005).

Channel Geometry

During the initial reconnaissance conducted during the site selection process, survey locations in each gauged and ungauged reach selected for assessment were marked with flags. Flags were used to mark upstream and downstream limits of each reach, USGS gauge benchmarks, cross section locations, tree lines along the banks, and bankfull indicators. In a second visit to each site, data was collected for development of regional curves. Gauge descriptions obtained from the USGS Kentucky Water Science Center were reviewed for indications of historical channel processes that had been observed by station monitors. Extensive photographic documentation was recorded for all sites. The specific geomorphic features that were recorded included bankfull markers, bed configuration, 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 marked features and cross-sectional and longitudinal profile data.

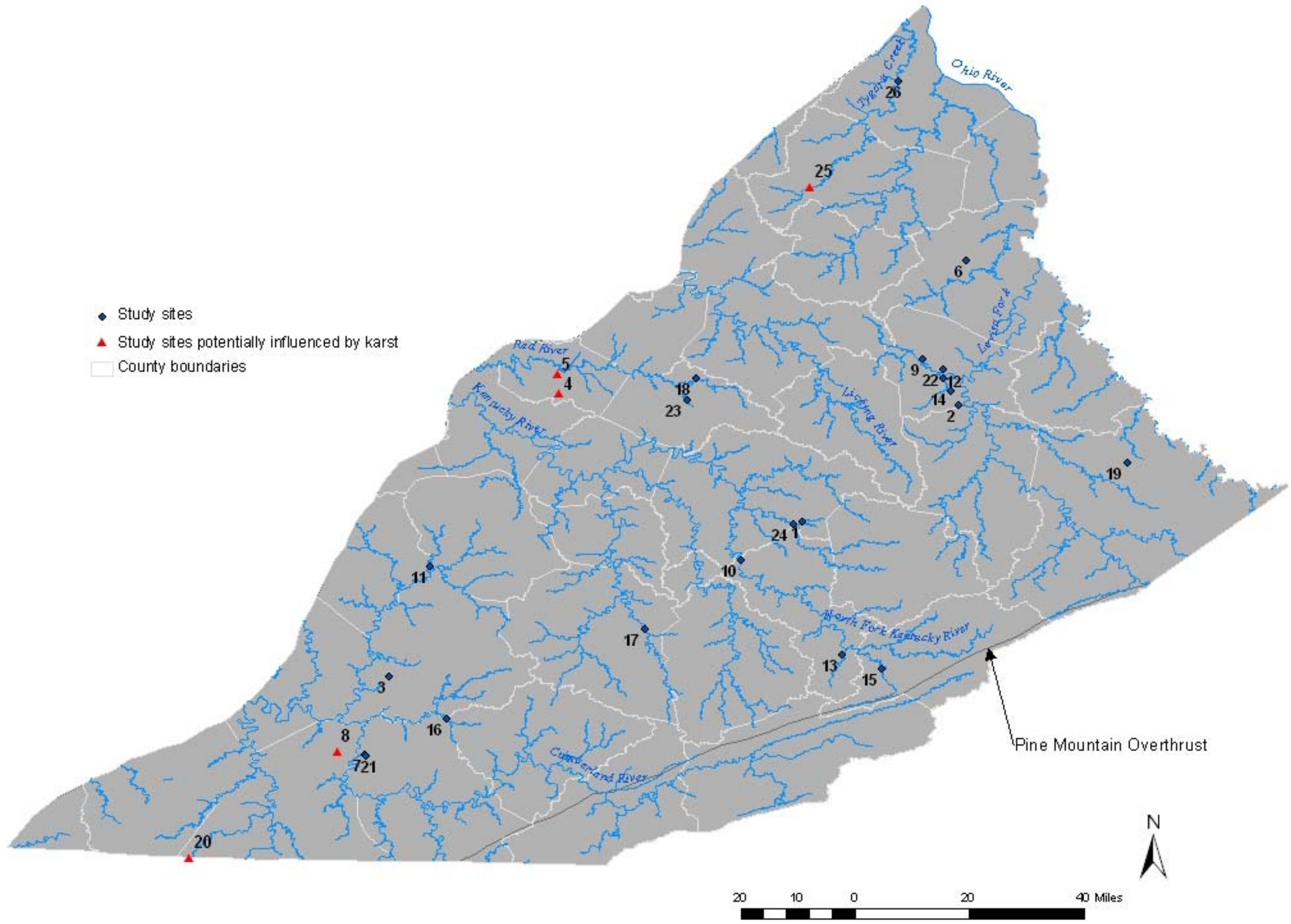


Figure 3.4 Locations of assessment sites (KGS 2002; USEPA and USGS 2005). Streams shown are Strahler order 3 and above.

Survey data were collected according to the procedures described in Harrelson et al. (1994). Survey control points were installed at each cross section location. Where practical, these consisted of at least two permanent concrete monuments. Where permanent monuments were not practical, or where landowner permission was not granted, wooden stakes were substituted. Cross sections, marked features, and longitudinal profiles were surveyed using a Topcon GTS-226 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.

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. 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. All survey data at gauged sites were referenced to the gauge datum wherever gauge benchmarks could be identified.

The amount and extent of the survey data collection at each site depended largely on whether and how bankfull discharge was going to be determined. At sites where bankfull discharge was not to be determined, a single cross section was typically surveyed. At the nine sites where bankfull discharge could be estimated from a rating curve, one or two cross sections and a longitudinal profile were surveyed. The longitudinal survey extended through the length of the assessment reach and past the gauge location. At all other sites, bankfull discharge had to be estimated by numerical modeling. Therefore, more extensive channel geometry data (i.e., a greater number of cross sections taken over a greater reach length) were surveyed.

Bed Sediment Characteristics

The surface particle-size distribution was evaluated at each site on the riffle surveyed to compute bankfull parameters. The Wolman (1954) pebble counting procedure was used at each site where bankfull discharge would be estimated by numerical modeling. At several other sites, the size class corresponding to the median sediment size was visually estimated for the riffle.

3.3 DATA ANALYSIS

Bed Sediment Sizes

A cumulative frequency distribution was plotted from the particle sizes recorded in the pebble counts. From the distribution curve, the particle sizes that equaled or exceeded 50% (D_{50}) and 84% (D_{84}) of the sampled material were determined for use in classifying each reach (Rosgen 1996) and modeling bankfull discharge. For classification purposes, the D_{50} of the riffle used to compute bankfull parameters 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. At sites where field surveys were referenced to gauge benchmarks, all elevations were plotted relative to the benchmark heights given by USGS gauge descriptions.

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 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 cross section taken at the most clearly defined riffle crest 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 ($D_{BKF} = A_{BKF} / W_{BKF}$).

    - Classifying each assessment reach according to the Rosgen (1996) Level II classification system: maximum bankfull depth; 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 types of vegetation on the banks and floodplain were identified from the photographs for use in assigning roughness values for sites where flow would be modeled.
- For sites where flow would be modeled, geometric data for each cross section were tabulated for input into HEC-RAS.

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 and the elevations of peak flows recorded by crest gauges, if used, were also plotted on each longitudinal profile. Based on each profile plot, multiple parameters were analyzed as follows:

- 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. In some cases, the bankfull level indicated by the regression line was 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.
- For sites where flow would be modeled, values required for input to HEC-RAS to either define or derive a boundary condition were calculated based on various parameters:
    - When a bankfull indicator was identified at the most downstream cross section, a known bankfull water surface elevation was obtained from the elevation of the indicator.
    - A water surface slope was obtained from the regression line through the bankfull indicator points.
    - A water surface slope was obtained from the riffle-crest-to-crest slope. At sites where the surveyed water surface slope between riffle crests varied within the assessment reach, the riffle-crest-to-crest slope was calculated from the two most downstream riffles; otherwise, the slope was derived from the best-fit line regressed through the riffle crest points of all cross sections.

Bankfull Discharge

Estimation of Bankfull Discharge from Gauge Rating Curve

Bankfull discharge at a total of 17 sites was estimated using field survey data and either a numerical model (HEC-RAS) or current stage-discharge relations (rating curves). HEC-RAS was used to estimate bankfull discharge at eight of the un-gauged sites. The other nine sites for which bankfull discharge was estimated were located near USGS stream-flow gauging stations. Rating curves for each of the nine gauge stations were derived from gauging information (Form 9-207) obtained from the USGS Kentucky Water Science Center. The gauge rating curve was used to determine bankfull discharge based on the bankfull level identified at the cross section used for computing bankfull parameters. In each case, the bankfull level coincided with the top of bank at or near the level of the valley flat.

At each of the gauged sites, the bankfull geometry at the location of the cross section was similar to that at the gauge. Thus, the stage-discharge relation was considered to be the same at the gauge and the cross section. The bankfull stage at the gauge was determined by measuring the elevation difference between the water surface and the bankfull level at the cross section and adding it to the water surface elevation surveyed at the gauge at the same time; the rating curve was then used to derive the bankfull discharge associated with that stage. For six of the nine gauged sites (i.e., Sites 13, 16, 17, 18, 23, and 24), the cross section for bankfull geometry was within three bankfull widths of the gauge. The bankfull geometry cross sections for other three sites (1, 25, and 26) were each more than three bankfull widths from the gauge location. Because the similarity of the bankfull geometry was visually determined instead of measured, the error in the estimate of bankfull discharge for these three sites may be greater than for the other sites.

HEC-RAS Estimation of Bankfull Discharge

Bankfull discharges and friction slopes for eight un-gauged reaches were modeled using the one-dimensional water surface profile program HEC-RAS 3.1 (Brunner 2001). Inputs to define channel characteristics in the model are cross-sectional geometry data (minimum of two cross sections) and an estimate of channel roughness using the Manning *n* roughness coefficient. Cross sections were input directly from the tabular data prepared in Excel. Roughness values were estimated using the Limerinos (1970) relation and Chow's (1959) roughness coefficient tables. Where the resistance of the channel at bankfull flow conditions could be attributed primarily to the channel bed, the Limerinos relation was applied to calculate *n* using the D_{84} particle size from the pebble count and the magnitude of the average bankfull depth derived from the surveyed bankfull cross-sectional area and width. Where resistance of the channel could also be attributed to dense bank vegetation, as was the case for many of the larger streams where mature trees were found well down the banks, the *n* values for the entire bank and the overbank areas (Brunner 2001) were selected from those presented by Chow (1959:Table 5.6) for floodplains.

An iterative approach was adopted to estimate the bankfull discharge using HEC-RAS, whereby discharge was varied incrementally until the modeled flow best matched the regression line plotted through the elevations of the bankfull indicators. Roughness value inputs were also adjusted to obtain a flow that matched observed water surface elevations. Another input, the downstream boundary condition, was adjusted to obtain the best fit with the cross-sectional data and crest gauge data (when available for events near the identified bankfull level). The boundary condition at the most downstream cross section was defined by either a known bankfull elevation or a water surface elevation computed by HEC-RAS using an input water surface slope and the normal depth assumption (Henderson 1966).

Frequency of Bankfull Discharge

Annual maximum series data for the nine project site gauges were obtained from the USGS Kentucky Water Science Center or from their online datasets. Using the log-Pearson Type III distribution (McCuen 1998) as described in *Guidelines for Determining Flood Flow Frequency* (USIACWD 1982), frequency analysis was conducted for each of those nine stations. From the frequency distribution for each station, flows corresponding to the 1.5-year event were estimated, and the return periods of the bankfull discharges were estimated.

Elimination of Sites from Dataset

Much of the western third of the EKCF is underlain by carbonate rock, and stream flow at several sites was therefore potentially susceptible to karst effects. The determination of whether sites were influenced by karst was based primarily on comparison of collected geometry and flow data for upstream and downstream reaches of a single channel. Changes in geometry or flow measurements that indicated that the stream was losing or gaining significant amounts of flow were considered to be indicators that the anomalous reach was influenced by karst. One site on Rock Creek was identified as losing a significant amount of flow and was eliminated. Five other sites identified in the map review as being in areas potentially influenced by karst did not exhibit clearly anomalous characteristics; they were included in the dataset used to develop the bankfull regional curves. The drainage areas calculated for these five sites are subject to an undetermined degree of error because the methods used to derive them relied exclusively on topographic data and could not account for groundwater conduits that cross topographic divides.

4. Bankfull Characteristics of Eastern Kentucky Coal Field Channels

Bankfull channel parameters calculated for each assessment reach (Table 4.1) were used to develop regional curves for EKCF streams and to classify each reach. The curves describe the relationships between drainage area and bankfull channel geometry and bankfull discharge. Bankfull discharge was also compared to the 1.5-year discharge for nine sites. Classification of each reach according to Rosgen (1996) Type II classification parameters identified 12 Bc-, 4 C-, 7 E-, and 3 F-type channels; the stream type was consistent for the entire length of each reach.

4.1 BANKFULL REGIONAL CURVES

Bankfull regional curves for gravel- and cobble-bed streams draining from 0.31 to 242 mi^2 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 and 4.2). A best-fit line was regressed for each plot in the form of a simple power function:

$$Y_{bkf} = a \, DA^{b} \tag{1}$$

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.

Coefficient of determination (R^2) values show that drainage area accounts for over 87% 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).

4.2 BANKFULL DISCHARGE RECURRENCE INTERVAL

Bankfull return periods computed for streams draining from 2.21 to 242 mi^2 range from just over 1.0 to 1.5 years (Table 4.1). The mean bankfull return period is 1.09 years; the median is

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

	Stream Site	USGS Gauge	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)	RI (yrs)	No.Yrs. Q_{peak} Data§	No.Yrs. $Q_{bkf} < Q_{peak}$
1	Bear Branch near Noble	3278000	2.21	15.8	14.5	1.09	2.3	13.3	1.1†	46	C4/1	192	61	1.02	28	27
2	Bear Hollow Tributary	—	0.55	6.4	6.7	0.95	3.4	7	1.16†	C	E3	—	—	—	—	—
3	Cane Creek**	—	7.46	60.3	33	1.83	1.4	18.1	0.46	46.3	B4c	—	153	—	—	—
4	Cat Creek	—	1.31	12	15	0.8	1.5	18.8	1.3†	C	B3/1c	—	—	—	—	—
5	Cat Creek	—	7.81	35.2	22	1.6	1.4	13.8	0.45†	40	B4c	—	—	—	—	—
6	Daniels Creek	—	0.80	9.1	9.3	0.98	2.2	9.5	1.08	37	C4/1	—	30.5	—	—	—
7	Dog Slaughter Creek**	—	6.02	56	37.5	1.49	1.2	25.2	0.96	90.5	B3c	—	200	—	—	—
8	Eagle Creek**	—	3.52	47.4	31.8	1.49	1.1	21.3	0.33	37	F4/1	—	150	—	—	—
9	Glade Branch	—	0.36	4	5.5	0.73	2.3	7.5	—	G	E4	—	—	—	—	—
10	Grapevine Creek	—	13.85	44	25.5	1.73	1.6	14.8	—	S	B5c	—	—	—	—	—
11	Horse Lick Creek**	—	55.75	210	62.6	3.36	1.7	18.7	0.17	27.5	B4c	—	750	—	—	—
12	Jenny's Creek	—	35.6	141.6	59	2.4	1.2	24.6	0.23†	S	F5	—	—	—	—	—
13	Leatherwood Creek at Daisy	3277400	40.9	154.4	49.5	3.12	1.6	15.9	0.13†	70	B3/1c	2188	450	1.01	26	26
14	Lick Fork	—	6.78	33	23	1.43	1.7	16	0.41†	G	B4/1c	—	—	—	—	—
15	Line Fork Tributary	—	0.31	3.8	7	0.62	2.4	11.3	—	G	C4	—	—	—	—	—
16	Lynn Camp Creek at Corbin	3404900	53.8	141.4	71.4	1.98	1.2	36.1	0.07†	28	F4/1	1834	614	<1.01	49	49
17	Red Bird River near Big Creek	3281040	155	1095	147.9	7.4	2.1	20	—	28	E4	9476	5992	1.06	28	26
18	Red River near Hazel Green	3282500	65.8	400	56	7.14	>2.2	7.8	—	G	E4	1711	1710	1.5	53	36
19	Road Fork	—	2.82	11.5	9.8	1.17	3.5	8.4	1.4	42	E4	—	70	—	—	—
20	Rock Creek**	—	18.79	85.4	53	1.61	1.2	32.9	0.76	46.3	B4/1c	—	350	—	—	—
21	South Fork Dog Slaughter Creek**	—	3.48	42.2	26.3	1.61	1.7	16.3	1.64	135	B3c	—	135	—	—	—
22	Stave Branch	—	0.49	5.9	8	0.73	4.5	10.9	0.8†	15.5	C4	—	—	—	—	—
23	Stillwater Creek at Stillwater	3283000	24	66.5	32.6	2.04	1.4	16	0.26†	51	B4c	1569	194	<1.01	29	29
24	Troublesome Creek at Noble	3278500	177	775.1	94.1	8.24	2.1	11.4	—	18	E4	7360	3800	1.1	32	28
25	Tygarts Creek at Olive Hill	3216800	59.6	255.3	82.7	3.09	1.7	45.5	0.11†	27	B4/1c	4078	818	<1.01	38	38
26	Tygarts Creek near Greenup	3217000	242	1027	112.7	9.11	>2.2	12.4	—	37	E4	5696	3571	1.11	67	62

* ER is entrenchment ratio (dimensionless).

† Riffle crest-to-crest slope. All other slopes are bankfull friction slope from HEC-RAS. Where no slope is provided, visually estimated slopes were used to classify the reach.

‡ C, G, and S indicate that the median sediment size for the riffle was visually estimated to be in the cobble, gravel, or sand range, respectively. Sand-bed streams were excluded from regional curves.

§ The number of years (through water-year 2007 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.

** Site data incorporated from prior study of Upper Cumberland river basin management unit (Parola, Skinner, et al. 2005).

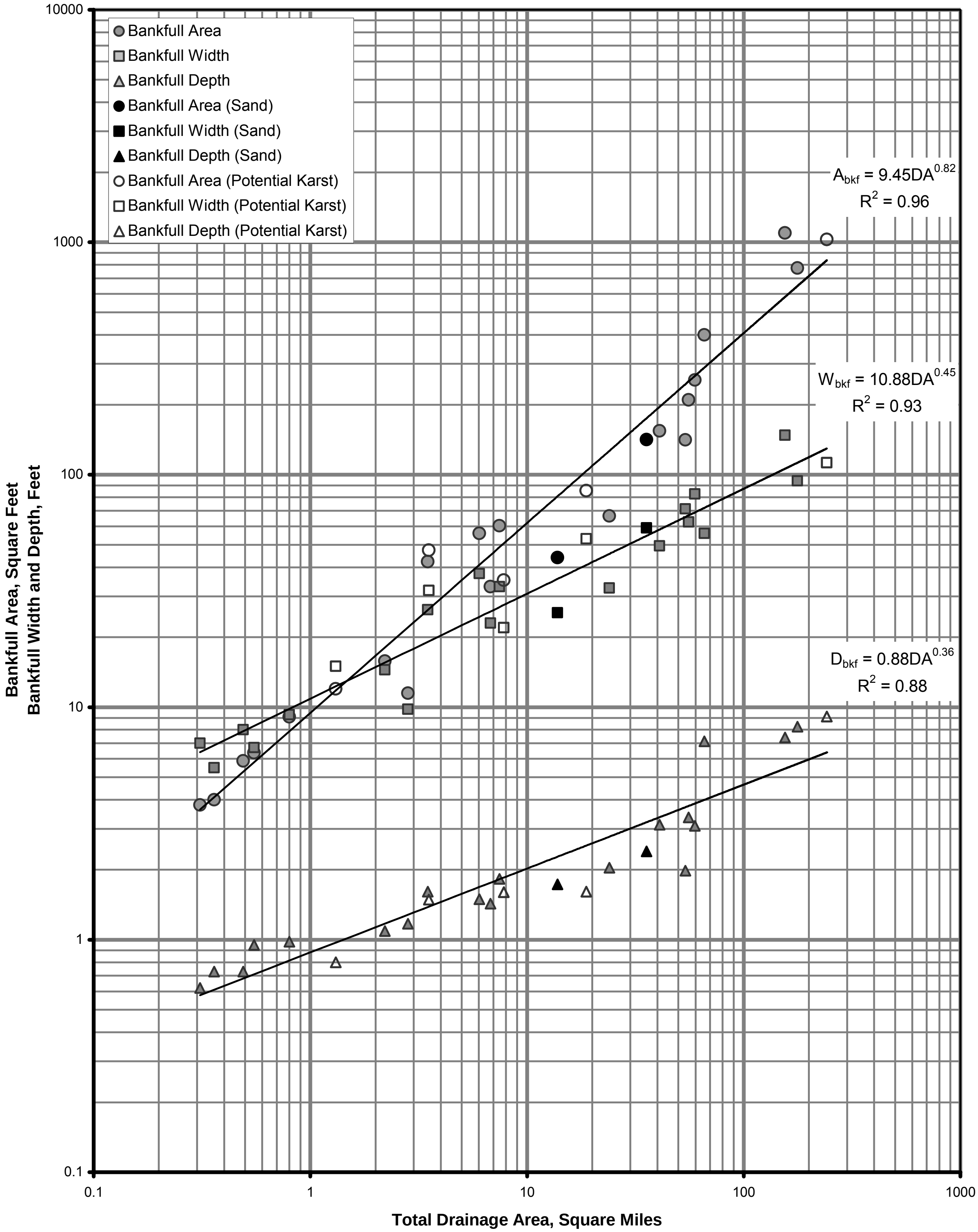


Figure 4.1 Bankfull cross-sectional characteristics as a function of drainage area for gravel- and cobble-bed streams in the EKCF region. Study sites in areas potentially influenced by karst are shown as hollow points. The two study sites with sand-bed streams are shown as solid-fill points on the plot for reference only; they were not included in the derivation of the equations.

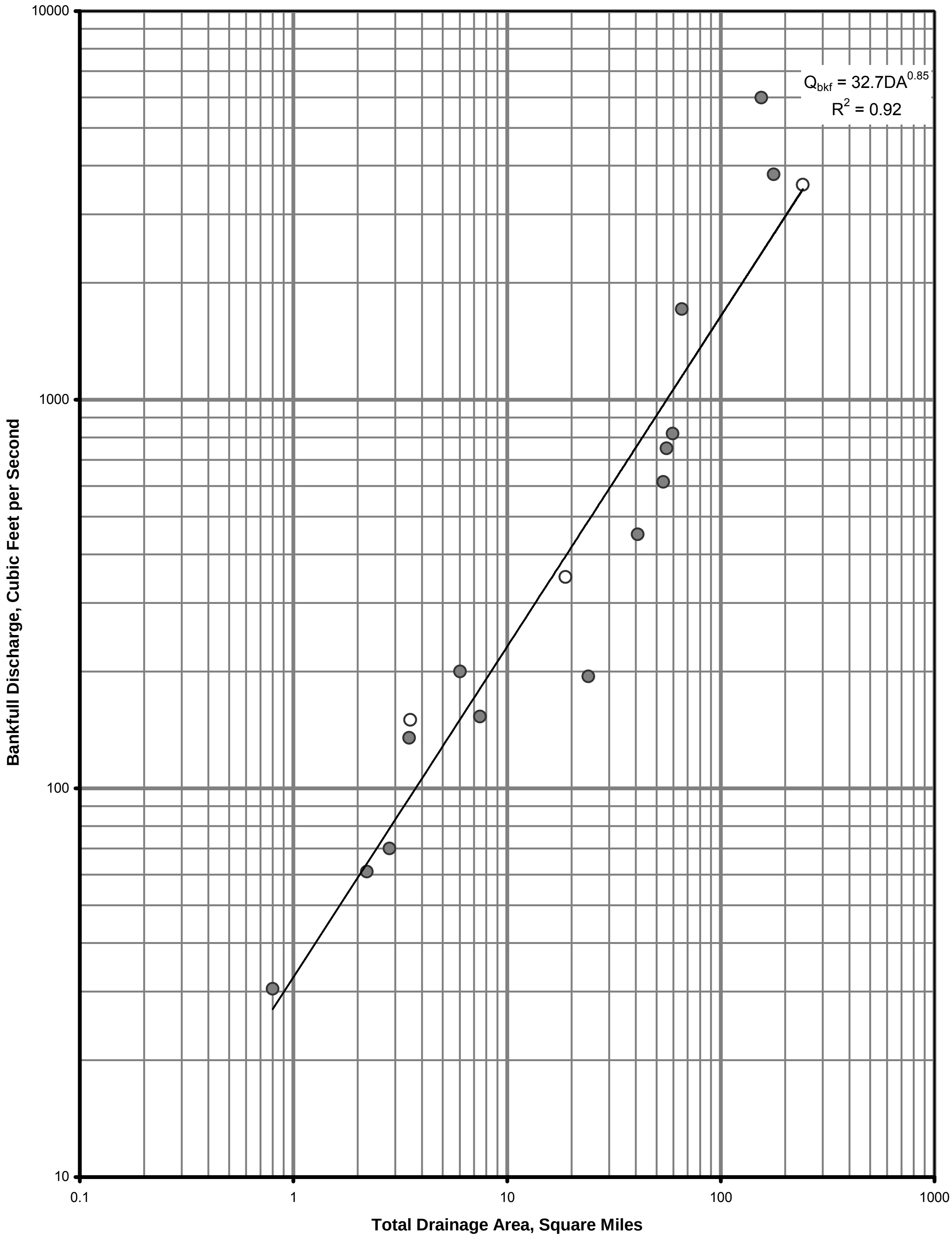


Figure 4.2 Bankfull discharge as a function of drainage area for gravel- and cobble-bed streams in the EKCF region. Study sites in areas potentially influenced by karst are shown as hollow points.

1.02 years. These return intervals are within the range of 1 to 2 years considered to be typical for bankfull flow, and all but one are consistent with the 1- to 1.2-year range identified by Hey (1975) for gravel-bed rivers in England. They are, however, 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) and therefore do not support the concept of a universal return period that various researchers have either suggested (Dunne and Leopold 1978) or critiqued (Knighton 1998; Williams 1978).

The bankfull discharge is not only more frequent but also substantially less than the 1.5-year discharge for eight of the nine gauged assessment reaches. Of the nine sites for which the values were compared, eight had a Q_{bkf} less than or equal to 63% of $Q_{1.5}$ (Figure 4.3); on average, Q_{bkf} is approximately 44% of $Q_{1.5}$. Thus, the 1.5-year discharge cannot be considered to be a reasonable representation or estimate of the bankfull discharge for EKCF streams, and estimates derived from the regression equation for Q_{bkf} would likely be more accurate than those derived from flood frequency data.

Table 4.2 Bankfull Regression Equations for Streams of the EKCF Physiographic Region

Regression Equation	n	Coefficient of Determination, R^2	Standard Error*, S_e (%)	Standard Deviation†, s (%)
$A_{bkf} = 9.45\ DA^{0.82}$	26	0.96	37.2	189.7
$W_{bkf} = 10.88\ DA^{0.45}$	26	0.93	27.5	140.2
$D_{bkf} = 0.88\ DA^{0.36}$	26	0.88	29.0	147.9
$Q_{bkf} = 32.7\ DA^{0.85}$	17	0.92	48.0	197.9

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

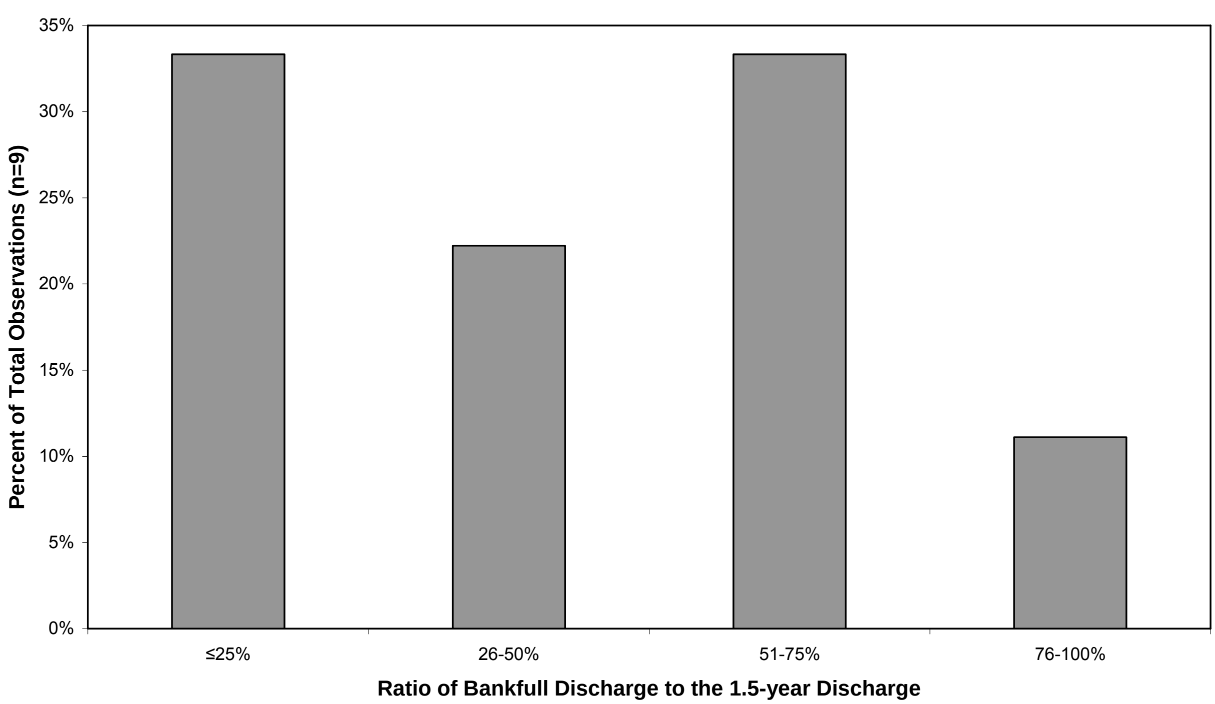


Figure 4.3 Bankfull discharge as a proportion of the flow associated with the 1.5-year return interval for the same site.

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 EKCF region were developed from sites with watersheds between 0.31 and 242 mi^2 where the channel was stable and had unambiguous bankfull indicators. The relationship between bankfull parameters and drainage area in the EKCF region is well described by the curves, which explain over 87% of the variation within the datasets for bankfull area, width, depth, and discharge. Standard errors are less than 38% for the bankfull geometry and less than 48% for bankfull discharge. On average, the bankfull discharge was found to be approximately 44% that of the 1.5-year discharge, and no consistent frequency represented the return period of the bankfull flow. 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 inside the portion of the EKCF region east of the Pottsville or Cumberland Escarpment and west of the Pine Mountain overthrust fault.
- Land use. Streams in watersheds that are less than 10% urbanized are represented. Logging has occurred in all of the watersheds in the region, and mining has occurred in most of the watersheds; therefore, the curves represent the effects of typical land use and sediment loads from mining.
- Flow regulation. Streams that are not subject to flow regulation are represented.
- Drainage area. The curves apply only to streams draining between 0.31 and 242 mi^2.
- Karst susceptibility. Streams in watersheds with no evidence of subsurface conduits that cross topographic divides are represented, though the dataset includes five streams that may be influenced by karst. In karst landscapes, channels will convey less flow than non-karst stream reaches and may have a smaller cross section than those suggested by the regional curves.
- Sediment size. Gravel- and cobble-bed streams are represented. While data collected from two sand-bed streams generally plot within the range of the data used to develop the curves, the sample size of the sand-bed stream data was too small to determine whether these curves would accurately describe most sand-bed channels in the EKCF region.
- Slope. The curves apply only to streams with slopes of up to 3%.

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. Therefore, bankfull characteristics of channels formed under these 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 EKCF 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 EKCF 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 EKCF 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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