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Geomorphic Characteristics of Streams in the Western 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 20 un-gauged sites were used to develop regional curves for bankfull channel depth, width, area, and discharge for rural, unregulated Western Kentucky Coal Field (WKCF) streams draining fewer than 117 mi^2. The bankfull discharge was also compared to the 1.01- and 1.5-year flows estimated for gauged locations in the WKCF with at least 10 years of record of peak annual flow.

An extensive examination and collection of stream geomorphological characteristics in the WKCF 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 WKCF region is described by curves that explain between 54% and 92% of the variation within the datasets for bankfull area, width, depth, and discharge. Standard errors are less than 36%. At each of the sites for which bankfull discharge was estimated, the bankfull discharge was found to be no more than 15% of the estimated regional (WKCF) 1.5-year discharge and is thus likely associated with a smaller return interval. 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 Western Kentucky Coal Field Physiographic Region of Kentucky

By Benjamin D. Mater, 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 Western Kentucky Coal Field (WKCF) region 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 as a function of upstream drainage area in the WKCF physiographic region of Kentucky.

Data used to develop the regional curves were collected from 20 sites on 17 un-gauged WKCF streams in March and April of 2007; bankfull discharge was estimated for 11 of these sites. While the inclusion of channels with active stream-flow gauges was a priority in order to be able to estimate the bankfull flow return period, none were suitable for bankfull geomorphic assessment; therefore, data were collected only on un-gauged streams. 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 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 silt-bed streams draining from 1.56 to 117 mi^2 and gravel-bed streams draining from 0.25 to 2.88 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 Western Kentucky Coal Field Physiographic Region

The WKCF region encompasses all or part of 20 counties and covers roughly 4,800 mi^2. Those counties that lie almost entirely within the region are Daviess, Hancock, Henderson, Hopkins, McLean, Muhlenberg, Ohio, Union, and Webster. Portions of Butler, Edmonson, and Grayson Counties comprise its eastern extension. The major stream systems of the region include the Ohio, the Green, the Tradewater, the Pond, the Rough, and the Nolin rivers.

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. In the Western Kentucky Coal Field, gravel-bed streams dissect the Pennsylvanian rocks of the uplands, while silt-bed streams rework Quaternary sediments of the lowlands.

2.1 STRUCTURAL GEOLOGY

The Western Kentucky Coal Field physiographic region is part of a larger physiographic region known as the Illinois Basin, which extends throughout southeastern Illinois, southwestern Indiana, and into western Kentucky. The WKCF is bounded to the north and northwest by the Ohio River and to the west, south, and east by the Dripping Springs Escarpment, formed from sandstones and conglomerates in the lower part of the Pennsylvanian strata. WKCF Pennsylvanian rocks (Table 2.1 and Figure 2.2) are roughly 4000 ft thick and occupy the broad, subtle Moorman Syncline. The east-west trending axis of this syncline parallels and is 7-10 mi south of the region's most prominent band of normal and reverse faults: the Rough Creek Fault System (Rice 2001). Along the region's southern and eastern margin, basal Pennsylvanian strata meet underlying strata of Mississippian limestone to form the Pottsville Escarpment. The resistant Pennsylvanian rock forms a dissected plateau within the WKCF that resembles the physiography of the Eastern Kentucky Coal Field (EKCF) region. The similarity of portions of the two regions is due in part to their locations on the flanks of the Cincinnati Arch (Burroughs 1924), where formations have eroded less rapidly than those nearer its axis, which is oriented in an approximately north-south direction between Cincinnati, Ohio, and Lexington, Kentucky. The Axis formed in a series of folding and warping episodes that lifted Paleozoic strata far above the elevations at which they had been deposited (McFarlan 1943) and now separates the Pennsylvanian strata that were once continuous between the WKCF and EKCF regions.

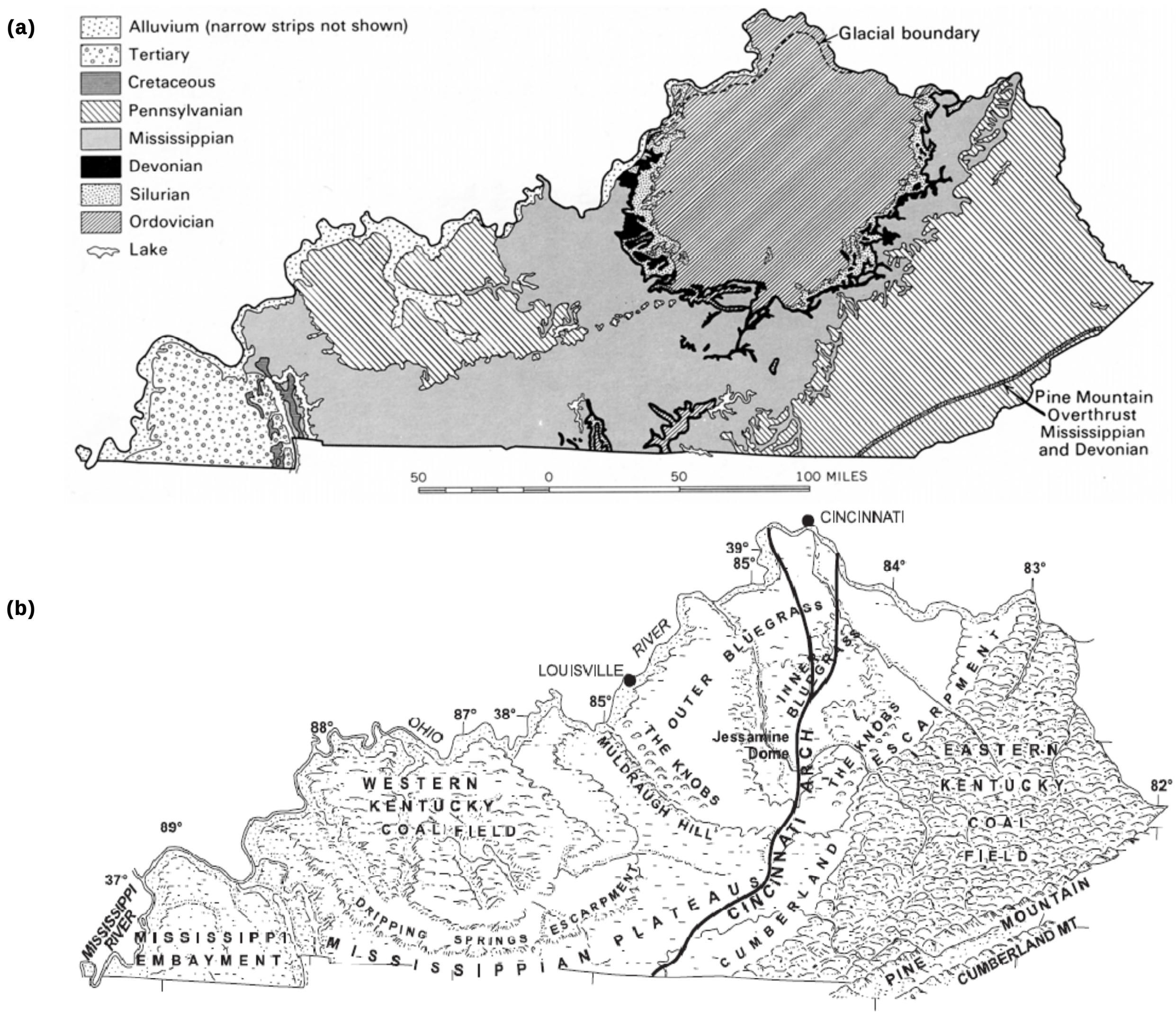

Figure 2.1 (a) Generalized geologic map of Kentucky (after McGrain 1983:12).
(b) Physiographic map of Kentucky (KGS 1980).

During the Pennsylvanian period (250-300 mya), sediment eroding from the ancestral Appalachian hills was deposited in a large inland sea extending throughout the Illinois 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. These largely alluvial or deltaic strata are of similar origin and characteristics to those of the Eastern Kentucky Coal Field. The massive, quartzose sandstone of the WKCF Caseyville and Tradewater Formations, for example, resembles that of the Lee Formation in the EKCF. In both regions, the erosion-resistant quality of this rock type is responsible for its presence in prominent cliff outcroppings. Overlying this resistant sandstone unit in the WKCF are the interbedded sandstones, siltstones, coal, and limestones of the Tradewater, Carbondale, and Sturgis formations. Clastic rock types dominate these lithologically similar formations, with marine carbonates forming less prominent but extensive layers formed by intermittent sea transgression. Economically valuable coal seams are most prominent within the middle of the Pennsylvanian stratigraphy, particularly within the Carbondale Formation (Rice 2001).

Table 2.1 WKCF Generalized Stratigraphy*

System	Series	Formation	Description
PENNSYLVANIAN	Upper Pennsylvanian	Sturgis	Sandstone, siltstone, shale, limestone, and coal: Sandstone, light-gray and light- to yellowish-brown, fine- to coarse-grained. Siltstone, light- to dark-gray, locally shaly and sandy. Shale, medium- to dark-grey, carbonaceous, generally silty and sandy. Limestone, gray, thin- to thick-bedded, fossiliferous. Coal is generally a minor constituent but locally very thick.
	Middle Pennsylvanian	Carbondale	Sandstone, siltstone, shale, coal, and limestone: Sandstone, light- to medium-gray or brown, very fine- to medium-grained, medium- to thick-bedded; Siltstone, medium-gray, sandy; Shale, light-brown to dark-gray, sandy, silty, partly limonitic and carbonaceous. Many thicker and more economic coal beds of the WKCF.
		Tradewater	Sandstone, siltstone, shale, coal, and limestone: Sandstone, light- to medium-gray, fine- to medium-grained; micaceous, friable. Siltstone, light- to medium-gray, locally interbedded with thin-bedded sandstone. Shale, light-gray to black, carbonaceous. Several economic coal beds. Limestone, light- to medium-gray, dense, thin- to thick-bedded, fossiliferous.
	Lower Pennsylvanian	Caseyville	Sandstone, siltstone, shale, and coal: Sandstone, white to yellowish-brown, fine- to coarse-grained; locally conglomeratic with scattered quartz pebbles as much as 2 inch in diameter; locally forms cliffs as much as 125 feet high. Siltstone, light- to dark-gray; locally micaceous and interbedded with thin-bedded sandstone. Shale, dark-gray to black, carbonaceous. Coal beds are thin, lenticular, and of very local extent.

* The typical stratigraphy of the region provided by the US Geological Survey (Hansen and Smith 1978; Palmer 1968; Amos 1970; Rice 2001).

2.2 PHYSIOGRAPHIC SETTING

The physiograpy of the WKCF ranges from dissected uplands with V-shaped valleys in the south and east and the western margin to gently rolling hills and wide, flat bottomlands in the north and interior areas.

Dissected Uplands

The region's southern and eastern margin is a dissected plateau with narrow ridges and valleys. Within this portion of the region, the close proximity of Pennsylvanian stratigraphy leads to its direct interaction with surficial geomorphic processes. As in the EKCF, this interaction has created a heavily dissected plateau drained by a dendritic pattern of mostly gravel-bed streams, although regional uplift has not provided the same expanse of rugged terrain as in the EKCF. Stream morphology within the relatively high-relief WKCF areas bears some resemblance to that found in similar areas of the EKCF (Figure 2.3).

The western extent of the WKCF is similar in character, though not as rugged, as the southern and eastern margins. The Tradewater River runs north-west along the boundary between the dissected uplands of the western extent and the rolling hills of the interior and north. Tributaries draining from the west to the Tradewater in Crittenden and Caldwell Counties encounter Mississippian material at headwater extremities and may locally encounter outcroppings of durable conglomerate sandstones of the Caseyville formation. Rock types along these tributaries may transition sharply where faulting has occurred. Headwater tributaries above widespread lacustrine and alluvial deposits of the lowlands often have gravel beds with high sand content. These smaller streams resemble those in the eastern portion of the WKCF and in some areas of the EKCF.

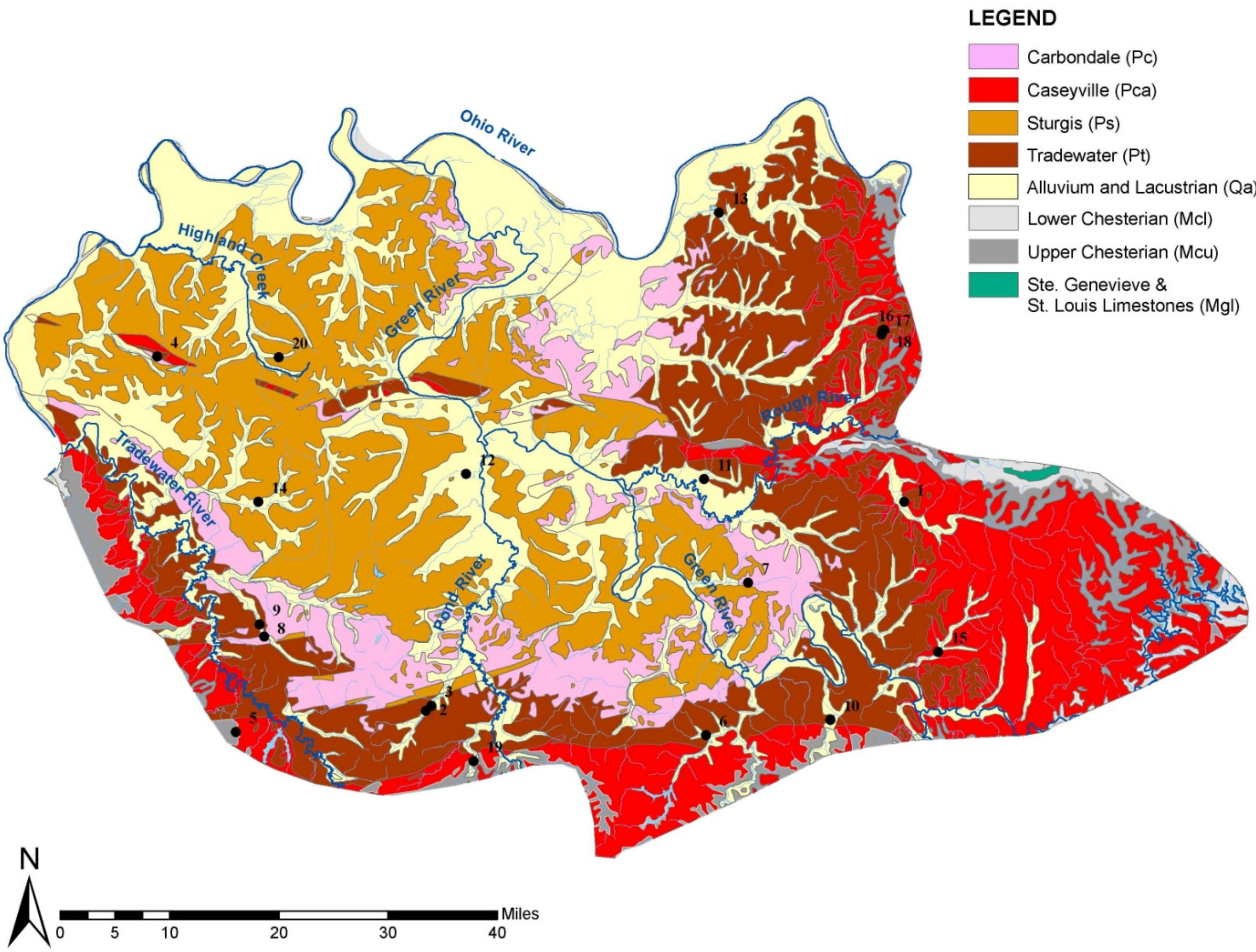

Figure 2.2 Geology of the WKCF region (KGS 2002; KYDGI 2005b; Noger 2002).

In the transition zone between these uplands and the more subdued topography of the north and interior, stream morphology is more variable due to changes in sediment regimes and boundary material. The transition is abrupt where upland tributaries encounter slackwater deposits of larger rivers as with many streams draining to the Tradewater River in Crittenden and Caldwell Counties.

Rolling Hills and Wide Valley Bottomlands

From the rough rim of Christian, southern Muhlenberg, Butler, Edmonson, Grayson, and eastern Ohio counties, the topography transitions to gently rolling hills within central Hopkins, Muhlenberg, and Ohio counties. Fine-grained sediment and alluvium derived from loess deposits are common and play a significant role in stream morphology. Along the Green River, alluvium is up to 100 ft thick, and depths of over 50 ft are common (Palmer 1972). Tributaries draining from the east to the Tradewater River traverse Quaternary lacustrine and alluvial deposits and are thus similar to those feeding the Green River on the east of the Green/Tradewater drainage divide (Franklin 1969). Lowland streams are low–gradient and silt-bedded, and where they have not been modified, they form multiple channel streams flowing through wetlands in wide valley bottoms filled with Quaternary silt, sand, and gravely alluvium.

Topographic relief becomes even more subdued in the interior region consisting of Webster, northern Hopkins, northern Muhlenberg, McLean, and northwestern Ohio counties. Within this area, loess is more common and mantles all but the steepest slopes to depths up to 25 ft (Hansen and Smith 1978). This loess is generally a soft, clayey silt and is easily eroded, thus constituting a major portion of sediment supplied to the area's streams. Below elevations of approximately 400 ft msl, clay and silt of valley bottoms is often of lacustrine origin, deposited in Quaternary lakes formed as a result of Wisconsin outwash in the Ohio River Valley (Johnson and Smith 1972). Alluvium found in the valley bottoms is chiefly clay and silt with deposits of sandy gravel. Alluvial gravels are mostly subangular to subrounded pebbles of chert with smaller quantities of rounded pebbles of quartz, sandstone, siltstone, and fossiliferous limestone. Gravels are often cemented in limonitic deposits (Hansen and Smith 1978). Anthropogenic disturbance is widespread in these areas and propagates quickly throughout drainage networks, while morphological recovery appears to be slow (Figure 2.4). Although some valley bottoms are swampy and have stream morphology heavily influenced by large woody debris and beaver dams (Figure 2.5), most have been extensively drained for agriculture (Burroughs 1924). Streams within this area are generally bedded in silt with minor coarse bedload and are of low gradient. Headwater tributaries may have gravel beds associated with reworked Pleistocene and, potentially, Pliocene deposits (Hansen and Smith 1978) and eroded bedrock at headward extents.

Gently rolling loess-mantled physiography extends into the WKCF's northern counties of Union, Henderson, and Daviess. At the northern extent of the region, a distinct transition from rolling upland to river bottom parallels the Ohio River, becoming most prominent in the steep bluffs and narrow tributary valleys of Hancock County in the northeast. Loess deposits are up to 55 ft thick, and the larger streams occupy wide valley bottoms filled with deep deposits of Pleistocene and Holocene alluvium (Johnson 1973). Alluvium is sand, silt, gravel, and clay derived from contemporary deposition and older glacial outwash. Gravels are mostly subangular to subrounded quartz and chert pebbles less than 30 mm in length with larger particles at greater depths (Johnson 1973). Like the streams of the region's interior, streams of the northern counties transport mostly clay, silt, and sand-sized sediment and have beds and banks formed of the same material. Gravel bedload seems to be only a minor component of the total sediment load and thus has little observed influence on stream morphology with the exception of small headwater tributaries. Bottomlands that have not been drained are generally swampy, and backwater effects from the Ohio River may play an important role in the morphology of many streams. Morphological impacts of drainage enhancement projects such as channelization and debris removal are widespread, and such perturbations propagate swiftly throughout stream networks. As in the interior region, morphological recovery appears to be slow.

The mantling of fine-grained material derived from Pleistocene loess and thick deposits of alluvial and lacustrine material characteristic of the northern and interior portions of the WKCF are ubiquitous in the nearby Mississippi Embayment region. In both regions, this mostly fine-grained material dominates the sediment load of lowland streams, and through its accretion and erosional characteristics it plays a major role as a control on channel morphology. The similarities in sediment and topographic relief suggest that the low-gradient, silt-bed streams within this portion of the WKCF may resemble those found in the Mississippi Embayment.

Figure 2.3 Gravel-bed stream of southern Hancock County typical of headwater streams of the region's southern, eastern, and western margins (unnamed tributary to West Fork Adams Fork).

Figure 2.4 Disturbed silt-bed stream of southern Henderson County typical of lowland streams of the region's interior and northern margin (Beaverdam Creek).

Figure 2.5 Silt-bed stream of Hopkins County typical of undisturbed lowland streams of the region's interior and northern margin in which large woody debris and beaver dams influence morphology (Lick Creek).

3. Measurement and Analysis Methods

Bankfull channel characteristics were measured at un-gauged sites throughout the WKCF 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 some 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 WKCF 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 a frequency can be estimated for the bankfull flow event. Therefore, USGS gauging stations with drainage areas less than 200 mi^2 were initially considered in the selection of a sample to represent the region's population of streams. In order for the sample to be useful in 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. 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.

Twelve stations were screened, and half of those were eliminated according to three preliminary selection criteria prior to field reconnaissance:

1. Recording frequency and duration of available discharge data. 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. Extensive drainage projects and channelization have occurred in all of the watersheds in the region; therefore, associated 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 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. Abandoned, remnant channels were identified.
   d. Any structures spanning or encroaching on the stream channel were identified.
   e. 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. 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 200 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 200 mi^2 had significant portions of their watersheds outside the WKCF region.

Initial Screening of Un-Gauged Sites

The limited number of potential gauged sites 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 and on remnant channels bypassed by channelized reaches were identified on the USGS 7.5-minute quadrangle maps; sinuous reaches that appeared to be un-channelized were screened according to land use and site characteristics (see above). The un-gauged sites' drainage areas and geographic locations were also included as factors in screening and selection in order 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. Approximately 35 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 each of the remaining six gauged sites and all but 20 un-gauged sites based on four 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 pattern. Only single-thread channels were selected.
3. 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.
4. At gauged sites, physical gauge configuration was capable of recording flows within the range of that which may be considered bankfull; gauges that recorded higher flows only were eliminated. A site was also rejected if the estimated bankfull flow was not within the range of flow data used in developing the gauge rating curve.

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 WKCF 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—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, 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). Some of these non-incised channels were remnants (Figure 3.4) bypassed by channelized reaches. In many cases, these remnants were functioning as sloughs or slackwater areas of intense deposition of fine-grained material; therefore, only the distance between the tops-of-bank was considered to be representative of bankfull channel geometry.

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.

Figure 3.1 Whitelick Creek in southern Henderson 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 West Fork Adams Fork, Hancock County.

Figure 3.3 Lick Creek in western Hopkins County. The bankfull level coincides with the valley flat.

Final Site Selection

A total of 20 un-gauged reaches on 17 streams were selected as study sites; 12 reaches were on active channels, and 8 were on remnant channels (Table 3.1). Drainage areas ranged from 0.25 mi^2 to 117 mi^2. No gauged reaches were selected.

Table 3.1 Assessment Site Location Summary

	Stream Site	Drainage Area (mi^2)	County	Latitude	Longitude
1	Caney Creek*	117.00	Ohio	N37.460317	W86.653767
2	Drakes Creek	29.10	Hopkins	N37.174000	W87.444083
3	Drakes Creek at Old Nortonville-Whiteplains Road	31.79	Hopkins	N37.180783	W87.435267
4	Eagle Creek Tributary	0.77	Union	N37.637350	W87.903333
5	East Fork of Flynn Fork	2.88	Caldwell	N37.140817	W87.758800
6	Hazel Creek*	10.97	Muhlenberg	N37.147150	W86.978667
7	Lewis Creek	8.30	Ohio	N37.350500	W86.912117
8	Lick Creek	19.66	Hopkins	N37.268317	W87.714917
9	Lick Creek at Paul Peyton Rd	23.00	Hopkins	N37.284317	W87.723033
10	Muddy Creek*	83.15	Butler	N37.169600	W86.772783
11	No Creek*	9.40	Rough	N37.487933	W86.987983
12	Otter Creek	40.36	Hopkins	N37.489533	W87.384417
13	Pup Creek*	26.13	Daviess	N37.842100	W86.968533
14	Slover Ditch Tributary*	1.56	Webster	N37.447383	W87.729333
15	Welch Creek*	45.47	Butler	N37.261217	W86.595100
16	West Fork Adams	0.87	Hancock	N37.688833	W86.690250
17	West Fork Adams near Newton Springs Church	1.53	Hancock	N37.682867	W86.694717
18	West Fork Adams Tributary	0.25	Hancock	N37.687983	W86.692667
19	West Fork Pond River*	43.00	Christian	N37.108244	W87.363503
20	Whitelick Creek	3.82	Henderson	N37.639967	W87.700800

* Remnant channel.

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.

Channel Geometry

During field reconnaissance on un-gauged streams, assessment reaches were identified and morphologic data was subsequently collected for the development of regional curves. Extensive photographic documentation was recorded for all sites. The specific geomorphic features that were recorded 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.

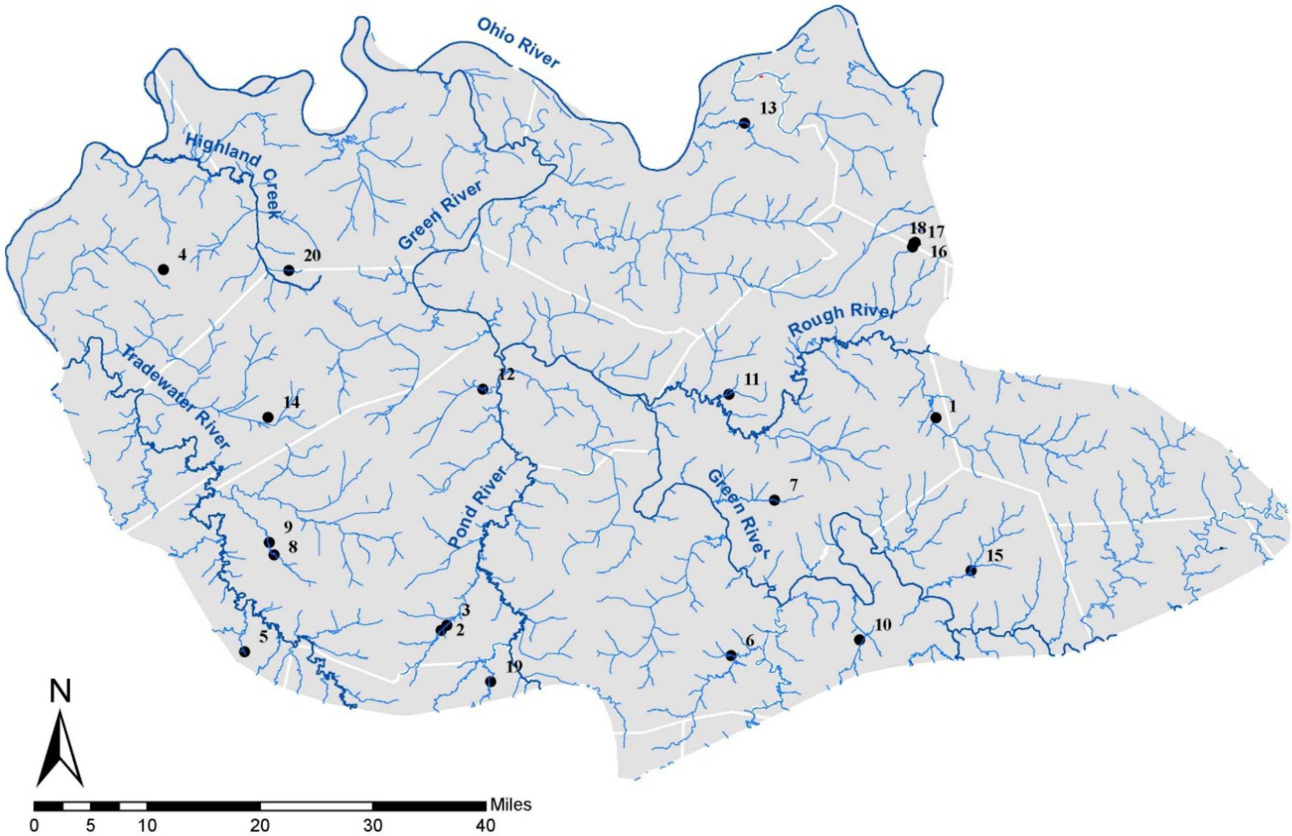

Figure 3.4 Locations of assessment sites. All blue line streams having a drainage area of more than 2 mi^2 are shown (KGS 2002; KYDGI 2005a, 2005b, 2006).

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:

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. 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 and whether the study reach was an active or a remnant channel. 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. At one site where the channel had recently incised and at sites in those remnant channels functioning as sloughs or slackwater areas of intense deposition of fine-grained material, only bankfull width was measured.

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 size class corresponding to the median sediment size was visually estimated. For classification purposes, this estimate was considered to be representative of the dominant particle size throughout the reach.

3.3 DATA ANALYSIS

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 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. Where un-incised reaches exhibited natural 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 ($D_{BKF} = A_{BKF} / W_{BKF}$).
    - 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. For sites where flow would be estimated, the dominant size fraction of the bed sediment was identified from the photographs for use in assigning average bankfull velocities.

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.

Bankfull Discharge

Bankfull discharge at 10 active channel sites and 1 remnant channel site was estimated from measured cross-sectional area and assumed average bankfull velocity. Velocity estimates were based on average channel velocities developed for streams of different bed material size classes in the Southeastern US Coastal Plain (Table 3.2). The error associated with the use of these average velocities in discharge calculations is assumed to be no greater than that associated with other less practical methods that would require extensive surveying and numerical modeling.

Table 3.2 Estimated Average Channel Velocity for Bed Materials in the Southeastern US Coastal Plain (Parola, Vesely, et al. 2005)

Bed Material	Average Channel Velocity at Bankfull Conditions (feet per second)
Silt	1.5
Sand	2.0
Bimodal gravel and sand	2.5
Gravel	3.5

Flood Flow Frequency at Gauging Stations

Annual maximum series data for the eight USGS gauging stations in the WKCF region with more than 10 years of record (Table 3.3) 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 by USIACWD (1982), frequency analysis was conducted for each of the eight stations. From the frequency distribution, flows corresponding to the 1.01- and the 1.5-year events were estimated for each station.

Table 3.3 Gauged Sites Used for Flood Frequency Analysis

USGS Site Name	Gauge ID	County	No. Yrs. Q_{peak} Data*	Drainage Area (mi^2)	Latitude	Longitude
1 W Fk Adams Fk Tributary near Fordsville	03319520	Hancock	11	0.26	N37.686944	W86.692500
2 Rhodes Creek Tributary near Owensboro	03321465	Daviess	10	0.29	N37.786389	W87.206111
3 Rose Creek at Nebo	03384000	Hopkins	30	2.10	N37.382778	W87.633056
4 Beaverdam Creek near Corydon	03322360	Henderson	19	14.30	N37.703889	W87.697778
5 Bear Branch near Leitchfield	03312000	Grayson	34	30.80	N37.426667	W86.279167
6 South Fork Panther Creek near Whitesville	03321350	Ohio	15	58.20	N37.618889	W86.887500
7 Caney Creek near Horse Branch	03318800	Ohio	36	124.00	N37.463889	W86.655556
8 Pond River near Apex	03320500	Muhlenburg	65	194.00	N37.122222	W87.319444

* 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.

4. Bankfull Characteristics of Western Kentucky Coal Field Channels

Bankfull channel parameters calculated for each assessment reach (Table 4.1) were used to develop regional curves for WKCF streams and to classify each reach. The curves describe the relationships between drainage area and bankfull channel geometry and bankfull discharge. Estimates of bankfull discharge for 11 sites were also compared to estimates of the regional 1.01- and 1.5-year discharges. Classification of each reach according to Rosgen (1996) Type II classification parameters identified 3 Bc-, 2 C-, and 15 E-type channels; the stream type was consistent for the entire length of each reach.

4.1 BANKFULL REGIONAL CURVES

Bankfull regional curves for silt-bed streams draining from 1.56 to 117 mi^2 and gravel-bed streams draining from 0.25 to 2.88 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 4.1-4.3). 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.

Coefficient of determination (R^2) values show that drainage area accounts for over 75% of the variation in the relationships between drainage area and channel bankfull parameters for gravel-bed streams. In silt-bed streams, drainage area accounts for over 54% of the variation. 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). For example, the relatively weak relationship between drainage area and the bankfull parameters of silt-bed streams may reflect the influence of beaver dams and large woody debris. Such local controls are common in these low-gradient streams, but their influence on channel morphology is highly variable, depending on relative debris size, in-channel jam configuration, degree of beaver activity, and degree of channel disturbance.

Table 4.1 Bankfull Geometry, Classification, and Discharge Data for Silt- and Gravel-Bed Streams of the WKCF Region

	Stream Site	Total DA (mi^2)	A_{bkf} (ft^2)	W_{bkf} (ft)	D_{bkf} (ft)	ER*	W/D Ratio	Dominant Substrate	Rosgen Stream Type†	Q_{bkf} (cfs)	$Q_{1.5}$ (cfs)‡
1	Caney Creek§	117.00	237.3	46.5	5.10	>2.2	9.12	Silt	E6	356	5200
2	Drakes Creek	29.10	216.4	39.0	5.55	>2.2	7.03	Silt	E6	325	2100
3	Drakes Creek at Old Norton-ville-Whiteplains Road	31.79	--	31.8	--	--	--	Silt	E6	--	--
4	Eagle Creek Tributary	0.77	8.3	12.8	0.65	1.4	19.66	Gravel	C4	25	200
5	East Fork of Flynn Fork	2.88	14.2	13.6	1.04	1.6	13.07	Gravel	B4c	43	500
6	Hazel Creek§	10.97	--	17.7	--	--	--	Silt	E6**	--	--
7	Lewis Creek	8.30	57.5	23.4	2.45	>2.2	9.56	Silt	E6	86	900
8	Lick Creek	19.66	71.0	32.4	2.19	>2.2	14.76	Silt	E6	107	1600
9	Lick Creek at Paul Peyton Rd	23.00	126.4	36.1	3.50	>2.2	10.29	Silt	E6	190	1800
10	Muddy Creek§	83.15	--	35.1	--	--	--	Silt	E6**	--	--
11	No Creek§	9.40	--	36.4	--	--	--	Silt	E6**	--	--
12	Otter Creek††	40.36	147.4	31.5	4.68	9.1	6.73	Silt	E6	221	2600
13	Pup Creek§	26.13	--	39.3	--	--	--	Silt	E6**	--	--
14	Slover Ditch Tributary§	1.56	--	13.0	--	--	--	Silt	E6**	--	--
15	Welch Creek§	45.47	--	32.0	--	--	--	Silt	E6**	--	--
16	West Fork Adams	0.87	9.1	10.9	0.83	1.6	13.20	Gravel	B4c	27	200
17	West Fork Adams near Newton Springs Church	1.53	14.8	16.2	0.92	1.4	17.66	Gravel	B4c	44	300
18	West Fork Adams Tributary	0.25	3.6	6.0	0.60	2.4	10.00	Gravel	C4	11	100
19	West Fork Pond River§	43.00	--	48.0	--	--	--	Silt	E6**	--	--
20	Whitelick Creek‡‡	3.82	--	23.3	--	--	--	Silt	E6**	--	--

* ER is entrenchment ratio (dimensionless).
† Visually estimated slopes were used for classification purposes.
‡ Estimated from WKCF regional regression (see Table 4.3).
§ Remnant channel.
** Probable stream type before abandonment or incision.
†† The study site was approximately 3.4 miles upstream of a confluence with a larger stream (Pond River), but bankfull geometry appeared to be consistent with study sites not influenced by a downstream confluence.
‡‡ Recently incised; only bankfull width measured.

Table 4.2 Bankfull Regression Equations for Silt- and Gravel-Bed Streams of the WKCF Physiographic Region

Bed Material	Regression Equation	n	Coefficient of Determination, R^2	Standard Error*, S_e (%)
Silt bed	$A_{bkf} = 19.31 DA^{0.56}$	6	0.72	35.1
	$W_{bkf} = 14.43 DA^{0.25}$	15	0.66	21.8
	$D_{bkf} = 1.23 DA^{0.33}$	6	0.54	30.4
	$Q_{bkf} = 28.97 DA^{0.56}$	6	0.72	35.1
Gravel bed	$A_{bkf} = 9.27 DA^{0.60}$	5	0.92	19.2
	$W_{bkf} = 11.56 DA^{0.36}$	5	0.75	22.0
	$D_{bkf} = 0.80 DA^{0.24}$	5	0.86	10.0
	$Q_{bkf} = 27.80 DA^{0.60}$	5	0.92	19.2

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

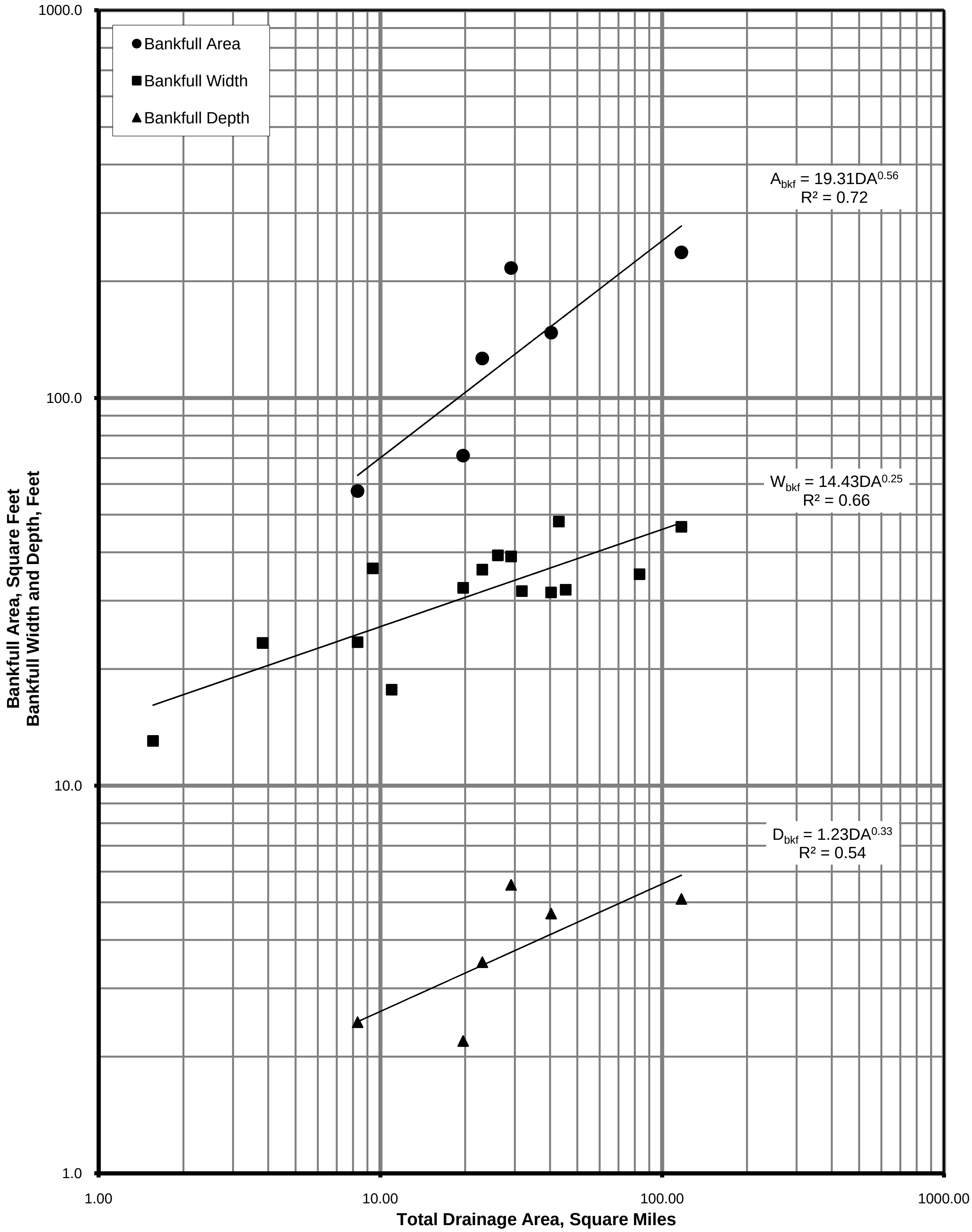

Figure 4.1 Bankfull cross-sectional characteristics as a function of drainage area for silt-bed streams in the WKCF region.

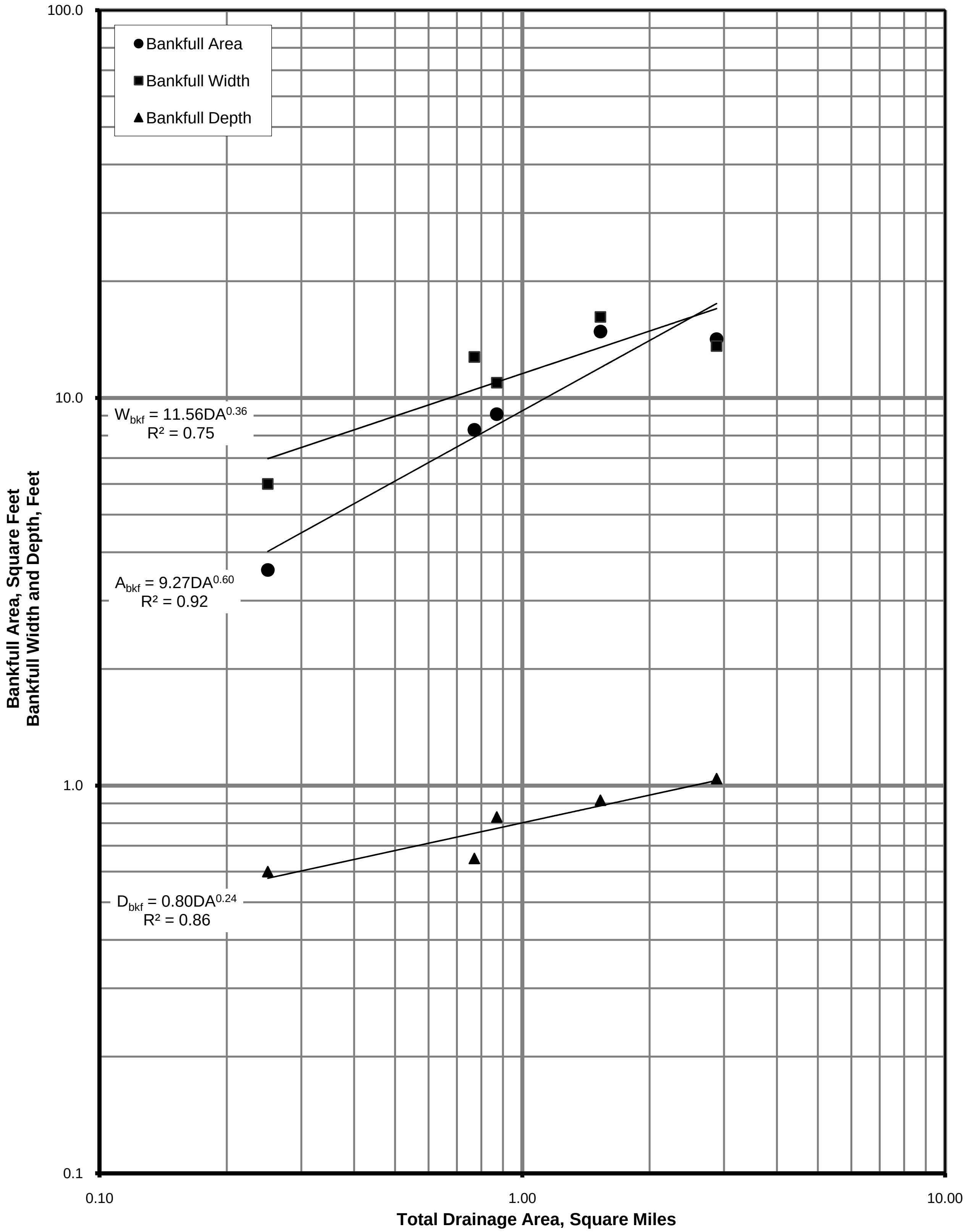

Figure 4.2 Bankfull cross-sectional characteristics as a function of drainage area for gravel-bed streams in the WKCF region.

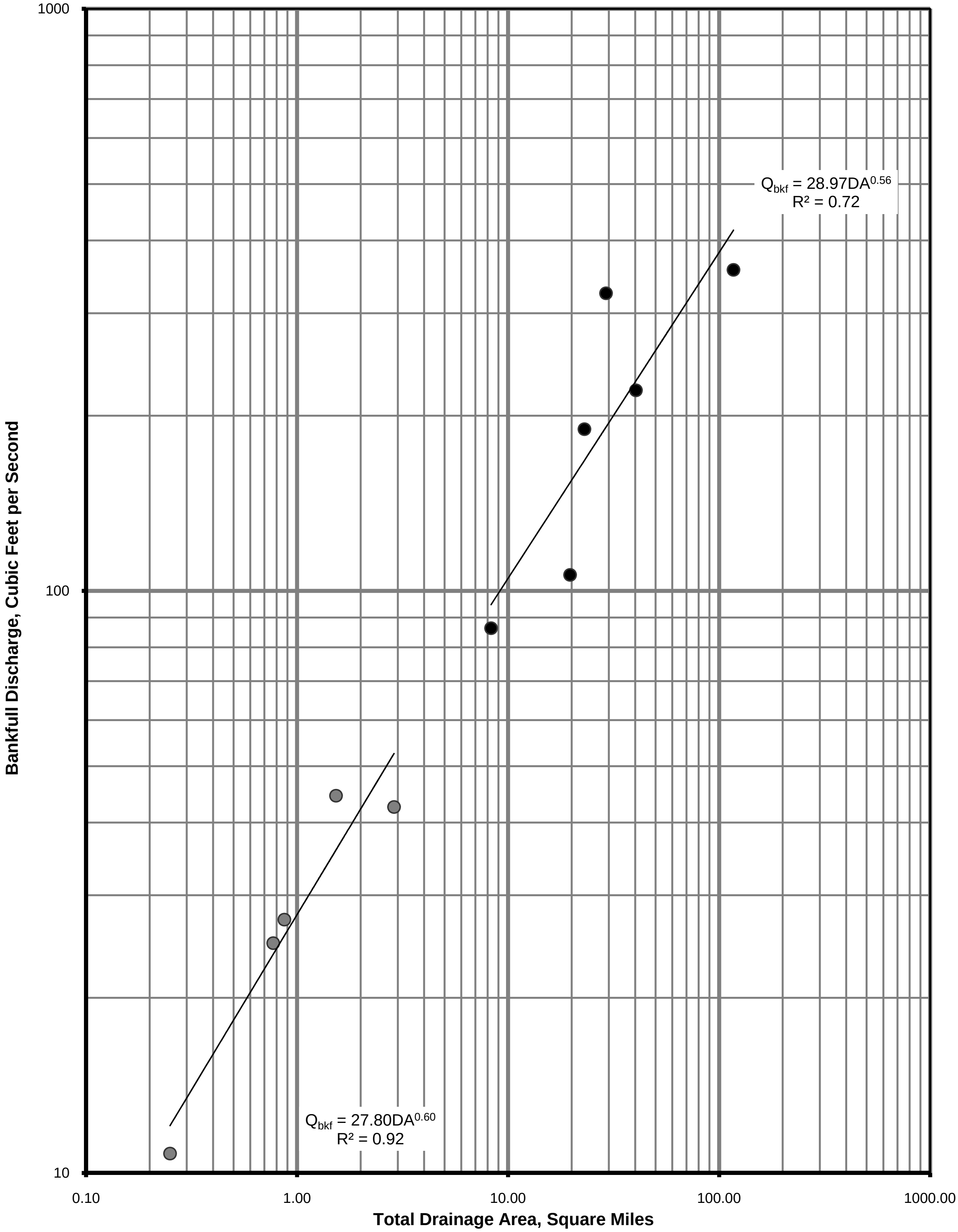

Figure 4.3 Bankfull discharge as a function of drainage area for silt- and gravel-bed streams in the WKCF region. Silt-bed streams are shown as solid points; gravel-bed streams are shown as shaded grey points.

4.2 BANKFULL DISCHARGE RECURRENCE INTERVAL

Because bankfull geometry data could be collected only at un-gauged sites, no annual peak flow data for the study sites were available for use in flood frequency analysis. Likewise, even though several WKCF gauging stations had flow data suitable for flood frequency analysis (Section 3.3), none of the gauged channel reaches were suitable for geomorphic assessment, and flow at the gauging stations could not be related to the bankfull stage. Therefore, bankfull return periods were not calculated for the study sites. Bankfull discharge of the un-gauged study sites were, however, compared to the regional 1.01- and the 1.5-year flows estimated from WKCF gauging station data.

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 eight WKCF gauge stations for which frequency analysis was conducted (Figure 4.4). Best-fit lines were regressed in the form of a simple power function:

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

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 (%)
WKCF	$Q_{1.01} = 88.81\ DA^{0.69}$	8	0.94	53.9
	$Q_{1.5} = 236.85\ DA^{0.65}$	8	0.95	44.5

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

The bankfull discharges that were estimated for 11 study sites were plotted to compare them to the regression lines. Bankfull discharge at each of the study sites was less than the estimated regional 1.01-year discharge for the same drainage areas, although some of the bankfull discharge values fell within the range of error associated with the regression line. The difference between the bankfull discharge at each site and the 1.5-year discharge estimated from the WKCF regional regression for the same drainage areas was substantial: all 11 sites for which the values were compared had a Q_{bkf} less than or equal to 15% of the estimated regional $Q_{1.5}$; (Figure 4.5). Therefore, the regional 1.5-year discharge cannot be considered to be a reasonable representation or estimate of the bankfull discharge for WKCF 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).

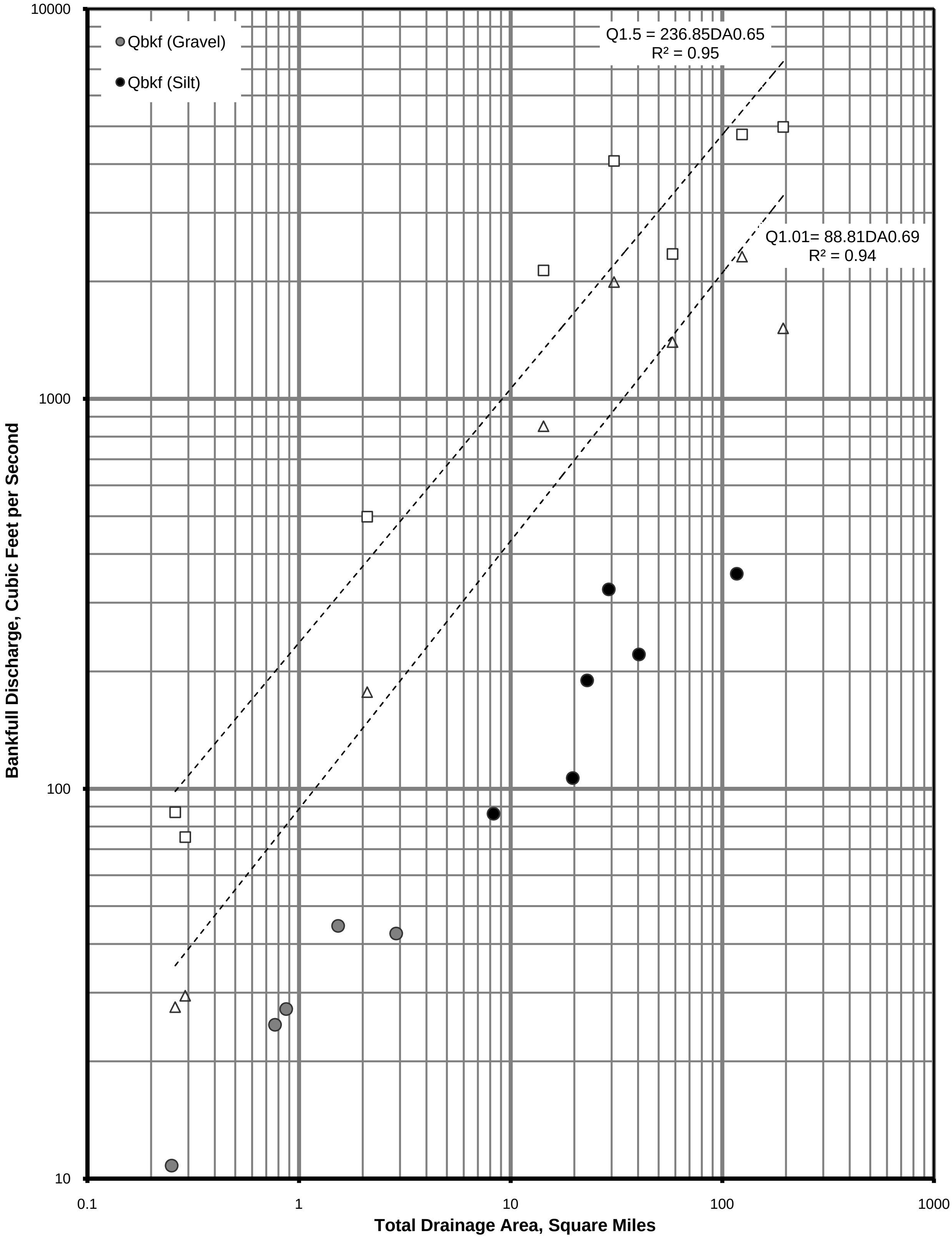

Figure 4.4 Regression curves for $Q_{1.01}$ and $Q_{1.5}$ derived from WKCF gauges. Bankfull flows estimated for study sites are plotted without regression lines.

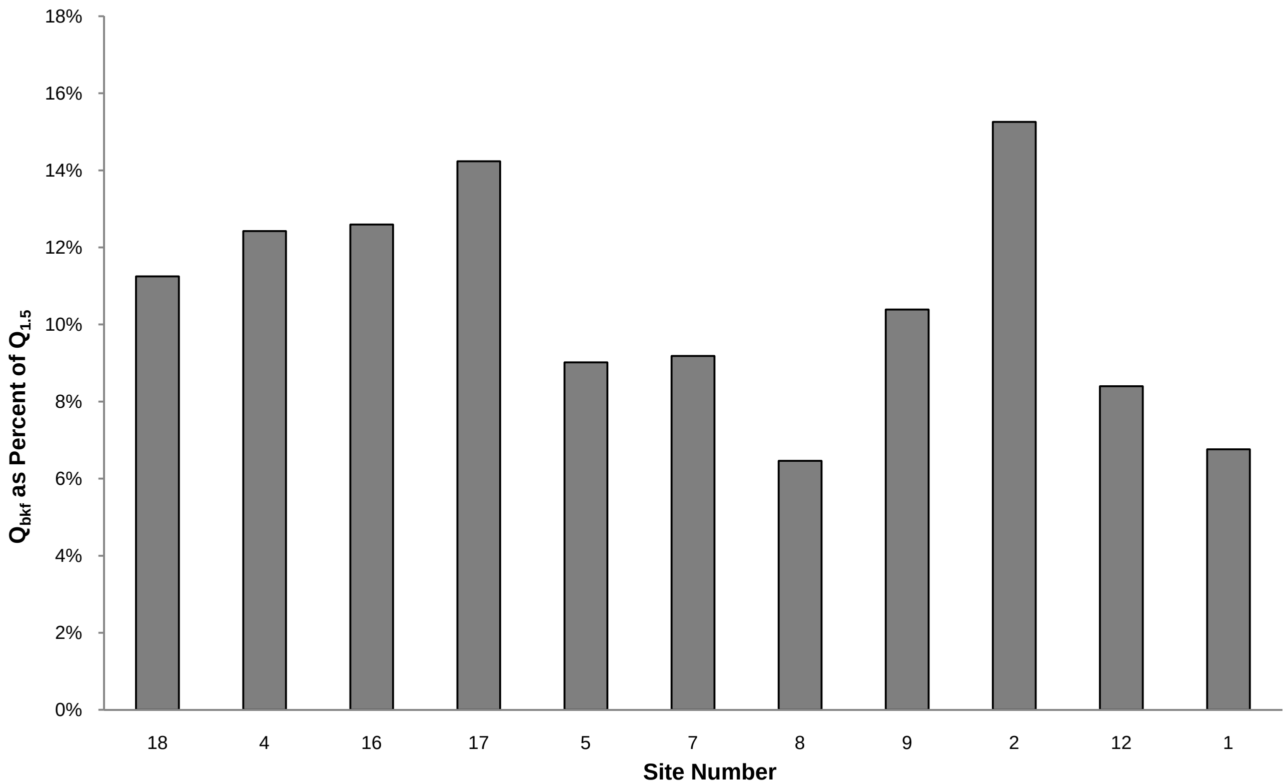

Figure 4.5 Bankfull discharge as a proportion of the flow associated with the 1.5-year return interval for the same site. (Drainage area increases from left to right.)

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 WKCF region were developed from sites with watersheds between 0.25 and 117 mi^2 (from 1.56 to 117 mi^2 for silt-bed streams and from 0.25 to 2.88 mi^2 for gravel-bed streams) where the channel was stable relative to other streams of the region and had unambiguous bankfull indicators. The relationship between bankfull parameters and drainage area in the WKCF region is described by curves that explain between 54% and 92% of the variation within the datasets for bankfull area, width, depth, and discharge. Standard errors are less than 36%. Bankfull discharge was found to be no more than 15% of the estimated regional (WKCF) 1.5-year discharge and is thus likely associated with a smaller return interval. 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 WKCF region.
- Land use. Streams in watersheds that are less than 10% urbanized are represented. Drainage projects and channelization have occurred in all of the watersheds in the region, and mining has occurred in several of the watersheds; therefore, the curves represent the effects of typical land use and sediment loads from channel alteration and mining.
- Flow regulation. Streams that are not subject to flow regulation are represented.
- Drainage area. The curves apply only to silt-bed streams draining between 1.56 and 117 mi^2 or gravel-bed streams draining between 0.25 and 2.88 mi^2.
- Sediment size. Silt- and gravel-bed streams are represented. Few sand-bed streams were located within the region, and none were found to meet the morphologic criteria for selection.
- Slope. The curves apply only to streams with slopes of up to 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. 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 WKCF 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 WKCF 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 WKCF 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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