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Geomorphic Characteristics of Headwater Streams in the Eastern Kentucky Coal Field Physiographic Region of Kentucky

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Executive Summary

The geomorphic and hydrologic characteristics of headwater streams throughout the US have not been as well-documented as higher-order streams. Four types of geomorphic descriptions of Eastern Kentucky Coal Field (EKCF) headwater channels were developed to improve future identification, assessment, protection, and restoration of the region's headwater streams and downstream water resources:

1. Quantitative descriptions (regional curves) that represent expected values and variation of bankfull cross-sectional area, width, and depth as a function of upstream drainage area.
2. A classification of headwater valley and stream morphology focusing on bedform (step-pool, riffle-pool, plane bed, boulder swale, etc.), substrate characteristics, and potential response to disturbance.
3. A description of morphological features associated with channel heads and changes in hydrologic condition.
4. An estimation of the extent and density of the channel network and the location of the ephemeral/intermittent transitions, and a comparison of those extents to the corresponding networks shown as blue line streams on USGS topographic 7.5-minute quadrangle maps.

Development of the quantitative and qualitative descriptions also incorporated consideration of the effects of geology, historical land-use, and current land use on sediment loads and channel evolution.

The descriptions were developed from geomorphic data collected during an extensive examination of five sub-watersheds of five publicly owned EKCF recreational areas. Drainage areas for all sites where data was collected ranged from 1.2 to 1792 acres (approximately 0.0019 to 2.8 mi^2). Channel and overbank topographic data were surveyed to compute bankfull parameters. Geo-referenced photo-documentation was collected to facilitate identification of morphologic trends and sequences. Recorded features included stream and valley morphology, locations of measured cross sections, locations and types of each channel head, and locations of ephemeral-intermittent transitions.

Bankfull regional curves were derived from cross section data by using ordinary least-squares regression to relate bankfull channel dimensions to drainage area. Although morphology of EKCF headwater channels is highly variable, the regional curves show relationships between cross-sectional dimensions and drainage area that are highly statistically significant ($P < 0.001$ for both Kendall's τ and Spearman's ρ tests). Drainage area accounted for approximately 46% of the variation within the datasets for cross-sectional area and bankfull width. For bankfull depth, however, it accounted for only 15%. Depth may be a more locally variable parameter due to due to the high variation in relative roughness of the channel bed and banks and the high frequency and irregularity of flow obstructions such as boulders and woody debris. Standard errors ranged from 39-68%.

Scatter in each of the regional curves indicated that factors other than drainage area must also be important in determining the cross-sectional dimensions of EKCF headwater channels. Data on several other key determinants of their morphology, such as bed material, channel slope, and valley confinement, were used to develop a general classification of valley and channel types according to measurable diagnostic features. Channel heads and ephemeral-intermittent transitions were also found to be associated with classifiable morphological features.

Channel head and ephemeral-intermittent transition data were used to estimate the extent of the channel and stream networks; these extents were compared to the corresponding networks shown as blue line streams on topographic maps. Results from the field assessment of hydrologic condition and simulation of the drainage networks showed that locations of channel heads, surface water, and continuous flow were typically located upstream of the start of the drainage network represented by blue line streams from the USGS 7.5-minute quadrangle maps. The blue line streams represent no more than 69% of the modeled stream length delimited by surface water—in some cases as little as 31%—and 48% to 262% of the modeled stream length delimited by continuous flow.

Geomorphic Characteristics of Headwater Streams in the Eastern Kentucky Coal Field Physiographic Region of Kentucky

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1. Introduction

Headwater streams comprise the vast majority of documented stream length in the United States (Benda et al. 2005) and are a source for much of the downstream network's water, sediment, and nutrients. Changes in their morphology can significantly affect both local and downstream water quality and habitat by changing functions and characteristics such as hydrologic retention capacity; contribution to base flows; flood attenuation; temperature maintenance; regulation of the base-level chemical composition of the watershed; nutrient retention, processing, and export; and sediment retention and supply (Schumm 1977; Vannote et al. 1980; NRC 2002). Conversely, changes in the downstream network can affect the lower-order channels, whose small size and susceptibility to intense rainfall (Jacobson et al. 1989) make them particularly sensitive to disturbance. Human manipulation of streams and their valleys may lead to the formation of headcuts, or zones of instability, which propagate up to and through headwater channels, thereby increasing the delivery of sediment to the downstream network (Schumm et al. 1984).

Because channel geometry is so closely related to the impairments that result from these processes, evaluation of geomorphic characteristics (e.g., bankfull parameters, local channel and valley morphology, and flow regime) is important not only for assessing stream conditions but also for identifying stream impairment sources and practical mitigation strategies. The geomorphic and hydrologic characteristics of headwater streams have not been well-documented (Leopold 1994), however. Most field studies have focused on higher-order, lowland streams, and information on headwater reach-scale morphology is dominated by results from the western US, especially the Pacific Northwest (e.g., Grant et al. 1990; Montgomery and Buffington 1997; Halwas and Church 2002; Benda et al. 2005). Headwater channels in the eastern US have received less scientific attention, and most studies have focused on the Appalachian mountains (the Valley and Ridge province and the Blue Ridge province) (e.g., Hack and Goodlett 1960; Eaton et al. 2003; Adams and Spotila 2005), where relief is considerably greater than in Kentucky, and rainfall events are much more intense (Jacobsen et al. 1989) due to the greater influence of remnant tropical storms.

1.1 BACKGROUND

One increasingly common quantitative method for evaluating geomorphic characteristics is the comparison of measured bankfull channel geometry and flow to estimates from regional geomorphic curves. Estimates derived from regional curves can provide a reliable point of reference for assessing stream conditions, especially in those channels where bankfull indicators are unapparent or ambiguous: they facilitate Rosgen (1996) classification of stream reaches and estimations of degree of incision, relative bank stability, some channel pattern characteristics, and sediment transport capacity. They are also critical for evaluating the reasonableness of channel dimension and flow designs for stream restorations.

Qualitative descriptions of geomorphic characteristics are similarly useful for these types of assessments and evaluations. Geomorphic and hydrologic classification of reach types is particularly useful for predicting channel evolution and response to disturbance. The ability of stream reaches to absorb or transmit disturbances to the drainage network is important for evaluating the potential supply of sediment to the downstream network. This type of analysis can increase the effectiveness of best management practices such as development of sediment total maximum daily loads (TMDLs) or Watershed Based Plans (WBPs), which otherwise might rely primarily on quantitative measures such as total channel length and characteristic erosion rates (USEPA 1999; Rosgen 2001).

Regional Curves

Estimates of bankfull parameters may be obtained by several means, including direct measurement of reference reaches (Rosgen 1998), use of analytical procedures such as the application of an effective discharge (Andrews 1980), or use of regional curves, which describe bankfull channel geometry and flow as a function of upstream drainage area for streams in a given region. Quantitative geomorphology has been used for over half a century to support the assessment of channels and floodprone areas, beginning with Horton's (1945) drainage basin studies and Leopold and Maddock's (1953) hydraulic geometry relations, which 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 (Wolman 1955; Brush 1961; Kilpatrick and Barnes 1964; Leopold et al. 1964). 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., Wolman 1955; Brush 1961; Kilpatrick and Barnes 1964; Leopold et al. 1964; Harman et al. 1999; Smith and Turrini-Smith 1999; McCandless and Everett 2002; Mulvihill et al. 2005; NRCS 2007).

Regional curves are based on the premise that, over time, rivers develop and maintain a bankfull channel geometry and discharge that have a measurable relationship to the landscape characteristics influencing the fluvial processes that shape the channel (Leopold and Maddock 1953). Stream and valley hydrology and morphological processes are closely linked, and the interaction between landscape and channel processes affects the morphology, extent, and flow regime of the channel. The flow of water and the erosion, transport, and deposition of sediments are influenced by several landscape characteristics, including land cover, valley slope and topography, climate, geology, soil types, vegetative cover, and drainage area. Because many of these characteristics are similar throughout a given physiographic region, their influence on channel geomorphology also tends to be similar. Therefore, when quantitative descriptions of channels are developed according to physiographic region, the influence of these similar landscape characteristics can be isolated, and bankfull geometry can be related directly to drainage area.

While regional curves cannot account for all sources of variability in channel characteristics, they do provide a reliable point of reference for assessment and design of alluvial channels with active floodplains and relatively low-gradient (generally less than 2%) valleys. In the higher-sloped valleys of small headwater channels, however, the relationship between bankfull geomorphic characteristics and drainage area may be less robust at a regional scale (Wohl et al. 2004; Adams and Spotila 2005). Variability of landscape characteristics from one basin to another within a region may introduce variability into regional curves (Ritter et al. 2002). Within each of those basins, landscape characteristics also tend to be more spatially variable than in lower-sloped valleys, and their increased variability contributes to increased variability in channel form. Moreover, hillslope processes (e.g., erosion and mass wasting) act more directly on the channel than in higher-order streams, and they not only introduce additional variability in the spatial distribution of channel forms but also may mask the influence of fluvial processes in shaping the channel, especially where bedrock exposure and colluvium deposits are frequent or extensive. At very small drainage areas, channels may be poorly defined and their morphology strongly controlled by colluvium.

In some regions, headwater channel morphology may be so variable that it precludes a quantifiable description altogether. In headwater streams draining less than 2 km^2 (about 1 mi^2) of the southern Appalachian Mountains of North Carolina and Virginia, the highly variable channel morphology could not be correlated with drainage area (Adams and Spotila 2005). Instead, valley topography, bedrock exposure, and past disturbance were identified as primary determinants of existing morphology.

The feasibility and applicability of regional curves for headwater streams in the Eastern Kentucky Coal Field (EKCF) physiographic region have not yet been tested. In spite of headwater channel morphology's local variability in small, high-gradient watersheds, it is still a product of measurable hillslope and fluvial channel-forming processes and therefore is likely to exhibit systematically distinct characteristics that are both qualitatively and quantitatively definable. The strength of the relationship described by regional curves for EKCF headwaters may depend on the presence or absence of a definable, well-developed floodplain. Because the floodplain acts as a buffer between hillslope and channel, regional curves estimated for sites with floodplains may exhibit less variability than curves estimated for sites without floodplains. Sites without floodplains tend to be located at the highest elevations in the drainage network. Therefore, regional curves may be more feasible at drainage areas large enough to allow for floodplains.

Classification of Reach-Scale Morphology

Bedforms and Substrate

Reach-scale (i.e., lengths of 10–20 channel widths) channel morphology can be associated with hillside and fluvial processes and characteristics that influence channel slope, discharge, sediment supply, shear stress, and sediment transport capacity. These characteristics may include land cover, valley slope and topography, bedrock lithology, coupling with hillslopes (Harvey 2001), degree of valley confinement, drainage area, bed-sediment gradation, and susceptibility to disturbance.

Some of these characteristics exhibit systematic changes with distance downstream and thus would support the development of a scheme for classifying reach types. In the Pacific Northwest, for example, mountain channels have been shown to be classifiable on a reach scale according to consistently identifiable, measurable characteristics (Montgomery and Buffington 1997). These reach types were found to follow a generally consistent downstream sequence (Montgomery and Buffington 1997): colluvial reaches; bedrock reaches (found throughout the channel network where valley slopes are locally steep); and five types of alluvial reaches (cascade, step pool, plane bed, pool-riffle, and dune-ripple). While not all reach types are found in all watersheds, and disturbances may locally disrupt general trends (Wohl 2006), this process-based classification system was designed to be adapted to high-gradient channels in other regions and thus may be applicable to EKCF headwater channels.

Channel Heads

Channel heads, are the start of the definable channel boundary (Dietrich and Dunne 1993), and their locations, therefore, delimit the total length of a channel network. While channel head locations tend to be relatively constant over time periods of weeks or even years, with cumulative processes producing upslope or downslope movement over a decade or more, they also may change with a single hydrologic event, which can produce upslope migration through propagation of headcuts or mass slope movements. Upslope migration increases the length of the channel network, thereby increasing the number of sediment sources, decreasing the response time to runoff events, and more rapidly delivering pollutants to downstream waters.

The upslope or downslope movement of the channel head is often limited by the morphological features that "control" its location. Because different features will have different influences on the susceptibility of channel head locations to change, classifying the features may be useful in assessing whether the channel head is stable or actively migrating. In general, the morphology of the features associated with the channel head may be classified as one of two types: gradual or abrupt. In the case of gradual channel heads, no single feature controls the channel head location. Instead, a relatively short transition zone is typically found between a channel incised into the hillslope and an upstream swale. A gradual transition indicates that the position of the channel head is relatively stable. Channel heads classified as abrupt, on the other hand, are often associated with a specific feature (boulder, large root, macropore, headcut, etc.). An abrupt transition indicates that the channel head is actively migrating upslope, though the rate of migration may vary between different types of abrupt features.

The rate of channel head migration is controlled by the dominant runoff process, which may be surface or subsurface flow (Dietrich and Dunne 1993), and by the boundary materials at the channel head. The influence of boundary materials on channel head migration is determined by two characteristics. First, the boundary materials' resistance to erosion determines the time period over which the channel head is stable. Channel heads located in bedrock will migrate much more slowly than channel heads in unconsolidated soil. Second, the distribution of the boundary materials determines the potential for future expansion of the channel network if the present control fails or is outflanked by channel erosion. On forested hillsides, the abundance of tree roots provides a large number of potential channel head controls. In contrast, on bare slopes with no controls, the potential for future headward expansion of the channel network is much higher.

Transitions in Flow Regime: Locations and Morphological Indicators

At any given channel location, the hydrologic condition is a combination of groundwater/ base flow and/or storm- or quickflow. Groundwater/ base flow is the longer-term, sustained discharge derived from natural storage zones, while storm- or quickflow refers to the direct response to a rainfall event, which includes overland flow (runoff), lateral movement in the soil profile (interflow), and direct rainfall onto the stream surface (direct precipitation). The distinction between these two types of flow can be used to identify locations of transition between ephemeral and intermittent flow regimes. Ephemeral channel reaches by definition respond to storm- or quickflow only, whereas intermittent channel reaches receive delayed or base flow, especially during wet periods. Thus, the upstream limit of base flow emergence during the wet season could also be considered the start of an intermittent reach and hence the location of the ephemeral-intermittent transition.

These locations can be identified most readily with a single field inspection during the wet season, which is approximately February through April in Kentucky. In many cases, however, the transition locations will be associated with morphological features that influence the infiltration or exfiltration of water between the surface and subsurface. Therefore, if field identification of the ephemeral-intermittent transition were to be based on the observed distribution of significant geological and geomorphic features that control the flow of groundwater and its presence or absence as surface water, then these locations could be identified during dry periods as well.

Drainage Density and Network Extents

The extent of the drainage network can be measured based on either the locations of channel heads, which define the start of the physical channel, or the upstream limit of a particular hydrologic characteristic, such as the presence of standing water or continuous flow. Herein, the extent based on channel head locations is termed the channel network, and the extent based on hydrologic condition is termed the stream network (after Dietrich and Dunne 1993).

A primary source for delineating channel or stream length and watershed topography in the United States has been the US Geological Survey (USGS) topographic 7.5-minute quadrangle maps produced at 1:24,000 scale. These maps also provide the topography for geology maps (e.g., Kentucky Geological Survey (KGS) 7.5-minute geologic quadrangles) and soil survey maps (e.g., US Department of Agriculture Natural Resources Conservation Service (USDA NRCS) soil surveys). A representation of the approximate extent of the channel network is shown on USGS 1:24,000 topographic maps by blue lines. These USGS blue line designations, however, significantly underestimate the length of headwater channels (Leopold et al. 1964). Generally, 1:24,000-scale topographic maps simplify the morphology of the valley, and many basins may contain more channels than are shown as blue lines (Mark 1983). Field surveys (e.g., Hansen 2001; OHEPA 2002; Rosenfeld et al. 2002) have established that USGS topographic maps under-represent headwater streams by 20%–100%. The omission of small channels from USGS topographic maps is not a flaw in the maps *per se*; instructions to cartographers include the guidance that, for the purpose of clarity, "[d]rainage should not be drawn nearer than 500 ft to the divide" (USGS 1964:80). The maps, therefore, offer the best reflection of the channel network for a large scale of inquiry and are not suited to delineating small channels.

Studies have shown that increased map resolution can allow greater detail in terms of identifying headwater channels (Werritty 1972), but obtaining such improved accuracy through traditional field surveys is labor intensive and prohibitively expensive over a wide area. Alternatively, some researchers have sought to extend the network of blue line streams by tracing depressions or notches in the contour lines, assuming that these "crenulations" represent the incision into the landscape that has been affected by the stream channel (Morisawa 1957). Opinion on the use of contour crenulations to infer the extent of stream channels is divided. Schneider (1961) criticized the effectiveness of such an approach, but Mark (1983), working on streams near Inez, Kentucky, found that it had merit. One distinct disadvantage of such a procedure is that it is subjective and relies on the experience of the investigator. To circumvent this problem, Shreve (1974) suggested using the point at which the channel reaches a critical gradient to delineate the terminus of the stream channel. For eastern Kentucky, Shreve (1974) proposed a critical gradient of 0.2 ft/ft (20 percent), but he acknowledged that this value would vary from region to region depending on the local geology and climate. This method would also fail to indicate the locations of channel bifurcations.

Because the locations of channel heads and hydrologic condition transitions cannot be accurately estimated from existing geospatial datasets (Mark 1983), field measurements offer the best option for estimating the length of the channel network. If all channel heads in a watershed were to be mapped, the total extent of the channel network could be measured. Locating all channel heads is impractical, however, even in small watersheds. One alternative to direct measurement of these locations would be the use of existing geospatial datasets and sampled field data to estimate the drainage densities of assessed watersheds. From these drainage density estimates, which are ratios of stream length to drainage area, the extents of the drainage networks for each assessed watershed could be derived. The drainage density estimates could also be used to estimate drainage densities and channel and/or stream lengths of similar un-surveyed basins in the region. These estimates could prove to be more accurate than those that would be obtained by using the blue line streams drawn on USGS topographic 7.5-minute quadrangle maps.

1.2 PROJECT PURPOSE AND SCOPE

The main purpose of this project was to provide geomorphic descriptions that will strengthen resource managers' ability to (1) assess the morphological condition of small EKCF headwater streams, especially with regard to their stability, extent, and flow regimes; (2) make informed, effective decisions in the identification, assessment, and protection of headwater streams and downstream water resources; and (3) develop or evaluate best management practices and restoration approaches in EKCF headwaters. The descriptions also may be useful to stream restoration designers and other individuals assessing the stability and morphological characteristics of EKCF headwater streams.

The geomorphic data used to develop the descriptions were collected from five sub-watersheds of five publicly owned recreational areas in March 2006. The sub-watersheds were chosen because they were easily accessible and they had not been subjected to recent logging, mining, or other major disturbance activities. None of the study areas had a USGS gauging station; therefore, data were collected only on un-gauged streams. Drainage areas for all sites where data was collected ranged from 1.2 to 1792 acres (approximately 0.0019 to 2.8 mi^2).

Four types of descriptions were developed from data collected at the sites:

1. Quantitative descriptions (regional curves) that represent expected values and variation of bankfull cross-sectional area, width, and depth as a function of upstream drainage area.
2. A classification of headwater valley and stream morphology focusing on bedform (step-pool, riffle-pool, plane bed, boulder swale, etc.), substrate characteristics, and potential response to disturbance.
3. A description of morphological features associated with channel heads and changes in hydrologic condition.
4. An estimation of the extent and density of the channel network and the location of the ephemeral/intermittent transitions, and a comparison of those extents to the

corresponding networks shown as blue line streams on USGS topographic 7.5-minute quadrangle maps.

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.

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.

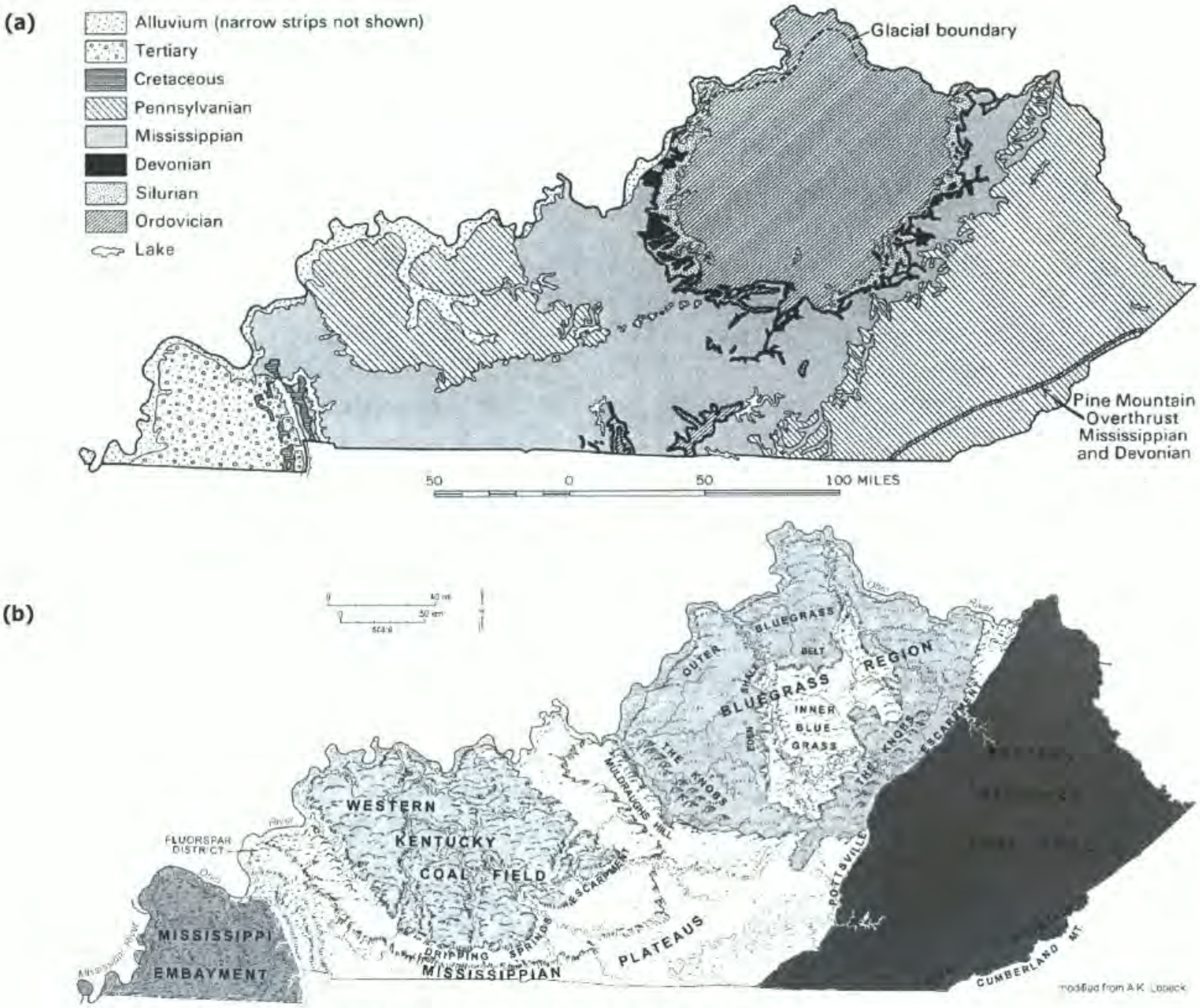

Figure 2.1 (a) Generalized geologic map of Kentucky (after McGrain 1983:12).
(b) Physiographic map of Kentucky (KGS 2001).

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;

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).

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.

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. Measurement and Analysis Methods

The main objective of data collection was to obtain both qualitative and quantitative descriptions of headwater channel morphology and drainage network extents in the Eastern Kentucky Coal Field region. Photographic documentation, detailed field notes, and geospatial datasets were used to record descriptions of bed material, valley confinement, and valley slope. These data were analyzed to identify morphologic trends and sequences. Bankfull channel characteristics, channel head locations, and locations of changes in hydrologic condition were measured. The surveyed channel geometric data were used to calculate channel dimensions and parameters needed for developing bankfull regional curves. Channel head and hydrologic condition data were used to calculate drainage areas that in turn were used to generate simulations of the channel and stream networks. Drainage densities were calculated for these simulated networks and for the corresponding networks shown as blue line streams on topographic maps.

3.1 SITE SELECTION

Initial Screening

To ensure ease of access to multiple headwater channels within a given area, only publicly-owned lands were considered for selection as study areas. An initial list of 22 publicly-owned EKCF lands, principally Wildlife Management Areas (WMAs) or State Resort Parks (SRPs), was compiled from readily-available map sources (DeLorme 2005). The boundaries of the WMAs and SRPs and their sub-watersheds were identified using a Kentucky atlas (DeLorme

2005); the boundaries were re-created in GIS and overlain on the most recent available USGS 7.5-minute topographic quadrangle maps (KEPPC 2002). Public lands 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. Public lands in the Ridge Top and Limestone Valley Settlements area, in which sinkholes and subsurface channels have formed (KGS 2005), were also excluded.

Within the 12 remaining potential study areas, sub-watersheds (HUC14 or smaller) were screened for further consideration. One sub-watershed was selected from each study area based on five primary criteria:

1. The majority of the sub-watershed is located within publicly-owned land.
2. The sub-watershed has not been subjected to mining, which would alter surface or sub-surface hydrology.
3. Sub-watershed is accessible by road.
4. No roads have been constructed on the sub-watershed's ridgetops.
5. Streamflow in the sub-watershed is unregulated.

Five study areas were eliminated from further consideration because none of their sub-watersheds met the above screening criteria. Within each of the sub-watersheds that met the screening criteria, one or two first-order blue line streams were then selected at random for field inspection to determine their suitability for assessment.

Prior to field reconnaissance, contour maps, orthoimagery (aerial photographs), and additional geospatial datasets were reviewed to identify characteristics that could be relevant to field evaluation of the randomly selected first-order blue line streams' suitability for assessment. The following tasks were completed in the review:

1. Each of the randomly selected sub-watersheds and the HUC10 watersheds of their trunk streams were located on USGS 1:24,000 orthoimagery (USGS 2004).
    a. The images were reviewed to identify land use changes that had occurred since the creation of the topographic and geologic maps. These changes principally consisted of logging and mining. Possible impacts to the valley, the stream channel, and the floodplain were considered.
    b. Evidence of debris flows was identified.
2. A valley profile was constructed for each HUC10 watershed's trunk stream from the ridge top to a point where its drainage area was at least 100 mi^2: contour elevations along the valley centerline were plotted against distance along the valley centerline. The valley profile reveals differences in the overall valley slope, which is an important influence on channel morphology. Steep valleys generally contain steep streams.
3. The bedrock materials underlying each selected HUC10 watershed were identified from the KGS 7.5-minute geologic quadrangle maps (KGS 2000).
4. The HUC14 watersheds were examined on the USGS topographic maps:
    a. Blue line streams were examined for evidence of channel straightening, realignment, or other modifications such as excavation for old mill races. Streams that were aligned on one side of the valley flat and had a straight planform were assumed to have experienced some degree of channel straightening.
    b. Any structures spanning or encroaching on the blue line streams were identified.
    c. Valley constrictions or sharp bends that could create backwater during high flows were recorded.

d. The 1950s course of the blue line stream was identified on the topographic maps and compared with the present alignment documented by aerial photographs. Discrepancies were recorded to identify locations where channel movement or straightening may have occurred since the 1950s.

5. Active or recently active landslides and debris flows in the HUC14 watersheds were identified from KGS 1:24,000 landslide potential maps (KGS 1979). The maps also show areas susceptible to landslides and debris flows, and these were recorded.

Field Reconnaissance

Prior to data collection, final selection of each first-order blue line stream was conducted in the field on a site-by-site basis. Where field conditions indicated that the selected first-order blue line stream did not meet all of the initial screening criteria, a proximate first-order blue line stream within the same sub-watershed was substituted if it better met the criteria. For instance, at Greenbo Lake SRP, only three first-order blue line streams—Pruitt Fork, Claylick Creek, and Buffalo Branch—were located within the SRP boundary. The northern stream, Pruitt Fork, was found to have a road along the ridgetop and was rejected. Claylick Creek was considered preferable to Buffalo Branch because it had no ridgetop road, and its headwaters were located further from Greenbo Lake (and any associated impact due to the lake's dam) than Buffalo Branch. The substituted first-order blue line stream was usually the one most easily accessible by road.

Final Site Selection

A total of six first-order blue line streams within five sub-watersheds of five study areas (Table 3.1 and Figure 3.1) were chosen for assessment. (A sixth study area, Fishtrap Lake, was initially part of the sample, but equipment malfunctions during data collection required that the site

Table 3.1 Study Area and Study Site Locations

	Study Area	County	HUC10 Watershed & HUC14 Sub-Watershed	First-Order Blue Line Stream	Study Site Lat/Lon*	Stratig. Label	Stratigraphic Description
1	Greenbo Lake SRP (GL)	Greenup	HUC10: Lower Little Sandy River HUC14: Greenbo Lake	Unnamed trib. of Claylick Creek	N 38° 29.254' W 82° 53.994'	Pbl Pbm	Breathitt Formation, lower part. Breathitt Formation, middle part.
2	Lilley Cornett Woods (LCW)	Letcher	HUC10: Line Fork–N. Fork Kentucky River HUC14: Line Fork	Unnamed trib. of Line Fork	N 37° 4.661' W 82° 59.542'	Pbm	Breathitt Formation, middle part.
3	Paintsville Lake WMA (PL)	Johnson	HUC10: Paint Creek HUC14: Mudlick Creek	Glade Branch	N 37° 51.699' W 82° 53.430'	Pbl	Breathitt Formation, lower part.
4	Robinson Forest WMA (RF)	Breathitt	HUC10: Troublesome Creek HUC14: Clemons Fork	Clemons Fork	N 37° 29.937' W 83° 7.845'	Pbm Pbu	Breathitt Formation, middle part. Breathitt Formation, upper part.
			HUC14: Clemons Fork	Falling Rock Creek	N 37° 28.586' W 83° 8.401'	Pbm Pbu	Breathitt Formation, middle part. Breathitt Formation, upper part.
5	Yatesville Lake WMA (YL)	Lawrence	HUC10: Middle Blaine Creek HUC14: Brushy Creek	Evans Branch	N 38° 2.944' W 82° 47.400'	Pbu Pbm	Breathitt Formation, upper part. Breathitt Formation, middle part.

* Location of the downstream limit of the study site.

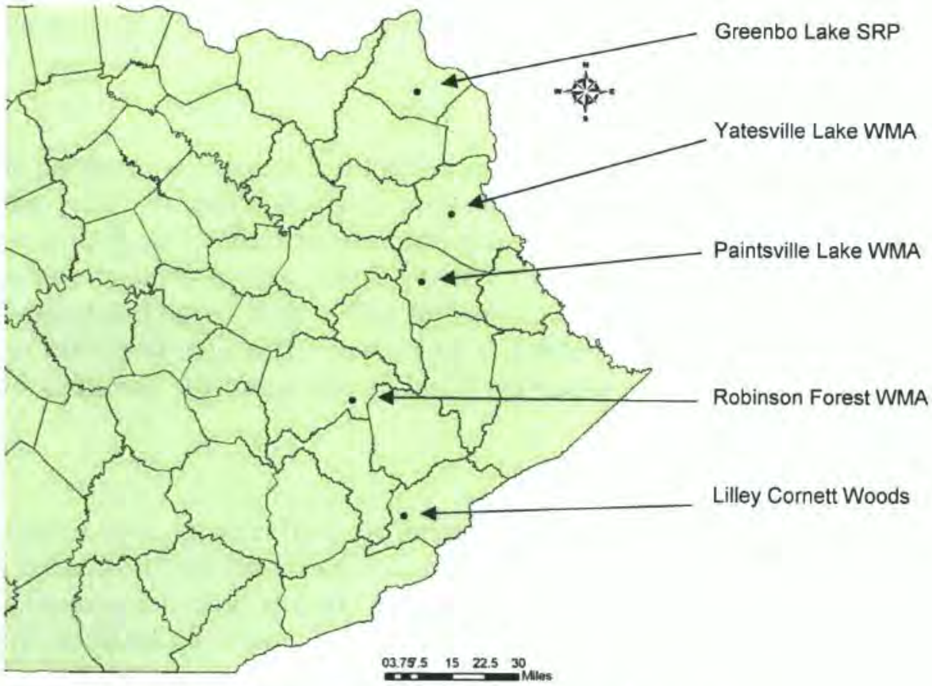

Figure 3.1 Location of study areas within the EKCF physiographic region.

be excluded.) A first-order blue line stream and at least three of its tributaries constituted a study site. For all study areas except Paintsville Lake WMA, the blue line streams were perennial streams denoted by solid blue lines. For Paintsville WMA, no perennial streams were denoted. Therefore, an intermittent stream denoted by a dash-dot blue line was selected.

3.2 DATA COLLECTION

Field data were collected in March 2006. Geo-referenced photo-documentation was collected along the selected first-order blue line streams and tributaries to facilitate identification of morphologic trends and sequences. Recorded features included stream and valley morphology, locations of measured cross sections, locations and types of each channel head, and locations of changes in the hydrologic condition (i.e., the degree of departure from completely dry condition (Fritz et al. 2006)). Channel and overbank topographic data were surveyed in multiple reaches to calculate parameters for bankfull regional curves.

Photo-Documentation

At each study site, the selected first-order blue line stream, its valley, and at least three of its tributaries were photo-documented using a high-resolution digital SLR camera and a handheld Geographical Positioning System (GPS) receiver pre-loaded with USGS 1:24,000 topographic maps. A road crossing, a confluence, or another relatively permanent feature was selected as a reference point that marked the downstream limit of the study site (Table 3.1). The geo-referenced photo-documentation was initiated at the reference point and continued up to the drainage divide. At regular intervals (not more than 10 channel widths), a GPS reading and photograph were taken. The identifier numbers of each photograph and its corresponding GPS data point were synchronized so each photograph could be tied to a specific geographic location. To maximize the accuracy of GPS measurements, multiple readings (typically 30-60) were averaged to produce each GPS data point.

Stream and Valley Morphology

Starting at the downstream reference point, the field crew identified transitions in stream and valley morphology. Where bedrock exposure, channel bedforms, stream slope, or valley morphology changed, a GPS reading and photograph were taken, and a description of the feature was recorded in a field notebook. Evidence of landslides or debris flows, past or present, was described and photographed. Bed material was photographed at riffles or steps and at locations where it had been deposited upstream of these features; a scale (typically a ruler or pocket rod) was included in each photograph to enable post-survey visual estimation of the dominant bed material type.

Channel Head Morphology and Location

The morphologic characteristics and locations of the channel heads of each assessed tributary were photo-documented. Based on the premise that a channel is a watercourse that has created its own boundary through erosion by surface or sub-surface flow, the channel head was determined as the highest point that a topographic depression *with definable banks* could be identified. This definition is compatible with those of Dietrich and Dunne (1993) and Calver (1978:233), who defined a fluvial channel as "an incision into the ground surface such that, if water ceased to flow, morphological evidence of its former course would, at least initially, remain apparent."

If the channel head had the form of an abrupt step instead of a gradual transition, the height of the step was recorded as well as any evidence of controlling factors (e.g., large boulders or tree roots that might be stabilizing the step). Any signs of either recent flow or pathways of concentrated flow were documented in a field notebook and photographed. In many instances, multiple channel heads were recorded for a single stream because the transition from swale to channel was discontinuous, or because deposition had buried a segment of the stream channel.

Hydrologic Condition

The hydrologic condition was identified by visually assessing the surface and near-surface water and flow according to five categories (Hunter et al. 2005; Fritz et al. 2006):

- No surface water
- Surface water in pools only
- Surface water present but no visible flow (i.e., standing water over the riffles)
- Flow only interstitial
- Continuous surface flow

Subsurface water was examined by removing surficial sediment to a depth of at least 0.5 ft. Locations where the hydrologic condition changed were recorded using a handheld GPS device. Morphological features influencing the infiltration and exfiltration of groundwater (e.g., change in bed material from planar bedrock to alluvium) were documented in a field notebook and photographed. Other features relevant to the presence or absence of flow, such as where water emerged from a piping cavity, were recorded and photographed.

The field assessments were conducted during the wet season, which is the optimal time for determining the length of the stream network based on hydrologic condition. The amount of recent precipitation between sites varied, however. At Lilley Cornett Woods, Robinson Forest, and

Paintsville Lake, only minimal rain (<0.3 in) had fallen during the week preceding data collection (NOAA 2006). At Yatesville Lake WMA and Greenbo Lake SRP, over 1 in of rain had fallen during the two days prior to field measurements.

Bankfull Channel Geometry

Cross sections were surveyed in multiple reaches at locations that both coincided with a clear bankfull indicator (Rosgen 1996) and were representative of the reach morphology. Selected reaches were those with geomorphic characteristics suitable for surveying of bankfull indicators; suitability was determined based on evaluation of the channel and floodplain morphology. At a minimum, the reach had to have cross-sectional geometry with unambiguous depositional indicators of the bankfull level.

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).

The primary indicator used to identify the active or actively-forming floodplain was a fine-grained depositional feature (Schumm 1960; Kilpatrick and Barnes 1964; Bray 1972; Williams 1978). Only level depositional surfaces with a length exceeding one bankfull width were used as bankfull indicators. Close to the ridgetop, these features formed in the lee and wake of large boulders (Figure 3.2a), whereas further downstream the deposits were more continuous (Figure 3.2b). Where depositional benches suggested two or more possible bankfull levels within a reach, the lowest level was considered to be bankfull. The break in slope between this level surface and the stream bank was identified as the bankfull level.

Identification of the bankfull level was refined by evaluating secondary, non-morphological indicators. 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.

In each selected reach, cross section data were collected with the use of a line level, station tape, and elevation rod according to the following procedures:

Figure 3.2a Lilley Cornett Woods near the ridgetop. The channel reach is an alluvial section upstream of abundant boulders that were produced by weathering and erosion of the sandstone caprock.

Figure 3.2b Yatesville. At larger drainage areas, colluvial material from hillslopes is present, but the level surface found along the top of the banks is the result of alluvial sediment deposition.

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.

This rapid survey method allowed for collection of a larger dataset than could be collected in rugged terrain using total station surveying equipment. The surveys extended 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. Points were taken at intervals of approximately 1-2 ft and at all breaks in slope (Figure 3.3). The toes of each bank were identified based on sediment size, structure, and frequency of movement: bank sediments are typically finer and more layered than bed material and may have been deposited years, decades, or centuries prior to assessment, whereas bed material is coarser and more frequently mobile and is a product of more recent flows.

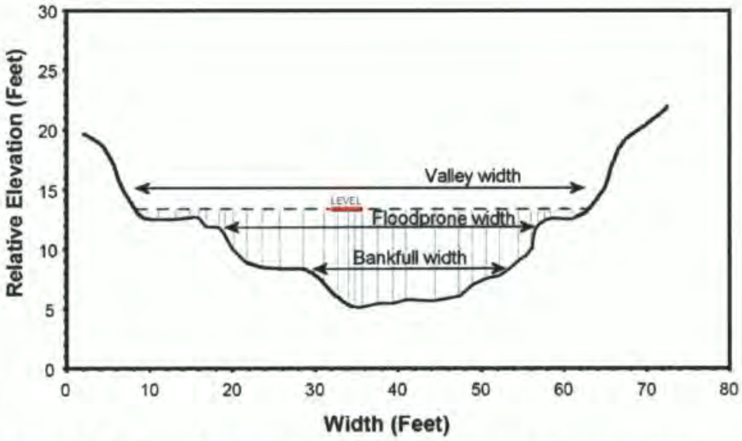

Figure 3.3 Typical cross-section of headwater stream showing multiple-level banks and proximity of hillslope to the channel.

3.3 DATA ANALYSIS

Cross Sections

Cross section data were imported into 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, the following parameters were computed for developing regional curves: bed width (W_{BED}); bankfull cross-sectional area (A_{BKF}); bankfull width (W_{BKF}); and mean bankfull depth ($D_{BKF} = A_{BKF} / W_{BKF}$).

Stream and Valley Morphology

Field notes and photographic documentation were examined to identify bedforms, which were delineated according to a visual analysis of the bed profile (smooth and flat versus stepped), the bed sediments (boulders vs. cobbles vs. gravels), and the presence or absence of large woody debris. Photos of bedforms of different study sites were visually compared to evaluate their similarities and differences, and the sequences of bedforms for each study site were plotted on the valley profiles that also revealed changes in valley slope.

Bed Material

The bed sediment was visually assessed in each bed sediment photograph, and the dominant bed material was assigned to one of four categories: sand (< 2 mm), gravel (2-63 mm), cobble (64-255 mm), or boulder (≥ 256 mm). Where a mixture of grain sizes was present, the dominant material type was assigned based on the size of material controlling the grade of the stream reach. For example, where cobbles and boulders were present in roughly equal proportions but the long profile was characterized by alternating pools and cobble riffles, the dominant bed material type was cobble. Conversely, where the majority of drops occurred over boulder steps, the dominant bed material type was boulder. The dominant bed material type was plotted on longitudinal valley profiles to illustrate the sequence and variability of different substrates within each study site.

Hydrologic Condition

Stream reaches were categorized according to three designations of hydrologic condition: "no surface water," "surface water in pools only" (SW), and "continuous surface flow" (CF). The other two of Fritz et al.'s (2006) five categories of hydrologic condition were not well represented at the time of the field visits for this project (during the wet season): reaches with "flow only interstitial" and "surface water present but no visible flow" were rarely observed.

Because the hydrologic condition is a combination of surface/direct runoff, which is the rapid response to recent rainfall, and groundwater or base flow, which is sustained discharge derived from storage zones, transition locations will vary with precipitation changes. Rainfall at Yatesville Lake WMA and Greenbo Lake SRP likely caused the measured locations of hydrologic condition transitions to be closer to the drainage divide than they would have been without a recent rainfall event. The potential significance of this rainfall cannot be determined, as several other factors (e.g., geology, vegetative cover, relief) also influence the locations of transitions. Because of the rapid response of headwater streams and the absence of precipitation during the day of assessment, however, any errors should be minimal.

Source Areas and Distance to Drainage Divide

The drainage area of the channel heads (e.g., Montgomery and Dietrich 1992) and the drainage area contributing to surface runoff (e.g., Sidle et al. 2000) are both referred to as the *source area*. Herein, the source areas are differentiated as the channel head (CH) source area, the SW source area, and the CF source area. Source areas were calculated for each channel head and each transition in hydrologic condition (SW and CF points), and drainage areas (DA) were calculated for the locations of each surveyed cross section, as follows:

1. USGS 7.5-minute topographic quadrangle maps and GPS coordinates of each location were imported to ArcGIS.
2. Drainage or source area boundaries for each location were delineated manually on the topographic maps by following ridgelines represented by contour lines. Where the scale of the topographic map rendered the location of the drainage divide unclear, orthoimagery and photographs showing the area around each channel head were used

to define the boundary. Therefore, the source areas calculated for those channel heads are less accurate than those calculated for points lower in the sub-watershed.

3. The contributing drainage or source areas for each location were calculated from the manually delineated boundaries.
4. Summary parameters (mean, maximum, and minimum) were calculated for the source areas of the channel heads, SW points, and CF points in each study site. The regional mean source area was also calculated for the channel heads of all of the study sites taken collectively.
5. Distances from the delineated ridge tops to three types of locations were calculated: (1) the locations of the channel heads; (2) the locations where the hydrologic condition changed; and (3) the start of the USGS perennial blue line streams on the topographic maps (or in the case of Paintsville WMA, the intermittent blue line stream). Relative to source areas, the distance from the drainage divide is less sensitive to map resolution and is a simple parameter to measure even at small drainage areas.

Drainage Density

Drainage density (mi/mi^2) is the total length of channel per unit area (Horton 1945), described as

$$D_d = \frac{\sum L}{A_d} \tag{3.1}$$

where $\sum L$ is the total channel length in a basin of area A_d. For a given valley network, the closer the channel heads are to the drainage divide, the greater the extent of the channel network and, therefore, the greater the drainage density (Knighton 1998).

Hydrologic modeling was used to generate the channel network for each HUC14 sub-watershed (see Table 3.1). At Lilley Cornett, the HUC14 was too small (<2.5 mi^2) for representative modeling; there, the HUC10 was used. At Greenbo Lake and Paintsville Lake, a HUC14 watershed immediately adjacent to the study site was used because the lakes cover a large percentage of the watersheds, which shortens the extent of the blue line stream network. The models were generated and analyzed as follows:

1. Thirty-foot resolution digital elevation models (DEMs) of the sub-watersheds were imported into GIS.
2. Standard ArcGIS Spatial Analyst routines were used to generate channel networks for each sub-watershed based on topography and user-input values defining the initial source areas at the upstream limits of the networks. The summary parameters (mean, maximum, and minimum) calculated for the source areas of the channel heads, SW points, and CF points were input to generate a total of nine networks (three networks for each type of feature) in each sub-watershed. A tenth channel network for each sub-watershed was generated using the regional mean source area calculated for the channel heads of all of the study sites taken collectively. Because each drainage network is based on the USGS DEM, the input source areas were rounded to the nearest 900 ft^2 (the pixel size of the USGS DEMs).
3. The generated channel lines were used to calculate the channel length from the downstream limit of the sub-watershed up to the channel heads, the SW points, and the CF points. Four values were calculated for each of these channel lengths based on the source areas of the sub-watersheds: L_{DAmean} for length using mean source area, L_{DAmax}

for length using maximum source area, L_{DAmin} for length using minimum source area, and $L_{DA\text{-}EKCF}$ for length using the regional mean source area. The lengths of the solid blue line streams (dashed for Paintsville) for each sub-watershed were also calculated.

4. Drainage densities of the sub-watersheds were calculated as the ratios of each of the 10 channel length values to the drainage area of the sub-watershed, as follows:

$$D_{d-DAmean} = \frac{L_{DAmean}}{A_d} \tag{3.2}$$

$$D_{d-DA\,\max} = \frac{L_{DA\,\min}}{A_d} \tag{3.3}$$

$$D_{d-DAmin} = \frac{L_{DA\,\max}}{A_d} \tag{3.4}$$

$$D_{d-EKCF} = \frac{L_{DA-EKCF}}{A_d} \tag{3.5}$$

   The drainage densities of the blue line streams for each sub-watershed were also calculated in order to compare them with the densities of the generated channel networks.

The choice of the source area value produces bias in the estimation of total network length and drainage density. Use of the maximum field-measured source areas for the start of the channel network tends to underestimate the total drainage network length (Type II error). Use of the mean source area improves the estimation of network length but remains an underestimate of the true channel network. Use of the minimum field-measured source areas (<0.1 acre) for the initiation of channel heads works well in the upper reaches of the drainage network (Figure 3.4a), but it can overestimate the number of channels and total network length (Type I error) in wider floodplains, where vegetation and lower slopes reduce likelihood of incision (Figure 3.4b). In principle, the minimum source area could be used to generate a channel network, and some artificial channels could be removed based on a slope criterion because most of the false channels appear in lower-gradient floodplains. However, this process would be extremely time-consuming and was unnecessary for these watersheds, as the generation of this fishbone pattern was minimal for all the networks.

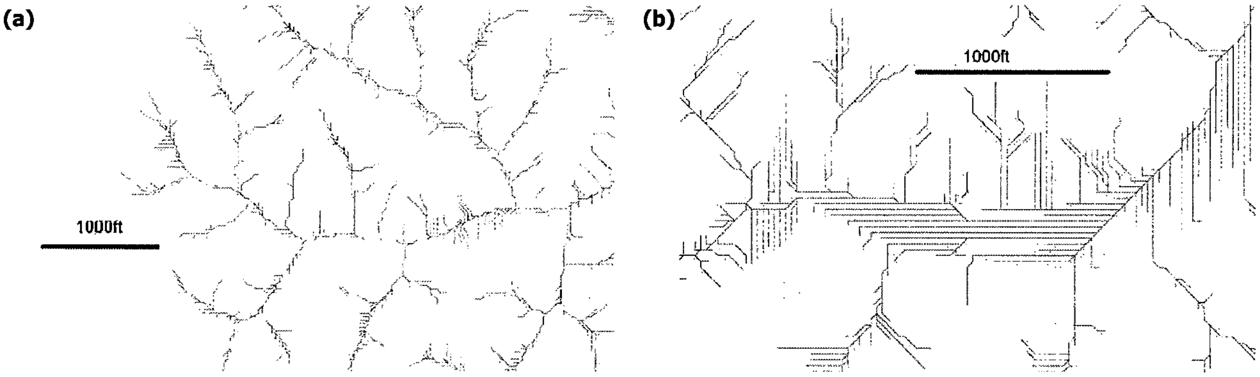

Figure 3.4 Drainage networks generated using small source areas in the (a) upstream and (b) downstream parts of the basin.

4. Morphological Characteristics of Eastern Kentucky Coal Field Headwater Channels

Bankfull channel parameters calculated for each cross section location (Table 4.1) were used to develop regional curves for Eastern Kentucky Coal Field headwater streams. The curves describe the relationship between drainage area, bankfull geometry, and bed width. A general classification of valley and channel types was developed based on qualitative and quantitative observations of the morphology of the headwater streams and their valleys. Those observations were also used to identify morphological features associated with channel heads and changes in hydrologic condition.

4.1 BANKFULL REGIONAL CURVES

Bankfull regional curves were derived from the bankfull geometry data (Figures 4.1-4.4 and Table 4.2) for headwater streams draining between 1.2 to 266.4 acres (approximately 0.0019 to 0.42 mi^2) and those draining at least 12.5 acres (0.02 mi^2), which corresponds to the point at which the valley is generally wide enough for the channel to have a well-developed floodplain. The relationship between cross-sectional parameters and drainage area was derived using ordinary least squares regression, from which power functions with the following form were developed:

$$Y = a\,\mathrm{DA}^{b} \qquad (4.1)$$

where a and b are empirically-derived constants, DA is drainage area (mi^2), and Y (ft) represents either the bed width, W_{bed} (ft), or one of the following bankfull parameters: cross-sectional area, A_{bkf} (ft^2); width, W_{bkf} (ft); or mean depth, D_{bkf} (ft).

The morphology of EKCF headwater channels is highly variable, with major changes in bankfull geometry, slope, and bed material composition occurring over relatively short distances (< 500 ft). Nevertheless, the regional curves show relationships between cross-sectional dimensions and drainage area that are highly statistically significant ($P < 0.001$ for both Kendall's τ and Spearman's ρ tests). The difference between estimates derived from the regional curves and the range of values within the 95% confidence limits, however, is large. The range between upper and lower confidence limits for cross-sectional area is approximately one order of magnitude (i.e., at 0.01 mi^2 the range is 0.29-3.13 ft^2, and at 0.1 mi^2 the range is 0.74-7.98 ft^2). The range for bankfull width, bed width, and depth is approximately a half order of magnitude.

Scatter in each of the regional curves indicates that factors other than drainage area must also be important in determining the cross-sectional dimensions of EKCF headwater channels (see Section 4.2). For cross-sectional area and bankfull width, the coefficient of determination (R^2) showed that drainage area accounted for approximately 46% of the variability within the entire dataset. For depth, however, it accounted for only 15%. Depth may be a more locally variable parameter due to the high variation in relative roughness of the channel bed and banks and the high frequency and irregularity of flow obstructions such as boulders and woody debris. Bed width, though not commonly included in regional curves, showed a stronger relationship with drainage area than bankfull width. At drainage areas greater than 12.5 acres, however, the advantage of using bed width was less distinct, indicating that bed width might be a more useful parameter for assessment at very small drainage areas, where floodplain development is limited.

Table 4.1 Bankfull Geometry for Headwater Streams of the Eastern Kentucky Coal Field Region

Study Area	Stream Site	Total DA (mi^2)	Total DA (acres)	A_{bkf} (ft^2)	W_{bkf} (ft)	D_{bkf} (ft)	W/D Ratio	Slope* (%)	W_{bed} (ft)
1 GL	UT1 Claylick Creek	0.01	5.8	0.63	2.70	0.28	9.6	12.7	1.80
	UT1 Claylick Creek	0.02	13.1	0.46	2.10	0.25	8.4	9.8	1.60
	UT1 Claylick Creek	0.02	14.3	1.65	4.10	0.47	8.7	9.8	2.90
	UT1 Claylick Creek	0.05	33.4	1.17	3.00	0.46	6.5	3.4	2.10
	UT1 Claylick Creek	0.21	137.5	2.18	5.70	0.38	14.9	2.6	4.10
	UT1 Claylick Creek	0.26	163.3	4.73	8.30	0.57	14.6	4.9	6.70
	UT2 Claylick Creek	0.03	17.6	0.71	2.60	0.33	7.9	8.7	1.70
	UT2 Claylick Creek	0.03	20.3	0.88	2.60	0.43	6.0	8.0	1.50
	UT3 Claylick Creek	0.02	10.4	0.61	2.50	0.29	8.6	3.4	1.70
	Claylick Creek	0.42	266.4	2.75	6.00	0.55	10.9	8.7	4.00
2 LCW	UT1 Line Fork	<0.01	3.2	2.66	4.30	1.12	3.8	35.7	0.45
	UT1 Line Fork	0.22	140.0	4.60	7.00	0.66	10.7	4.9	4.70
	UT1 Line Fork	0.22	140.8	4.13	6.80	0.70	9.7	4.9	5.00
	UT2 Line Fork	0.02	13.2	1.56	3.90	0.40	9.7	43.1	2.20
	UT2 Line Fork	0.31	197.7	3.83	7.00	0.62	11.3	4.9	5.40
	UT3 Line Fork	0.03	19.6	2.45	5.30	0.46	11.5	11.1	2.90
	UT3 Line Fork	0.02	10.1	3.33	7.60	0.55	13.8	20.6	4.50
3 PL	Glade Branch	0.01	8	0.48	1.5	0.34	4.4	9.8	0.85
	Glade Branch	0.02	10.6	0.37	1.5	0.2	7.5	4.1	1.1
	Glade Branch	0.04	22.4	0.74	1.9	0.46	4.1	4.1	1.3
	Glade Branch	0.06	39.7	1.95	3	0.75	4	2.3	2.2
	Glade Branch	0.06	39.7	1.65	2.6	0.7	3.7	2.3	2.1
	Glade Branch	0.06	39.7	1.75	2.9	0.7	4.1	2.3	2.1
	Glade Branch	0.36	232.9	3.99	5.5	0.73	7.6	3.4	4.5
	UT Glade Branch	0.01	7.4	0.59	1.8	0.42	4.3	12.5	1
	UT Glade Branch	0.04	24.3	1.35	3.9	0.37	10.5	3.8	2.3
4 RF	Clemons Fork	<0.01	2.6	0.26	1.4	0.23	6	52.8	0.8
	Clemons Fork	0.01	7.3	0.83	2.8	0.34	8.2	22.3	2.1
	Clemons Fork	0.04	23.7	3.01	5.1	0.7	7.3	9.6	3.5
	Clemons Fork	0.05	32.3	2.5	5.7	0.51	11.2	9.6	4.1
	Clemons Fork	0.1	66.1	3.36	5.3	0.73	7.3	3.9	3.9
	UT Clemons Fork	0.03	20.2	1.55	3.8	0.45	8.4	20.4	3.1
	Falling Rock Creek	<0.01	1.2	2.18	3.1	0.9	3.4	80	1.75
	Falling Rock Creek	0.02	10.4	2.95	3.8	1	3.8	8.6	2.1
	Falling Rock Creek	0.04	24.9	2.28	4.4	0.7	6.3	6.3	2.1
	Falling Rock Creek	0.07	41.6	3.15	5.4	0.67	8.1	6.3	4
	Falling Rock Creek	0.08	52.7	2.73	6	0.52	11.5	4.5	4.5
	Falling Rock Creek	0.1	65.2	3.72	5.7	0.68	8.4	4.5	4.3
	Falling Rock Creek	0.17	111.4	7.04	10.6	0.66	16	4.5	10.1
	Falling Rock Creek	0.19	120.4	6.37	11.8	0.54	21.9	1.5	11.1
	UT1 Falling Rock Creek	0.07	46.7	2.28	4.2	0.67	6.3	7.2	2.6
	UT2 Falling Rock Creek	0.01	8.3	0.58	2.25	0.32	7	25.2	1.4
	UT2 Falling Rock Creek	0.03	16	1.38	3.2	0.51	6.3	11.5	2.2
5 YL	Evans Branch	0.24	155.7	3.48	4.7	0.8	5.9	40	4
	UT1 Evans Branch	<0.01	2.3	0.48	2.2	0.32	6.9	16.5	0.8
	UT1 Evans Branch	0.05	33	2.22	4.5	0.57	7.9	5.6	3.3
	UT2 Evans Branch	0.03	16.9	1.98	5	0.44	11.4	11	4
	UT3 Evans Branch	0.02	11.4	0.37	1.95	0.22	8.9	11.4	1.45
	UT3 Evans Branch	0.02	12.8	0.91	3.3	0.31	10.6	11.2	2.6
	UT4 Evans Branch	0.03	20.8	0.69	2.7	0.3	9	6	1.9

* The valley slope derived from the valley profile is provided as a surrogate for the channel slope.

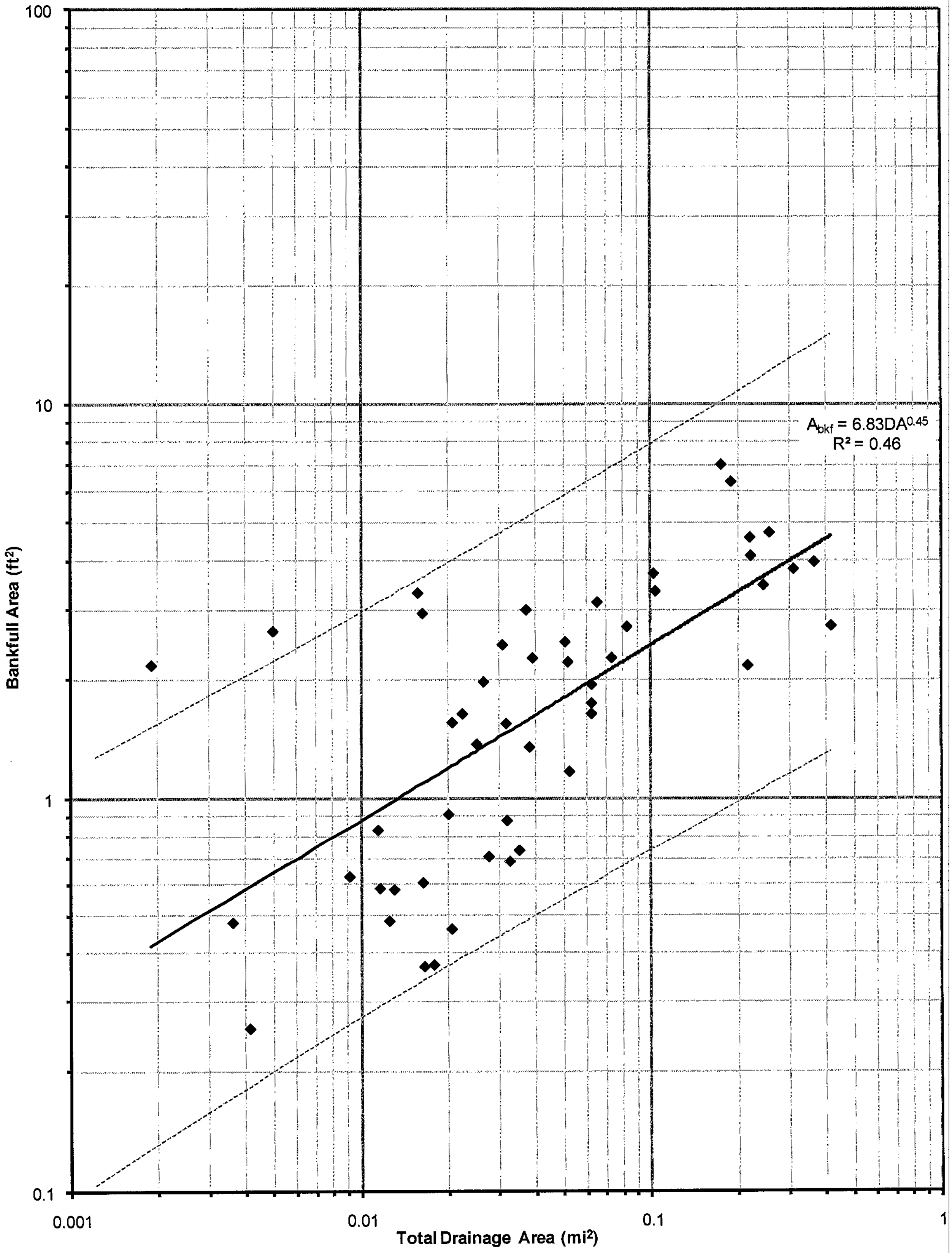

Figure 4.1 Bankfull cross-sectional area as a function of drainage area for EKCF headwater streams.

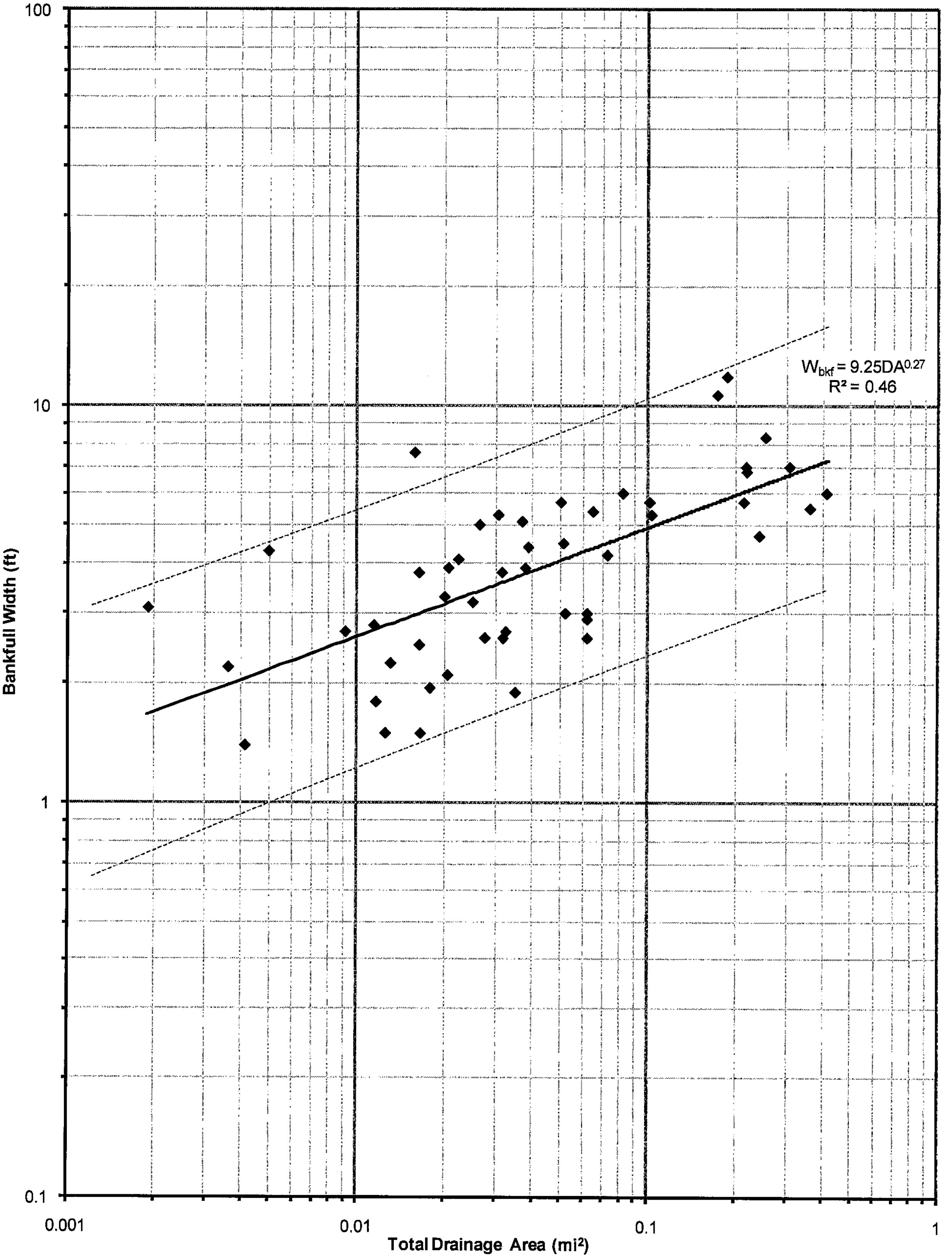

Figure 4.2 Bankfull width as a function of drainage area for EKCF headwater streams.

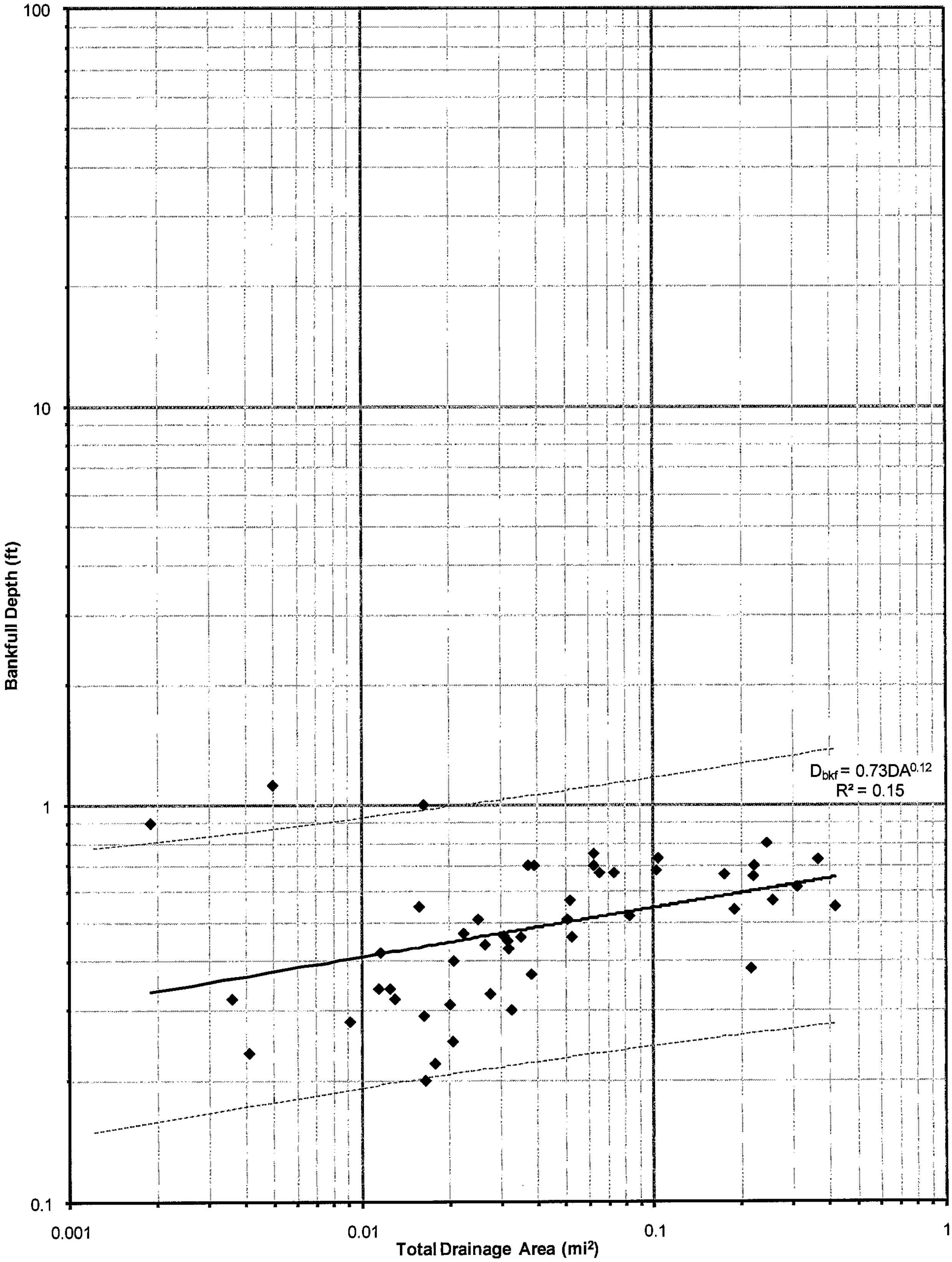

Figure 4.3 Bankfull mean depth as a function of drainage area for EKCF headwater streams.

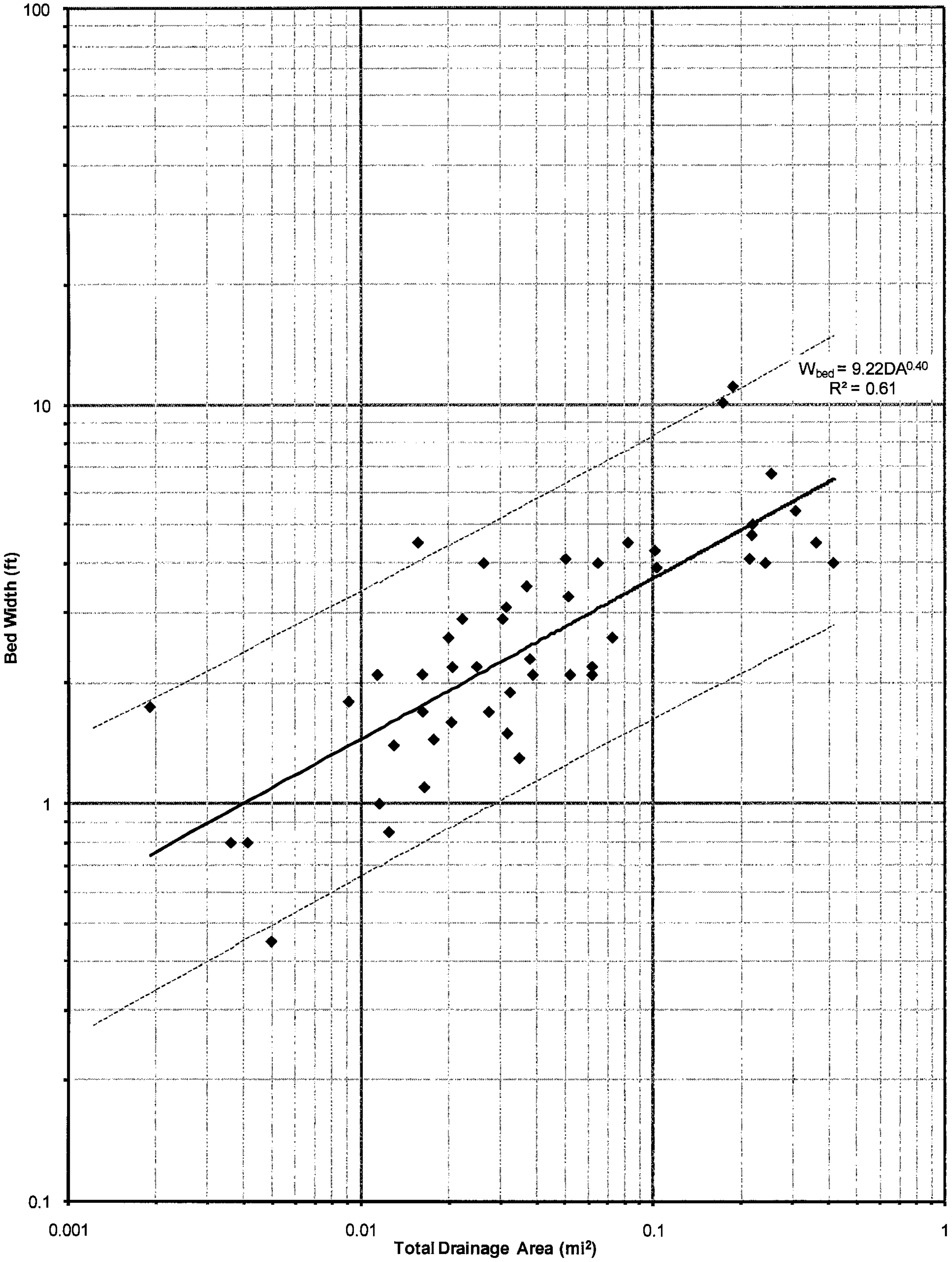

Figure 4.4 Bed width as a function of drainage area for EKCF headwater streams.

Table 4.2 Bankfull Regression Equations for Headwater Streams of the Eastern Kentucky Coal Field Region

All Data (DA = 1-270 acres)		Coefficient of	Standard	DA > 12.5 acres (0.02 mi^2)		Coefficient of	Standard
Regression Equation	N	Determination, R^2	Error, S$_e$ (%)*	Regression Equation	N	Determination, R^2	Error, S$_e$ (%)*
$A_{bkf} = 6.83\ DA^{0.45}$	50	0.46	67.8	$A_{bkf} = 8.30\ DA^{0.51}$	39	0.54	45.6
$W_{bkf} = 9.25\ DA^{0.27}$	50	0.46	38.9	$W_{bkf} = 10.81\ DA^{0.33}$	39	0.45	32.6
$D_{bkf} = 0.73\ DA^{0.12}$	50	0.15	39.1	$D_{bkf} = 0.77\ DA^{0.14}$	39	0.17	24.8
$W_{bed} = 9.22\ DA^{0.40}$	50	0.61	42.5	$W_{bed} = 8.74\ DA^{0.41}$	39	0.51	36.9

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

4.2 REACH-SCALE MORPHOLOGY

In spite of the considerable variability in the morphology of headwater channels, they tend to exhibit a sequence of morphological types (Table 4.3 and Figures 4.5 and 4.6) that can be classified according to diagnostic features (illustrated in Appendix C). Data on several other key determinants of their morphology, such as bed material, channel slope, and valley confinement, were used to develop a general classification of valley and channel types according to measurable diagnostic features. The classification scheme developed for EKCF headwater channels is based on a typology developed in the Pacific Northwest (Montgomery and Buffington 1997).

Diagnostic features also can be used to predict a channel reach's potential for response to disturbance, which often produces changes in discharge or sediment supply. The initial response to disturbance in headwaters streams is generally channel incision (bed degradation). While deposition (aggradation) may also result from some disturbances, in high-gradient streams it is more frequently a by-product of degradation, as sediment produced by headcuts may lead to aggradation downstream (Schumm 1973). The propagation of headcuts though the drainage network not only increases the sediment supply to downstream watercourses but also increases the length of stream channels and decreases the response time of streams to runoff events. Reaches that contain active headcuts or are incised may entrain soil and landslide debris to downstream waters and may undercut hillslopes, releasing further volumes of sediment from the side of the valley. Undercutting of the hillsides may promote landslides that increase sediment supply to the streams (Figure 4.7).

Some reach types were found to have a greater sensitivity to disturbance than others. The absorption or transmission of disturbance is influenced primarily by four factors (cf. Montgomery and Buffington 1997):

1. The relative position of the morphological reach type. The relative spatial distribution of the reach types influences how sediment is produced, stored, and moved, and hence, how disturbances are transmitted through the channel network.
2. The caliber and mobility of the sediment (or, occasionally, large woody debris) that is determining the local channel slope. The most resistant stream reaches are composed of materials that are immobile over all but the largest flood events. Typically, bedrock reaches will exhibit the least change of all the reach types. The strong mechanical resistance of bedrock reaches prohibits rapid erosion (Figure 4.8), and the steep slopes prevent widespread deposition. Colluvial channels and step-pool channels also have a high degree of resistance to disturbance due to the inherently immobile sediment that forms the channel boundary.

Table 4.3 Morphological Classification of Headwater Valleys and Channels of the Eastern Kentucky Coal Field Region

Landscape Segment Type	Valley Segment Type	Reach Type	Observed Local Valley Slope, % (Median)	Drainage Area, mi^2 (Median)	Diagnostic Features
Hillslope and Ridgetop			34.5-54.8 (43.7)	<0.001-0.002 (0.0015)	The ridgetops of four of the six study sites were well-rounded with gentle gradients and very little evidence of sediment erosion. At Lilley Cornett Woods and Yatesville WMA, an outcrop of resistant, massively jointed sandstones was located at the drainage divide. The breakdown of this caprock produced huge boulders that littered the hillslopes.
Valley	Unchanneled Colluvial	Hollows	12.8-54.8 (44.0)	0.001-0.006 (0.0015)	Hollows were of gentle-to-moderate slopes with little evidence of the material build-up or landsliding described in studies of other regions (Hack and Goodlett 1960; Dietrich and Dunne 1978; Reneau et al. 1984). Material accumulation followed by landsliding was only observed at Lilley Cornett Woods, where the relief is greater than in the other study areas.
		Boulder Swales	23.8-75.5 (46.5)	0.0016-0.004 (0.0027)	A boulder swale located below the hollow often marked the start of the channel network. The boulder swale is formed from convergence of topography that causes the build-up of coarse colluvial debris and concentrates the flow of surface water. It is differentiated from the hollow above by the steep hillsides and narrow valley bottom. The funneling of groundwater and surface water by bedrock and surface topography, respectively, is one reason why the channel head is often located in this reach.
	Channeled Colluvial	Colluvial Channel	12.0-66.7 (30.5)	0.016-0.12 (0.03)	Colluvium is material that is sourced from hillslopes and ridgetops and is transported by wash and mass movement processes (in contrast to fluvial agency). Colluvial channel reaches are by definition coupled with adjacent hillsides that provide most but not all of the sediment stored within the channel. This coupling means that the channel is largely undifferentiated from the valley bottom: fluvial banks are absent or poorly developed, and larger boulders and cobble may obscure banks. In some cases, a bank and bankfull indicators may be present on one side of the channel. Flows within the colluvial reaches are typically shallow and insufficient to mobilize the larger colluvial material. Hence, these reaches are a significant store of sediment that may be released only during rare large-flow events or debris flows.
	Bedrock	Bedrock Channel	2.4-50 (4.2)	0.036-0.34 (0.16)	Bedrock reaches do not have a continuous alluvial cover, although small amounts of alluvial material may be stored in the wake of obstructions. The scouring of the channel bed to reveal underlying bedrock is associated with a high transport capacity (Gilbert 1914). Bedrock reaches were found to occur throughout the watershed in locations associated with two different sets of geomorphic conditions contributing to high transport capacity: (1) a steep channel slope relative to reaches upstream and downstream and a greater degree of lateral confinement by hillslopes, or (2) a channel planform pattern that has been straightened and realigned adjacent to the valley wall, where depth to bedrock tends to be more shallow. Steep reaches may be the sites of debris flows that scoured to bedrock, especially where the channel has a chute- or canyon-like appearance. Where the stream had been straightened and relocated adjacent to the valley wall, a terrace occupied the center of the valley. The terrace may be the site for an existing road or it may have reverted to forest.

Landscape Segment Type	Valley Segment Type	Reach Type	Observed Local Valley Slope, % (Median)	Drainage Area, mi^2 (Median)	Diagnostic Features
	Colluvial-Alluvial transition	Step-Pool Channel	1.9-15.4 (4.2)	0.015-0.25 (0.18)	Step-pool reaches are characterized by channel-spanning accumulations of boulders or woody debris that form vertical steps and intervening pools that may store small amounts of finer material, primarily sand and fine gravel. In some reaches, roots may fulfill a similar role in holding grade and creating a plunge pool downstream. Like colluvial reaches, step-pool channel reaches have an abundant supply of coarse material because of the close coupling with the hillslopes, but during very large floods, these boulders are organized into a series of steps that are stationary during most flow events (Chin 2003).
		Plane-Bed Channel	2.1-10.4 (4.2)	0.012-0.39 (0.13)	Reaches with a plane-bed morphology lack discrete bars and significant variations in water surface slope but have significant cover of gravel- and cobble-sized material above the bedrock. Plane-bed reaches were observed in both confined and non-confined valleys, although a large supply of coarse colluvial material usually was absent or at least less abundant than more mobile alluvial sediment. Plane bed reaches invariably had a straight to mildly sinuous planform, as sharp bends tend to promote bar development.
	Alluvial	Riffle-Pool Channel	1.6-8.3 (2.7)	0.04-2.8 (0.22)	Riffle-pool reaches are characterized by an undulating bed profile with riffles and pools representing topographic high and low points (Leopold et al. 1964). Pools were generally shallow (<2 ft) unless flow impinged upon a root wad or large boulder to induce scour. Riffle sediments were generally coarser (gravel and cobble) than pool sediments (sand and gravel). Riffle-pool channel reaches are indicative of increasing storage within the channel boundary of gravel and small cobble that comprise the riffle framework (Montgomery and Buffington 1997). Riffle-pool reaches were generally unconfined, although they may receive some colluvial inputs. The planform of riffle-pool reaches with a high slope (1-2%) tended to be more sinuous than those with a lower slope (<1%), which had been straightened and aligned proximate to the valley side slope.

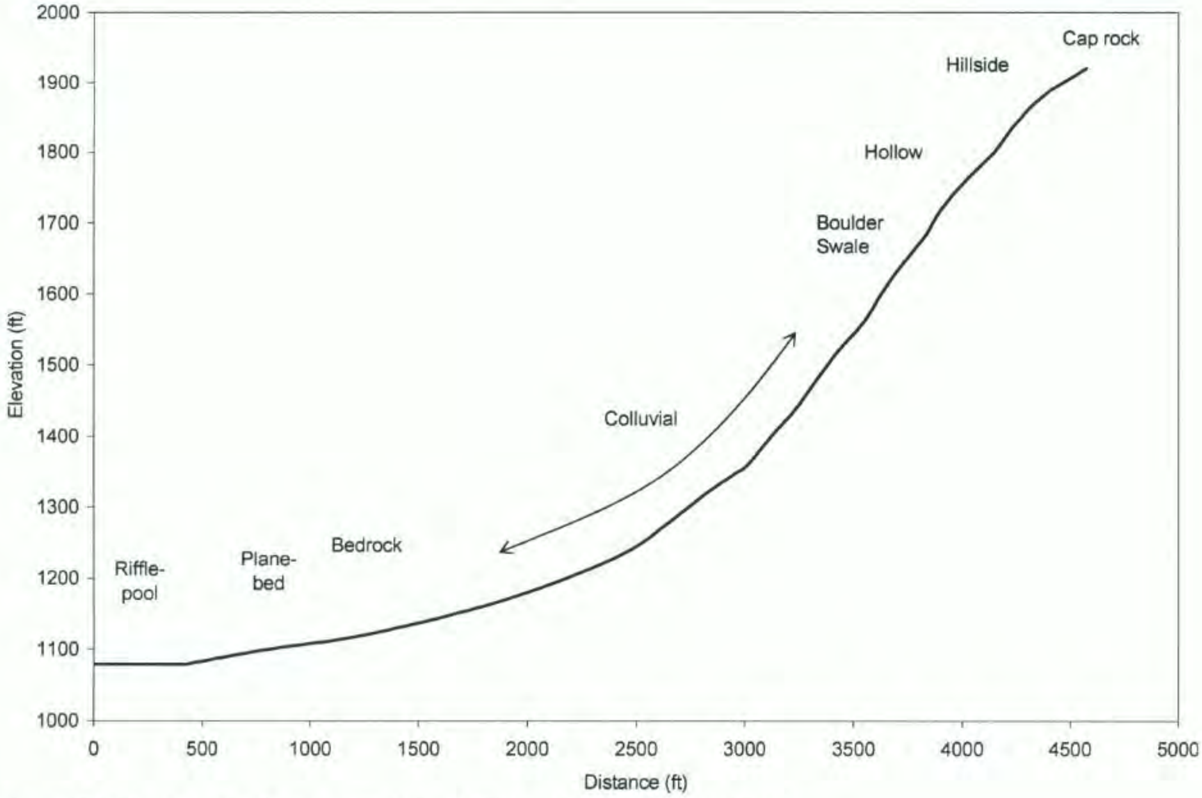

Figure 4.5 Long profile of un-named tributary of Line Fork in Lilley Cornett Woods.

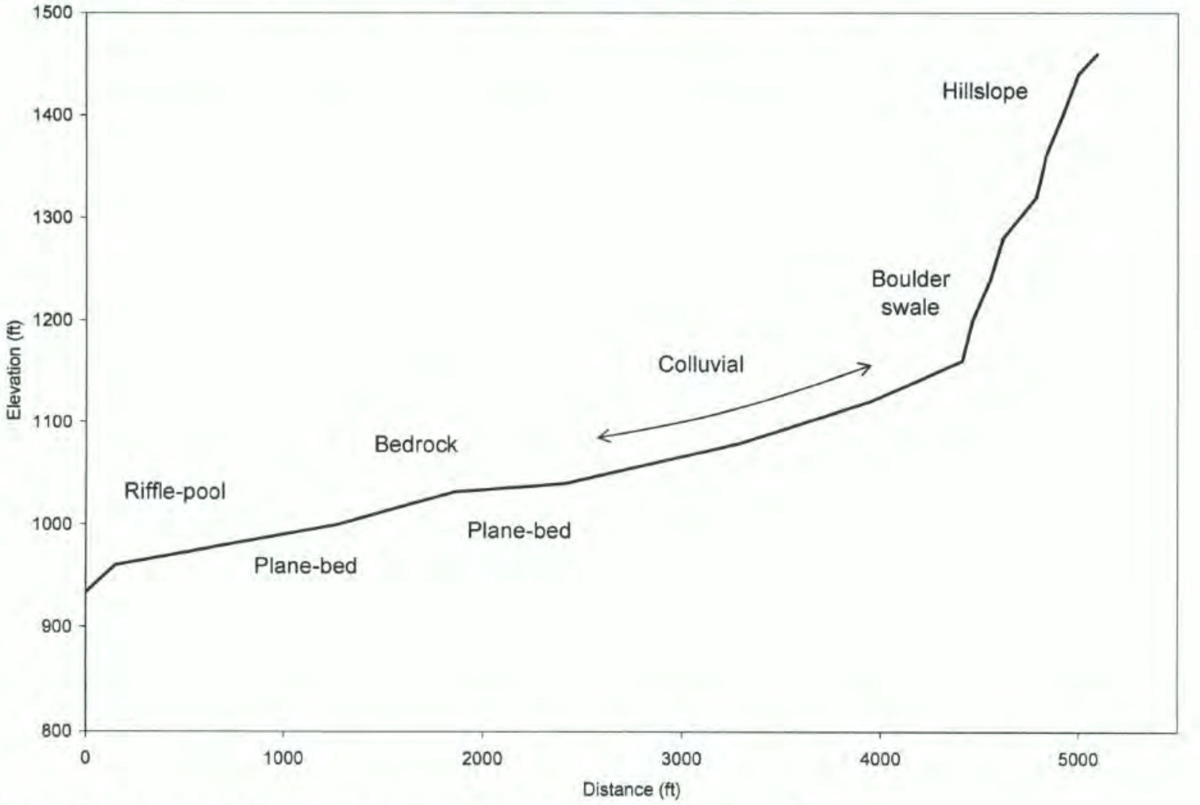

Figure 4.6 Long profile of un-named tributary of Falling Rock Creek in Robinson Forest.

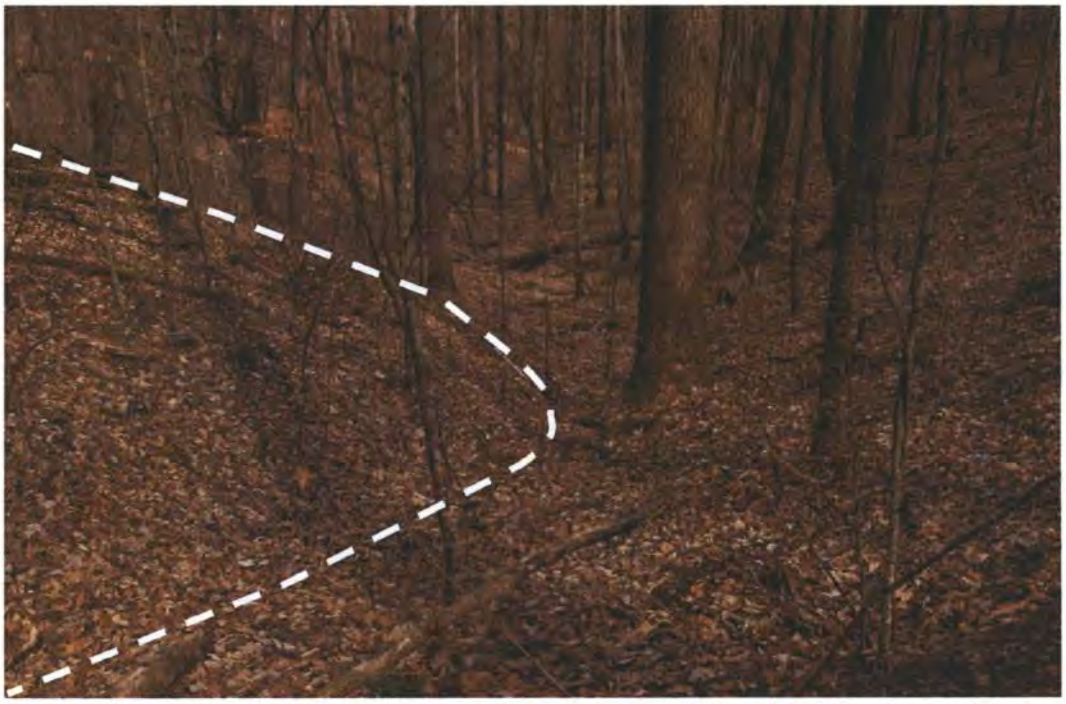

Figure 4.7 Landslide lobe which may have created locus for incision of channel. Note the absence of large trees on the lobe itself, indicating a recent (<15 years) landslide event.

Figure 4.8 "Geologic" knickpoint at Glade Branch forming a bedrock waterfall immediately upstream from confluence with Paint Creek (now Paintsville Lake). The waterfall prevents transmission of downstream disturbances to upstream reaches. Channel straightening and deposition of post-settlement alluvium, however, have resulted in channel incision upstream of the waterfall.

3. Volume of coarse sediment supply. Steep headwater reaches may be restructured only by large, infrequent floods (Grant et al. 1990; Chin 1998), and the abundance of boulders and large woody debris will influence how the morphology of the reach responds to these events. Structural elements of reach morphology, such as steps, riffles, or debris jams, can only re-form if eroded sediment is replaced.
4. The degree of interaction between the channel and the hillslopes. In general, the degree of interaction between hillsides and the stream channel decreases with increasing distance downstream, although structural controls and geomorphic history may disrupt this trend. Colluvial channels have a strong coupling with the adjacent hillslopes, so the sediment supply in these reaches is likely to be significantly impacted by the hillslope stability. Step-pool channels also show a high degree of interaction with

hillsides; large colluvial material typically comprises the key stones in channel-spanning steps. Wider floodplains downstream provide a buffer between stream channel and hillslope.

4.3 CHANNEL HEAD CONTROLS

Channel heads are typically located at an area where the valley morphology acts to concentrate groundwater or surface flow. The transition from upland swales or hollows to a definable channel was often discontinuous, with multiple channel heads for a single channel. Those channels become less well-defined downstream of the channel head before a headcut marks the re-initiation of a distinct channel boundary. The transition from swale/hollow to channel was found to occur abruptly at a small step in some cases (Figure 4.9) and over a more gradual transition zone in others (Figure 4.10). Most of the gradual channel heads appeared to be stable.

The majority of the studied channel heads were formed through subsurface flow, the pathways of which were commonly influenced by tunnels created by decaying tree roots. At a few sites, these piping processes were clearly responsible for channel head formation (Figure 4.11), and channel heads that were classified as having no control may include some that were held in their present location by root mats. The features controlling the head of the channel varied considerably, however, between different sites (Figure 4.12). Where an abrupt transition could be identified, the upstream extension of the channels appeared to be limited by one of three types of grade control:

1. Tree roots: collective mat of small roots or a single large root
2. Boulder: an isolated large boulder or possibly an outcrop of bedrock (Figure 4.13)
3. Boulder-lined swale: a narrow, v-shaped swale lined with cobble- and boulder-sized material

Figure 4.9 Small step marking the location of an abrupt transition.

Figure 4.10 Gradual channel head with no distinct break between unchanneled swale and channeled valley. Falling Rock Creek, Robinson Forest WMA.

Figure 4.11 Channel head with piping cavity and emerging subsurface flow in Evans Branch, Yatesville Lake WMA. Pen marks outlet of piping cavity.

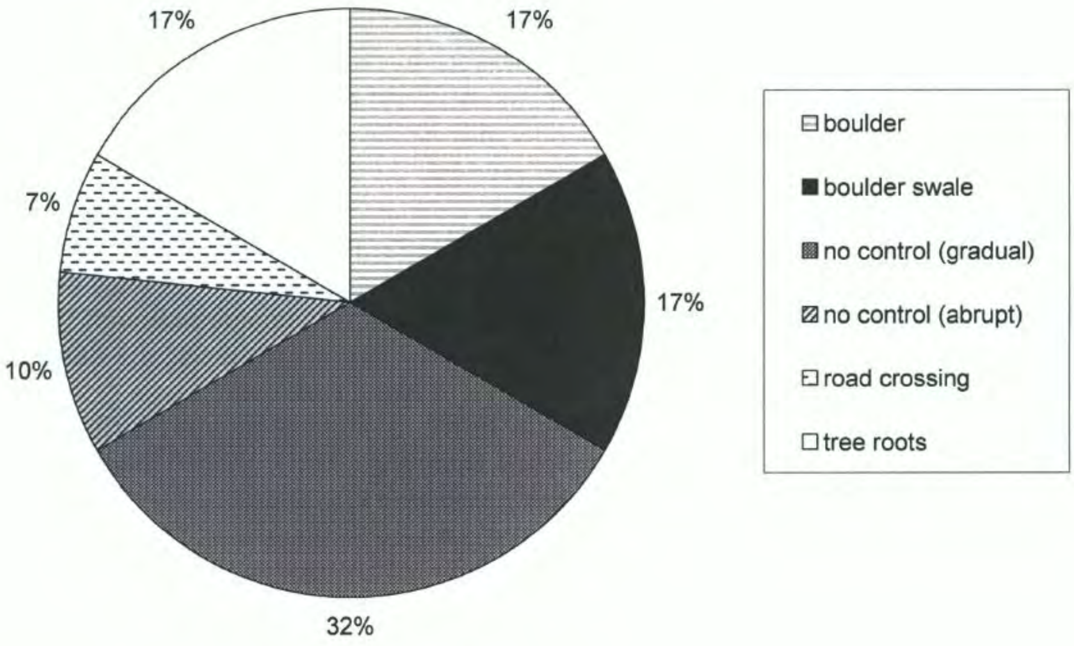

Figure 4.12 Types of channel heads found in the EKCF region.

Figure 4.13 Large boulder defines head of channel. Unnamed tributary of Line Fork, Lilley Cornett Woods.

4.4 CHANGES IN HYDROLOGIC CONDITION

The "clogging" of the valley floor with colluvium and coarser alluvial material significantly affects the stream channels, producing highly variable surface flow and altering the distribution and type of bedforms (step-pool, riffle-pool, plane-bed, and cascades). In areas where the valley slope decreases or the valley widens, the channel may be discontinuous, and/or the base flow water surface elevation may drop below the streambed. At these locations, the sediment from landslides and large runoff events accumulates, and the water flows subsurface through the deposited alluvium (see Figure 4.14). This alternation of surface and subsurface flow may be repeated from the channel head down to second- or even third-order streams (Strahler classification). Hence, the presence or absence of surface flow is dependent on a combination of the hydrology and morphology of the valley, and the surface flow may constitute (especially during low-flow conditions) only a small percentage of the total water flowing downvalley.

The pattern of subsurface and surface flow is further complicated by the differential permeability of the underlying rock strata that is typically fractured and weathered near the surface. Surface flow may disappear when underlain by bedrock that is highly permeable (typically fractured and weathered sandstone in eastern Kentucky). Where less permeable rocks are present (typically a shale layer), the surface flow re-emerges.

In general, the hydrologic condition changed with increasing distance downstream from no surface water to increasing amounts and flows of surface water. While the distance from the ridge top to the SW and CF points and to the channel head was highly variable, field observations indicated some consistencies in the location of these changes. Specifically, three geomorphic features were frequently associated with a change in hydrologic condition:

1. Headcuts: A common occurrence in the headwater streams was the emergence of surface flow at a headcut (Figure 4.15). Occasionally, the headcut was also the channel head. Flow generally emerged at a headcut in two situations:
    a. An impermeable rock layer was exposed at the base of the headcut. The relatively impermeable rock unit acted as an aquitard, concentrating subsurface flow into the rock or soil units immediately above it. In this situation, the incision of the channel bed had intersected the water table.
    b. A piping cavity outlet was discharging at the base of the headcut.
2. Colluvial valley fill: Some sections of the valley were particularly susceptible to the accumulation of coarse colluvial material supplied by mass wasting of the adjacent hillsides (Figure 4.16). These included sections where stream gradient decreased and/or valley side slopes were steep. Very large boulders often provided the main framework of the deposited material, and finer sediments and organic debris were trapped within open pockets created by the larger clasts. Close to the drainage divide (typically at locations with a drainage area less than about 15 acres (0.023 mi^2)), a transition from surface to subsurface flow was often observed at the upstream extent of the colluvial valley fill. In wider valley sections, though, the large framework boulders were not jammed together, and a small channel with surface flow was present between the individual larger rocks.
3. Alluvial fill: Sections of the valley where valley width increased and/or valley slope decreased were frequently sites of deposition of sand- and gravel-sized alluvial material (Figure 4.17). Alluvial deposition was also common immediately upstream of debris jams. In many situations, surface flow was observed upslope and downslope of alluvial fill, so subsurface flow through the alluvial material could be inferred.

Because these features are relatively stable, their associated changes in hydrologic condition would be expected to persist over time periods of months or years. This suggests that they could be used as a basis for a method to identify ephemeral-intermittent transitions.

Figure 4.14 Accumulation of colluvial and alluvial material in the valley bottom. During low flow, the majority of water flows subsurface through the deposited material. Extreme flow events may organize coarse material into bedforms (e.g. step-pools). Flow is towards the camera.

Figure 4.15 Ephemeral-intermittent transition is marked by headcut that has propagated upstream and is exposing groundwater. Valley also appears to widen appreciably where surface flow emerges.

Figure 4.16 Groundwater emerges at base of small step located at base of boulder swale. Falling Rock Creek, Robinson Forest WMA.

Figure 4.17 Alluvial fill of the valley bottom, creating discontinuous surface flow. Unnamed tributary of Claylick Creek, Greenbo Lake SRP.

5. Extents of Channel and Stream Networks

The locations of each surveyed channel head and each transition in hydrologic condition (SW and CF points) were used to estimate the extent of EKCF channel networks and stream networks, respectively. From these estimates of network lengths, drainage densities were calculated and compared between watersheds of different sizes. These estimates of drainage density were also compared to blue line channels to estimate the percentage of channel and stream networks represented by the USGS 1:24,000 topographic maps.

5.1 SOURCE AREAS

Channel head (CH) source areas ranged from 0.2 to 4.8 acres (0.0003 to 0.0165 mi^2) (Table 5.1 and Figure 5.1). The mean CH source area was 2.24 acres (0.0035 mi^2). Surface water (SW) source areas (Table 5.2) ranged from 0.23 to 23.1 acres (0.000355 to 0.0361 mi^2) or from very close to the channel head to very close to the start of continuous flow. CF source areas (Table 5.3) ranged from 7.2 to 289.9 acres (0.0112 to 0.453 mi^2), or from a confined colluvial channel to a meandering riffle-pool channel.

Table 5.1 Source Areas* for Field-Surveyed Channel Heads (CHs)

	No.	Source Area (acres)											
	CHs	**CH1**	**CH2**	**CH3**	**CH4**	**CH5**	**CH6**	**CH7**	**CH8**	**CH9**	**Mean**	**Min**	**Max**
GL†	5	1.48	2.59	1.22	0.88	1.49					1.54	0.88	2.59
LCW	1	3.17									3.17	3.17	3.17
PL†	9	0.38	0.96	0.96	0.83	0.19	0.83	0.77	1.60	10.6	1.9	0.19	10.6
RF	5	0.90	4.42	8.32	1.41	4.86					3.98	0.90	8.32
YL	7	0.83	0.82	0.77	1.73	1.79	1.86	0.64			1.21	0.64	1.86
All Sites	**27**										**2.24**	**0.19**	**10.56**

* Generally, the topographic information available from geospatial datasets was insufficient to accurately calculate the source area close to the drainage divide; therefore, source areas calculated to be less than or equal to 2 acres represent a maximum possible value.

† Adjacent HUC14 used because of presence of lake.

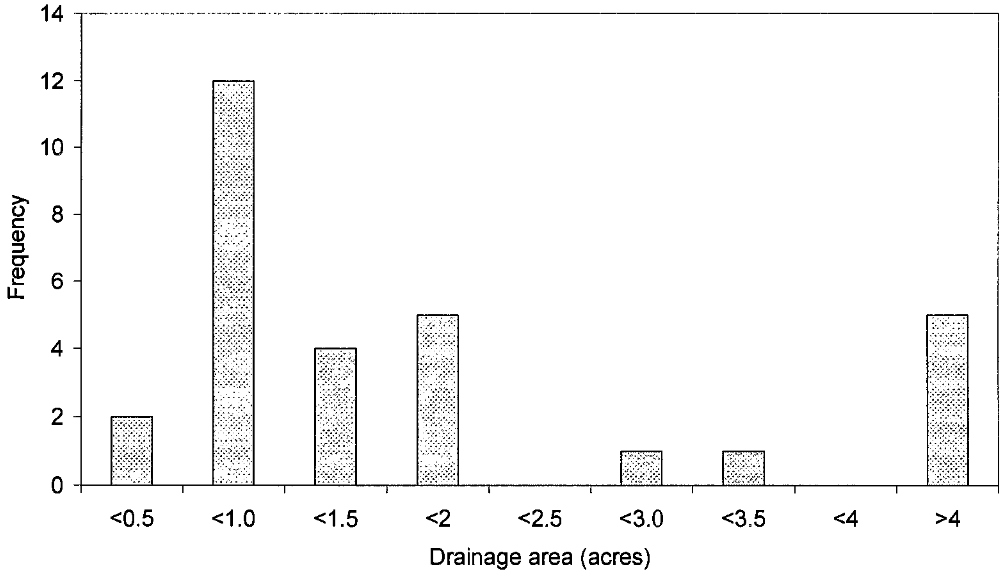

Figure 5.1 Source areas of surveyed channel heads in the EKCF region.

Table 5.2 Source Areas* for Field-Surveyed Upstream Extent of Surface Water (SW)

	Source Area (acres)								
	SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**Mean**	**Min**	**Max**
GL[†]	2.85	8.29	8.70	10.4			7.55	2.85	10.4
LCW	11.0	15.5	19.3				15.3	11.0	19.3
PL[†]	2.50	10.6	6.71	1.14	0.23	6.26	4.57	0.23	10.6
RF	23.1	16.5	20.3	10.6			17.6	10.6	23.1
YL	3.29	6.74	4.30	3.95	4.57		4.57	3.29	6.74

Table 5.3 Source Areas* for Field-Surveyed Upstream Extent of Continuous Flow (CF)

	Source Area (acres)								
	CF1	**CF2**	**CF3**	**CF4**	**CF5**	**CF6**	**Mean**	**Min**	**Max**
GL[†]	15.2	290	10.8	262			144	10.8	290
LCW	22.1	32.9	99.5				51.5	22.1	99.5
PL[†]	30.7	21.6	21.6	34.9	8.26	7.19	20.7	7.19	34.9
RF	27.6	20.1	32.0	23.4			25.8	20.1	32.0
YL	10.2	48.2	67.4	93.4	93.5		62.5	10.2	93.5

* Generally, the topographic information available from geospatial datasets was insufficient to accurately calculate the source area close to the drainage divide; therefore, source areas calculated to be less than or equal to 2 acres represent a maximum possible value.

† Adjacent HUC14 used because of presence of lake.

5.2 DRAINAGE DENSITY

Channel Network Drainage Density

Based on Equations 3.2-3.5, the drainage density of modeled channel networks ranged from 4.86 to 15.03 mi/mi^2 (Table 5.4), while the drainage density of blue line streams ranged from 1.45 to 2.46 mi/mi^2. The blue line streams represent no more than half of the total modeled channel length—in some cases as little as 15%—depending on the estimate of the channel head source area (maximum, minimum, or mean) used in generating a channel network. Even with the use of the maximum source area, which produces the smallest estimate of total stream length, the blue lines account for just 21-50% of the modeled channel network.

The percentage of the EKCF channel lengths represented by topographic maps is consistent with results from other surveys (e.g., OHEPA 2002; Rosenfeld et al. 2002; Benda et al. 2005) that indicate that the majority of headwater channels have not been identified or documented and that USGS topographic maps under-represent headwater channels by 20%–100%. In particular, a study in the Blue Ridge Mountains in the southeastern US showed the blue line (1:24,000 scale) streams representing about 20% of the channel network (Hansen 2001), which is very similar to results from the EKCF region. Moreover, the EKCF data were recorded for WMAs and an SRP that have experienced limited logging, mining, or other disturbances within recent decades. Headwaters with greater levels of disturbance may have considerably higher drainage densities; thus, even less of their lengths will be represented by blue line streams on USGS maps.

Stream Network Drainage Density

Results from the field assessment of hydrologic condition and modeling of the drainage networks showed that both surface water and continuous flow are typically located upstream of the start of the drainage network represented by blue line streams from the USGS 7.5-minute quadrangle maps (Tables 5.4 and 5.5 and Figure 5.2). The blue line streams represent no more than 69% of the modeled stream length delimited by surface water—in some cases as little as 31%—depending on the estimate of the SW source area (maximum, minimum, or mean) used in generating the stream network.

Table 5.4 Drainage Densities* (mi/mi^2) of Channel Networks Based on Field-Surveyed Channel Heads (and percentage represented as solid blue line streams)

Study Area	HUC14	Blue Line D_d	$D_{d\text{-}DAmean}$	$D_{d\text{-}DAmax}$	$D_{d\text{-}DAmin}$	$D_{d\text{-}EKCF}$
Greenbo Lake	North Fork[†]	2.49 (100)	9.44 (26)	11.7 (21)	8.06 (30)	8.43 (29)
Lilley Cornett	Line Fork	1.62 (100)	7.63 (21)	7.63 (21)	7.63 (21)	8.27 (20)
Paintsville Lake	Mudlick Creek[†]	2.48 (100)[‡]	8.96 (27)	N/A[§]	4.86 (50)	8.72 (28)
Robinson Forest	Clemons Fork	2.26 (100)	5.99 (37)	10.9 (21)	4.93 (45)	7.21 (31)
Yatesville Lake	Bushy Fork	2.25 (100)	11.0 (20)	15.0 (15)	9.12 (24)	8.47 (26)

* Generally, the topographic information available from geospatial datasets was insufficient to accurately calculate the drainage area close to the drainage divide; therefore, these drainage densities represent lower-limit estimates of the total lengths of the channel networks.

[†] Adjacent HUC14 used because of presence of lake.

[‡] For Paintsville WMA, the dash-dot blue line denoting an intermittent stream was used.

[§] Source area was too small to be a valid input.

Table 5.5 Distance from Ridge Top to Blue Line Stream; Uppermost Channel Head; Uppermost Surface Water (SW); and Uppermost Continuous Flow (CF)

Distance From Ridge Top (ft)	Percentage of Sites		
	Blue Line	SW	CF
<1000	5	89	41
<2000	63	100	100

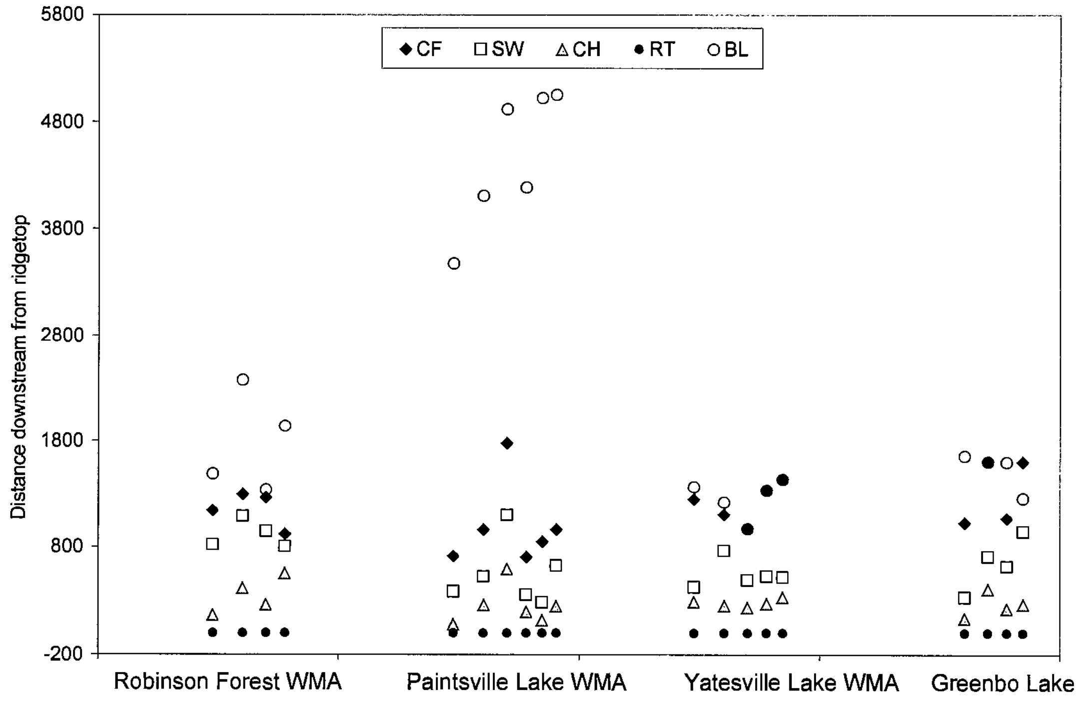

Figure 5.2 Distance from the ridge top (RT) to the channel head (CH), the uppermost point of surface water with no flow (SW), the uppermost observed continuous flow (CF), and the blue line stream (BL).

The drainage density of stream networks estimated up to the location of surface water ranged from 3.28 to 7.18 mi/mi^2 (Table 5.6), while the drainage density of blue line streams ranged from 1.45 to 2.46 mi/mi^2. Even with the use of the maximum source area, which produces the smallest estimate of total stream length, the blue lines account for just 41-69% of the modeled stream network. Use of the location of continuous flow as the starting point of the stream network produces a greater overlap between the predicted stream network and the blue line streams. Drainage density from CF points ranged from 0.95 to 5.51 mi/mi^2; blue lines represented 48% to 262% of the modeled CF stream length.

Table 5.6 Drainage Densities (mi/mi^2) of Stream Networks Based on Hydrologic Condition (and percentage represented as solid blue line streams)

		Blue Line	Surface Water			Continuous Flow		
Study Area	**HUC14**	D_d	$D_{d\text{-mean}}$	$D_{d\text{-max}}$	$D_{d\text{-min}}$	$D_{d\text{-mean}}$	$D_{d\text{-max}}$	$D_{d\text{-min}}$
Greenbo Lake	North Fork†	2.49	5.63 (44.3)	7.60 (32.8)	4.93 (50.5)	1.32 (188.9)	4.86 (51.2)	0.95 (262)
Lilley Cornett Woods	Line Fork	1.64	3.60 (45.5)	4.22 (38.8)	3.18 (51.4)	2.03 (80.7)	2.98 (54.9)	1.59 (103.1)
Paintsville Lake	Mudlick Creek†	2.48*	6.51 (38.1)	4.75 (52.3)	3.95 (62.8)	3.60 (68.9)	5.51 (45.0)	2.87 (86.5)
Robinson Forest	Clemons Fork	2.26	3.77 (60.1)	4.47 (50.6)	3.28 (69.1)	3.08 (73.6)	3.53 (64.2)	2.83 (80.1)
Yatesville Lake	Bushy Fork	2.25	6.37 (35.3)	7.18 (31.3)	5.54 (40.6)	2.13 (105.7)	4.72 (47.6)	1.68 (134)

* For Paintsville WMA, the dash-dot blue line denoting an intermittent stream was used.

† Adjacent HUC14 used because of presence of lake

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Appendices

Financial and Administrative Closeout

A

1. PROJECT OUTPUTS

Milestones	Expected Begin Date	Expected End Date	Actual Begin Date	Actual End Date
1. Submit all draft materials to the Cabinet for review and approval.	Jul 05	May 07	Jul 05	Jul 10
2. Investigate potential headwater stream sites.	Feb 06	Jun 06	Feb 06	Mar 06
3. Develop assessment site lists.	Mar 06	Mar 07	Mar 06	Mar 06
4. Collect assessment site data.	May 06	Apr 07	Mar 06	Sep 06
5. Analyze assessment site data.	Jun 06	Apr 07	Apr 06	Mar 08
6. Upon request of the Cabinet, submit annual report and/or participate in the Cabinet-sponsored biennial NPS conference.	Jul 05	May 07	Jul 05	Jul 10
7. Submit report for Cabinet review and approval.	Jan 07	Jan 07	Mar 08	Jun 10
8. Submit three (3) copies of all the deliverables and three (3) copies of the final report to the Cabinet.	Feb 07	May 07	Jul 10	Jul 10

2. BUDGET SUMMARY

Original Detailed Budget

Budget Categories	Section 319(h)	Non-Federal Match	Total
Personnel	$ 73,185	$ 30,380	**$ 103,565**
Supplies	2,000	—	**2,000**
Equipment	2,000	12,000	**14,000**
Travel	7,025	—	**7,025**
Contractual	—	—	—
Operating	22,000	33,077	**55,077**
Other	6,200	—	**6,200**
Total	**$ 112,410**	**$ 75,457**	**$ 187,867**

KDOW-Approved Revised Budget (December 2007)

Budget Categories	Section 319(h)	Non-Federal Match	Total	Final Expenditures	Unspent
Personnel	$ 81,985.00	$ 32,804.00	**$ 114,789.00**	$ 114,661.42	**$ 127.58**
Supplies	1,870.00	576.00	**2,446.00**	2,427.94	**18.06**
Equipment	1,000.00	9,000.00	**10,000.00**	9,396.06	**603.94**
Travel	3,725.00	—	**3,725.00**	3,280.85	**444.15**
Contractual	—	—	—	—	—
Operating	21,610.00	33,092.33	**54,702.33**	56,839.13	**(2,136.80)**
Other	2,220.00	—	**2,220.00**	2,417.57	**(197.57)**
Total	**$ 112,410.00**	**$ 75,472.33**	**$ 187,882.33**	**$ 189,022.97**	**$ (1,140.64)**

The budget was revised in December 2007 to accommodate approved changes in the project scope. Because the amounts that were reallocated between categories did not exceed 10% of the total budget, KDOW guidelines at the time permitted that the revisions be made without being submitted for review. Another budget revision was made during the project closeout, when the match and overall totals were determined to have been miscalculated in the original contract. The match and overall totals were increased by $15.33 each to correct the error.

The University of Louisville Research Foundation was reimbursed $112,410.00. All dollars were spent; there were no excess project funds to reallocate. This project did generate overmatch provided by University of Louisville Research Foundation. This overmatch was not posted to the grant.

3. EQUIPMENT SUMMARY

		Estimated	Actual Cost		
Equipment	**Units**	**Cost**	**319(h)**	**Match**	**Balance**
GPS unit	1	$ —	$ 242.88	$ —	$ **(242.88)**
Computer, desktop	2	3620.00	—	3614.00	**6.00**
Computer, laptop	1	1730.00	—	1722.58	**7.42**
Vehicle, four-wheel-drive – Lease	—	3650.00	—	3248.57	**401.43**
Maintenance of field research vehicle	—	1000.00	513.03	—	**486.97**
Maintenance of digital camera	—	—	55.00	—	**(55.00)**
Total		**$ 10,000.00**	**$ 810.91**	**$ 8,585.15**	**$ 603.94**

None of the equipment purchased has a current fair market value exceeding $5,000.

4. SPECIAL GRANT CONDITIONS

A Quality Assurance Project Plan (see Appendix B) was submitted in March 2006.

Quality Assurance Project Plan

B

Prepared by: Stream Institute
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March 2006

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Group A: Project Management Elements

A3 Distribution List

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A4 Project /Task Organization

The stream geomorphic data collected in this project may be used by individuals assessing the stability and morphological characteristics of headwater streams in the Eastern Kentucky

Coal Field physiographic region. The data will also be useful to designers of stream restorations in upland areas for determining the likely range of stream characteristics of restored channels.

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

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

A5 Problem Definition and Background

Land-use practices in Kentucky such as mining, land clearing, land development, channel relocation and modifications for flood protection, and roadway construction tend to increase stream peak flow rates, disturb riparian vegetation and alter stream channel characteristics. Although the Clean Water Act requires that states report on and protect all bodies of water, the majority of field studies have focused on larger, lowland streams. Compared to lowland alluvial rivers, the geomorphic characteristics, stability, and physical habitat of headwater streams have not been well-documented.

Stream evaluation and the development of methods of stream restoration to improve stream habitat, reduce bank erosion, and reduce sediment loads require a quantitative description of the regional geomorphic characteristics of streams. Mining, road-building, logging, and development activities in eastern Kentucky are affecting headwater streams with increasing frequency. Assessment of the effects of these activities on eastern Kentucky streams will require documentation of the current characteristics of headwater streams in the region. This project will extend the collection, analysis and development of regional geomorphic stream characteristic to headwater streams, for which little data has been collected. Collection of data describing the geomorphic characteristics of headwater streams will be initiated in 2006.

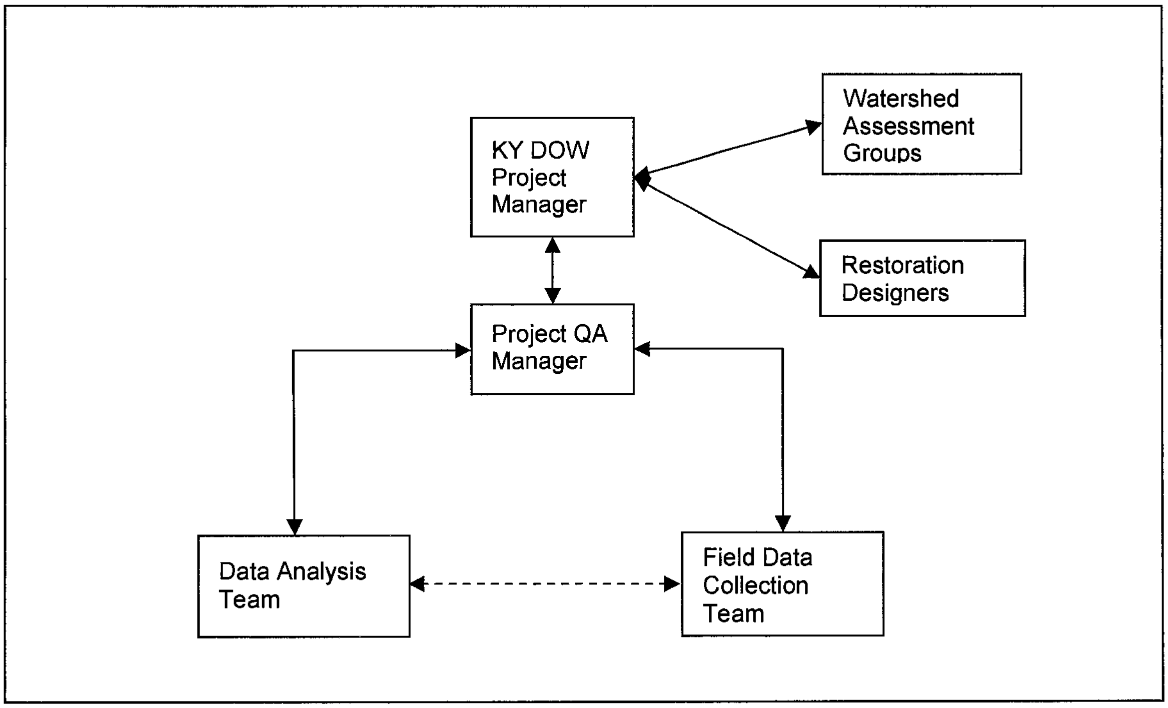

Figure 1 Organizational chart showing lines of communication.

A6 Project Task Description

Collect Available Site Information

In order to minimize landowner issues concerning access to stream reaches, GIS information on headwater streams within publicly-owned land will be obtained to determine the possible locations of assessment sites. This information will be used to develop a list of potential sites for data collection.

Collect Data of Assessment Reaches for Geomorphic Parameters

The site data required to characterize the bankfull conditions will be collected at each assessment site. The information will be stored and made available to the Kentucky Division of Water, Nonpoint Source Section in electronic format.

Analyze Initiation of Channel Network

The geomorphic data collected from each assessment site will be analyzed. Analysis will include identification of the channel head, or the starting point of the definable channel. The channel head is an important geomorphic feature that controls the drainage density and determines the total stream length and thus has regulatory implications. Where possible, bankfull channel geometry will be measured to allow comparison of regional curve methodology to streams draining less than 1 square mile. The information will be presented in a clear and simple format.

Submit Annual, Final and Closeout Reports

The University of Louisville Research Foundation (ULRF) will request current Final Project and Closeout Report guidelines from the Kentucky Division of Water no less than six months prior to the project end date. The Final Project Report will present the data and analysis of each assessment site in a clear and standard format. The data from each of the assessment sites will be stored in a database that will be submitted to the Kentucky Division of Water. The Kentucky Division of Water, Nonpoint Source Section, will receive an electronic copy of the data. The report will also present and describe the geomorphic characteristics of headwater streams in the Eastern Kentucky Coal Field physiographic region. A Closeout Report will be prepared and submitted as required by the US EPA.

A7 Quality Objectives and Criteria

The objective of this study is to develop a geomorphic characterization of headwater stream channels in the Eastern Kentucky Coal Field physiographic region. Three basic groups of data will be collected: identification and description of the channel head; identification of the transition from intermittent to ephemeral stream flow; and a description of the stream and valley geomorphology.

To achieve a broad distribution of study sites within the physiographic region, a rapid assessment procedure will be developed to allow the efficient examination of the entire length (from head to confluence of larger stream) of each stream The use of standard surveying techniques with total station equipment or levels was considered unsuitable for the project objectives because (1) cross section measurements could be obtained to the required accuracy by other methods, (2) the steep slopes would complicate the transportation of the survey equipment, and (3) the time required to set up and obtain measurements with a total station would unnecessarily limit the number of streams and sites which could be examined. Rather than surveying with total station equipment, ULRF will develop a mapping program that uses handheld GPS receivers, existing USGS topographic maps, and photographic documentation to assess stream conditions. Stream channel geometry will be measured using a line level and pocket rod to describe the cross section with an accuracy of ±5 cm in the vertical and horizontal directions. A rapid assessment procedure will enable field teams to collect data from different sites within the physiographic region in order to develop comparisons between different locations. The bed material characteristics will be identified using photographic evidence to enable Rosgen (1996) classification of bed material.

To ensure consistency in the selection of sampling locations for channel heads, intermittent-ephemeral transitions, and cross section channel geometry, the QA manager will conduct on-site quality checks.

A8 Special Training and Certification

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

A9 Documents and Records

The QA manager will be responsible for ensuring that the data collection team and all others on the distribution list receive the most current QA project plan through email distribution. However, we do not anticipate significant changes to the QAPP.

A final report that documents the procedures used to collect the data, difficulties in the data collection process, and factors that influenced data quality will be produced. The final report will include the raw field data in a Microsoft Excel format. The final report will also include the analysis and products derived from the analysis such as regional curves of stream geomorphic characteristics and any other relations derived from these analyses (see Table 1).

Table 1 Final Report Data

Type of Data	Source Data	Analysis
Site location, geology, and topographic data	USGS topo maps, KY geologic maps, state GIS database	Identification of channel type according to USGS blue lines and calculation of valley slope and drainage area
Cross-sectional stream characteristics	Geometric data collected by field team	Intra- and inter-basin comparison of channel parameters
Surface and subsurface sediment characteristics	Photographic documentation collected by field team	Bed material classification
Locations of channel heads	GPS data collected by field team	Analysis of channel-hillslope transition
Flow regime data	GPS data collected by field team	Identification of the intermittent-ephemeral transition

Group B: Data Generation and Acquisition Elements

B1 Sampling Process Design (Experimental Design)

Headwater streams represent the combined influence of stream and hill slope processes. Above the channel head, the hill slope processes are dominant and there is insufficient incision to form a channel. Below the channel head, fluvial processes are active in shaping the channel geometry, but the influence of hill slope processes through landsliding and debris avalanches is still significant. As a result of the combination of fluvial and hillslope processes, headwater streams within a given physiographic region exhibit a wide variety of channel forms. The sampling of cross-sectional channel geometry will aim to capture this variability by purposely sampling channel cross sections that reflect the reach-average conditions and the geomorphic processes that are active within that reach.

No USGS gauging stations are available in the Eastern Kentucky Coal Field region due to the difficulty in accessing and sampling small, steep channels. As a consequence, no stream gauge data will be available for this study.

The natural variability in headwater streams necessitates that the sampling program to assess regional variations be wider than that used for lowland, alluvial streams due to relief, geology, and land use history. To achieve a broad distribution of study sites within the physiographic region, a rapid assessment procedure will be developed to allow the entire stream length to be examined.

B2 Sampling Methods

Sampling for this project can be grouped into three categories: (1) GPS measurements of channel locations; (2) photographic documentation of stream and valley configurations; and (3) rapid channel surveying using line level and pocket rod. Table 2 describes the types of data to be sampled and the corresponding method to be used.

Table 2 Sampling Methods

Type of Data	Method	Reference
Channel cross section	Line level and pocket rod	Adapted from Harrelson et al. (1994)
Channel head location	GPS survey	None
Intermittent-ephemeral transition	GPS survey	None
Bed material classification	Photographic documentation	Rosgen (1996), Bunte and Abt (2001)

Locations measured using the GPS receiver will be checked against USGS topographic maps and aerial photographs. Where the positional accuracy is found to have been poor, measurements will be corrected using photographic evidence and the topographic maps. All GPS points correspond to a photograph to enable easy geo-rectification with correlated time stamps recorded for each point and photograph.

B3 Sample Handling and Custody

Positional data from the GPS receiver will be collected in electronic format on an integrated data logger and downloaded each day to a laptop computer.

Photographic documentation will be taken using a high-quality digital SLR camera and will be downloaded at the end of each day.

Channel cross section data and other relevant geomorphic features will also be recorded on data forms to complement the GPS measurements and aid in interpretation of photographs. Notes and field sketches will be entered into electronic format.

The data will be archived by the project QA manager.

B4 Analytical Methods

Survey data will be analyzed and reduced using Microsoft Excel. All data will undergo quality control checks supervised by the QA manager during data processing to ensure satisfactory quality throughout the spreadsheet analysis.

The GPS data will be analyzed and mapped using ArcGIS software. The calculation of drainage area and the extraction of longitudinal valley profiles will be conducted in ArcGIS and the data entered into Excel for further analysis.

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

B5 Quality Control

Surveying of cross sections in the field using the line level and pocket rod will be performed by field-trained personnel under the direct supervision of the QA manager.

All calculations and parameters from ArcGIS will be reviewed by the QA manager prior to inclusion in the final report.

All maps used within the ArcGIS analysis will be obtained from reliable electronic sources and checked against hard copy maps to ensure accurate georeferencing.

B6 Instrument/Equipment Testing, Inspection, and Maintenance

All field equipment will be maintained to ensure proper function. This equipment will be tested against standards before and after field reconnaissance.

B7 Instrument/Equipment Calibration and Frequency

This does not apply to rapid field survey procedures.

B8 Inspection/Acceptance of Supplies and Consumables

This does not apply to geomorphic data collection.

B9 Non-direct Measurements

This does not apply.

B10 Data Management

The data will be entered into an Excel spreadsheet and archived electronically on dual mediums: CD-ROM and hard-drive.

Group C: Assessment and Oversight Elements

C1 Assessment and Response Actions

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

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

Correct functioning of the GPS receiver is imperative for rapid field measurements. At least one backup instrument will be made available to ensure that a GPS receiver is used.

C2 Reports to Management

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

Group D: Data Validation and Usability Elements

D1 Data Review, Verification and Validation

Random checks of data using a tape measure will be made to ensure that survey data are within an acceptable range for characterizing geomorphic parameters. Most problems with data error will be addressed at the time of data collection.

D2 Verification and Validation Methods

The geomorphic data and regional relations for this project will be compared to those of other similar projects of regional geomorphic characteristics (cf. McCandless and Everett 2002). Data incorporated in the database will be reviewed and tested by the QA manager. Although large variation in geomorphic parameters is anticipated, unusual deviations will be examined carefully to ensure that they represent variation in geomorphic characteristics and not error of data collection and analysis procedures.

D3 Reconciliation and User Requirements

The anticipated users of this data and the resulting regional relations developed from the data are individuals conducting stream assessments within the physiographic region. Large natural variations of stream and valley morphology occur because of variation in geology, vegetation, current land uses, land use history, and direct modification of stream channels. In spite of the relatively recent protection afforded to the state-owned lands where this project will be carried out, the streams that traverse them may exhibit the same kinds of effects from historic land uses as streams outside the protected areas do (Parola et al. 2005). Nevertheless, users of the reported information will be informed that the data may be biased toward streams within publicly held lands. In addition, users will be cautioned that local and basin conditions may cause substantial differences in stream characteristics. The database will provide information on the characteristics of streams and their watersheds so that users have information available to make direct comparisons with specific site conditions.

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Reach-Scale Morphology of EKCF Headwater Channels

C

Figure C.1 Hillslopes and ridgetops
The majority of the ridgetops in the study sites were well-rounded with gentle gradients and very little evidence of sediment erosion (A). Hillsides immediately downstream of the ridgetop and above the start of the channel network were also of moderate slopes with no obvious signs of mass movements or fluvial erosion (B). The exception to these scenarios was observed at Lilley Cornett Woods and Yatesville WMA, where an outcrop of resistant, massively jointed sandstones was located at the drainage divide (C). The breakdown of this caprock produced huge boulders that littered the hillslopes and may interact with the stream channel (D).

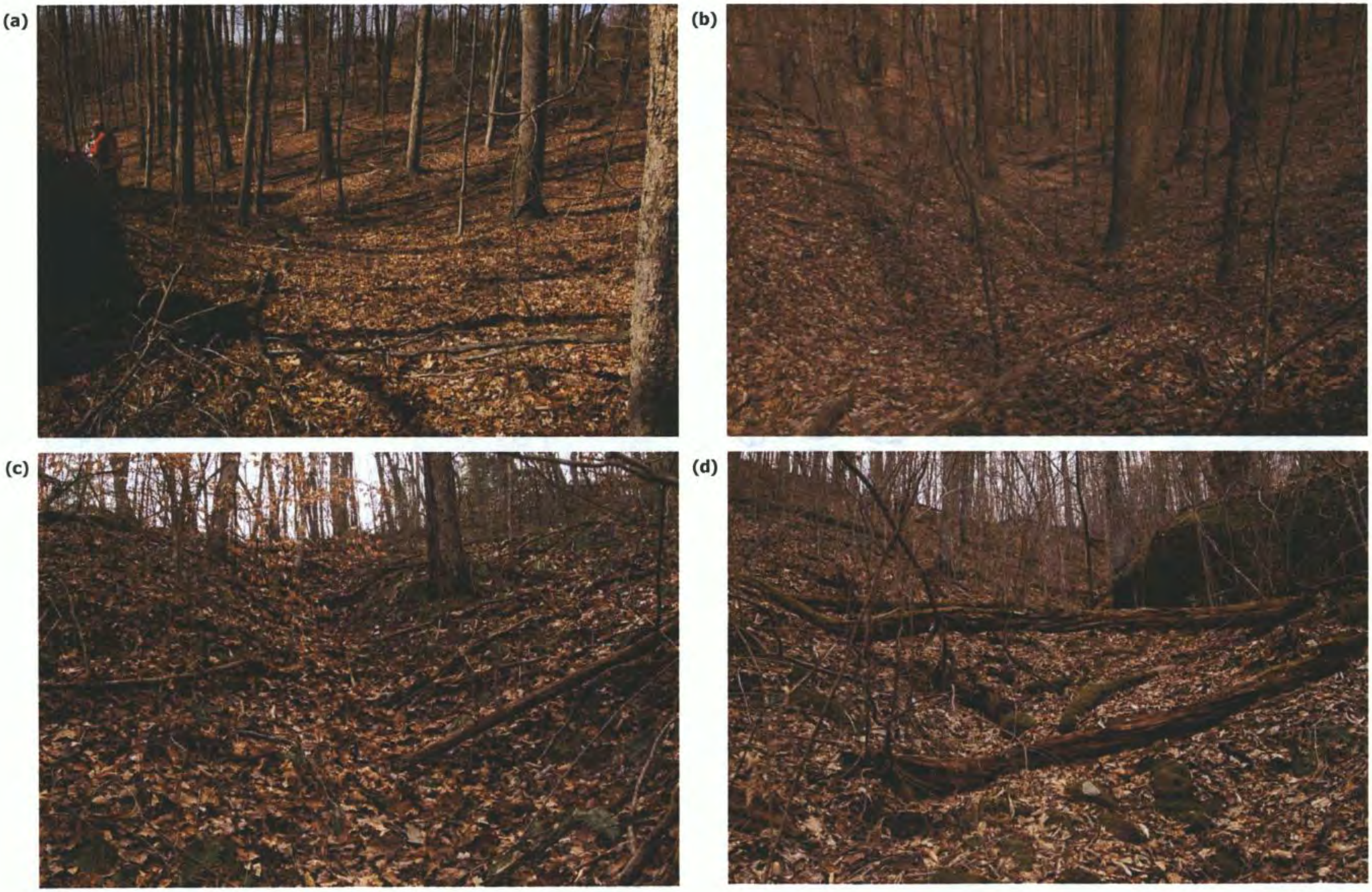

Figure C.2 Hollows

Hollows or zero-order basins are spoon-shaped depressions typified by concave contours on a topographic map (Hack and Goodlett 1960). In the EKCF sites, the hollows were typically of gentle-to-moderate slopes with little evidence of material build up (A and B). Abundant tree roots may prevent incision and channel formation (C). The only location where hollows were observed to be sites of colluvium deposition and infrequent but recurrent evacuation of material by landsliding (Hack and Goodlett 1960; Dietrich and Dunne 1978; Reneau et al. 1984) was Lilley Cornett Woods (D), where the relief is greater than in the other study areas.

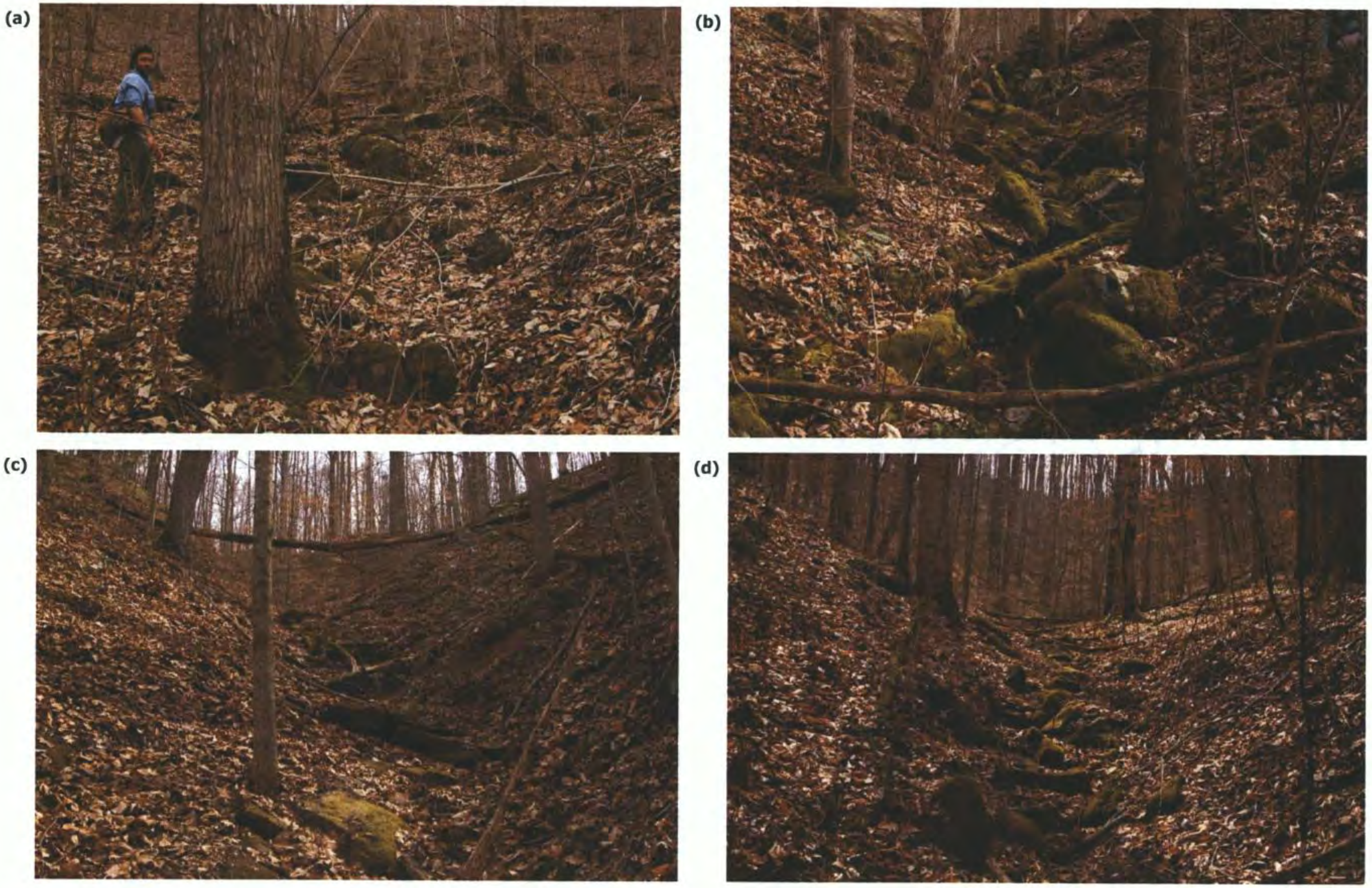

Figure C.3 Boulder swales
A typical feature of EKCF headwaters was a boulder swale located below the hollow and often marking the start of the channel network. The boulder swale is formed from convergence of topography that causes the build-up of coarse colluvial debris (A and B). It is differentiated from the hollow above by the steep hillsides and narrow bottom. The funneling of groundwater and surface water is one reason why the channel head is often located in this reach (C and D).

Figure C.4 Colluvial channel
Colluvium is material sourced from hillslopes (A) and ridgetops (B) that is transported by wash and mass movement processes (as opposed to fluvial agency). Colluvial channels are by definition coupled with adjacent hillsides that provide most but not all of the sediment stored within the channel. This coupling means that the channel is difficult to distinguish from the valley bottom, as fluvial banks are absent or poorly developed, and larger boulders and cobbles may obscure any banks present. In some situations, a bank (and bankfull stage) may be present on one side of the channel (C). Flows within the colluvial reaches are typically shallow and insufficient to mobilize the larger colluvial material. Hence, these reaches are a significant store of sediment that may be released only during rare large-flow events or debris flows. Fine material deposited upstream of these large boulders may be a good indicator of a developing floodplain and, hence, bankfull (D).

Figure C.5 Bedrock channel
Bedrock reaches do not have a continuous alluvial cover, although small amounts of alluvial material may be stored in the wake of obstructions. The scouring of the channel bed to reveal the underlying bedrock is associated with a high transport capacity (Gilbert 1914). Bedrock reaches were typically located in two situations in the study sites with separate causes of high transport capacity. The first situation is where a reach has a steep slope relative to reaches upstream and downstream and greater degree of lateral confinement by hillslopes (A and B). These steep reaches may be the sites of debris flows that scoured to bedrock, especially where the channel has a "chute" or canyon-like appearance (B). The second situation is where the stream has clearly been straightened and relocated adjacent to the valley wall, with a terrace occupying the center of the valley (C and D). The terrace may be the site for a modern road (C) or may have returned to forest (D).

Figure C.6 Step-pool channel
Step-pool reaches are characterized by channel-spanning accumulations of boulders (A) or woody debris (B) that form vertical steps and intervening pools that may store small amounts of finer material (primarily sand and fine gravel). In some reaches, roots may fulfil a similar role in holding grade and creating a plunge pool downstream (C). Root-held steps may not reform once soil has eroded from around the root, so these reaches are considered to be a temporary condition rather than a long-term stable reach morphology. Like colluvial reaches, step-pool channel reaches have an abundant supply of coarse material because of the close coupling with the hillslopes, but during very large floods these boulders are organized into a series of steps that are stationary under most flow conditions. The grade control provided by the boulder and woody debris steps allows fine-grained material (D) to settle out and form depositional benches that are good, easily observed indicators of bankfull stage.

Figure C.7 Plane-bed channel

Reaches with a plane-bed morphology lack discrete bars and significant variations in water surface slope but have significant cover of gravel- and cobble-sized material above the bedrock. Plane-bed reaches were observed in both confined (A) and non-confined (B) valleys, although a large supply of coarse colluvial material typically was absent or at least less abundant than more mobile alluvial sediment (C). Bankfull was more readily identified in the non-confined reaches, as the floodplain provided a good bankfull stage indicator. Plane bed reaches invariably had a straight to mildly sinuous planform (D), as sharp bends tend to promote bar growth.

Figure C.8 Riffle-pool channel
Riffle-pool reaches are characterized by an undulating bed profile with riffles and pools representing topographic highs and depressions, respectively (Leopold et al. 1964). Riffle-pool reaches were generally unconfined, although some colluvial inputs may occur (A). Bankfull stage in these reaches may be represented by the valley flat level in non-incised reaches (B) and by a small in-stream depositional bench in incised reaches (C). Riffles are typically composed of a mixture of gravel and cobbles and flow conditions must be suitable for the deposition of these size classes for riffle formation; hence most riffle-pool reaches were located in valleys with a slope of less than 2%. The planform of riffle-pool reaches with higher slope (1-2%) tended to be more sinuous than lower slope (<1%) reaches that were typically straightened and aligned proximate to the valley side slope (D).

Eastern Kentucky Coal Field Headwater Streams Data

D

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