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DEVELOPMENT OF REGIONAL AND HYDRAULIC GEOMETRY CURVES FOR THE EASTERN KENTUCKY COALFIELDS

Ashlan Berry
University of Kentucky, ancl227@uky.edu
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Dr. Carmen Agouridis, Major Professor

Dr. Donald Colliver, Director of Graduate Studies

DEVELOPMENT OF REGIONAL AND HYDRAULIC GEOMETRY CURVES FOR THE EASTERN KENTUCKY COALFIELDS

THESIS

A thesis submitted in partial fulfillment of the requirements
for the degree of Masters of Science in Biosystems and Agricultural Engineering in the
College of Engineering
at the University of Kentucky.

By

Ashlan Nicole Berry

Lexington, Kentucky

Director: Dr. Carmen Agouridis, Professor of Biosystems and Agricultural Engineering

Lexington, Kentucky

2016

ABSTRACT OF THESIS

DEVELOPMENT OF REGIONAL CURVES AND HYDRAULIC GEOMETRY CURVES FOR THE EASTERN KENTUCKY COALFIELDS

Regional curves and hydraulic geometry curves relate bankfull channel dimensions to drainage area and bankfull discharge, respectively. These curves are used in the natural channel design process to help identify bankfull and to estimate bankfull dimensions of the design channel. Nineteen streams were surveyed to determine their bankfull parameters (cross-sectional area, width, mean depth, discharge, slope, and Manning's n), along with 27 streams previously surveyed in other studies. The data were used to create regional and hydraulic geometry curves for three hydrologic landscape regions (HLR 9, HLR 11, and HLR 16, individually) in the Eastern Kentucky Coalfields (EKC) as well as the combined region (all HLRs). Results indicated that separating the EKC into HLR improved the R^2 of the regional curves. Statistical differences were noted between HLRs with regards to regional curves further suggesting subdivision is beneficial. For hydraulic geometry curves, lack of discharge data limited interpretations and hence recommendations on the need to further subdivide the EKC into HLRs. Results for both regional curve and hydraulic geometry curve analyses suggest that datasets from the EKC may be supplemented using data from other physiographic regions in the U.S. as long as the data are obtained from the same HLR.

Keywords: stream restoration, geomorphology, natural channel design, hydrologic landscape region

Ashlan Nicole Berry
Signature

October 24, 2016
Date

DEVELOPMENT OF REGIONAL AND HYDRAULIC GEOMETRY CURVES FOR THE EASTERN KENTUCKY COALFIELDS

By

Ashlan Nicole Berry

Carmen Agouridis
Director of Thesis

Donald Colliver
Director of Graduate Studies

October 24, 2016
Date

For my family

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The United States has over 3.5 million miles (5.6 million kilometers) of streams and rivers (USEPA, 2013) which provide numerous benefits such as habitat for aquatic species, drinking water, recreational opportunities, and hydroelectricity. According to the USEPA's National Rivers and Stream Assessment (NRSA), 46% of assessed streams are in poor biological condition (USEPA, 2010). When assessing streams for their ability to support aquatic life such as benthic macroinvertebrates, the USEPA uses an index (Rapid Bioassessment Protocol or RBP) that allows the user to quickly evaluate the habitat, water quality, and biologic condition of wadeable streams in relation to reference (i.e. preferred or ideal) conditions. Benthic macroinvertebrates are organisms typically 0.4-1.2 inches (1-3 cm) in length that live at the bottom of streams. These organisms are often useful indicators of the health of a stream because of their sensitivity (or lack thereof) to changes in water quality and physical conditions (e.g. EPT taxa require high levels of dissolved oxygen and low levels of embeddedness) meaning the biologic health of a stream is inferable from the presence and/or absence of certain species. Not all streams that are geomorphically unstable are in poor biological condition, and vice versa, not all geomorphically stable streams support vibrant biologic communities; however, a strong link exists between a stream's physical stability and its biological condition. Fischenich (2006) found that by addressing a stream's hydrologic, hydraulic, and geomorphic processes, a stream is capable of sustaining more diverse biological communities, varied habitats, and improved water and soil quality.

Throughout the U.S., efforts are underway to restore streams to stable and biologically healthy conditions. Restoration is defined as the "re-establishment of structure and function of ecosystems" to pre-disturbance conditions as closely as possible while also taking into consideration anticipated future watershed conditions (NRC, 1992). The process of stream restoration involves redesigning the physical aspects of a stream (e.g. its dimension, pattern and profile) in an effort to restore dynamic equilibrium with the intent that restoration of chemical and biological conditions will soon follow (Lakly and McArthur, 2000). Streams are dynamic systems that fluctuate in response to watershed inputs such as water and sediment. Lane (1955) showed the connection between these stream variables:

$$Q_s \cdot D_{50} \propto Q_w \cdot S \qquad \text{(eqn. 1.1)}$$

The variable Q_s refers to the sediment discharge, D_{50} refers to the sediment particle size, Q_w refers to the stream flow, and S refers to the slope. If one variable in Equation 1.1 increases or decreases the other variables on the opposite side of the equation will also decrease or increase to remain in equilibrium (Figure 1.1). For example, an increase in runoff (e.g. Q_w) due to urbanization will produce erosive conditions while an increase in sediment load (Q_s) due to land disturbance activities (e.g. road construction, mining) will result in aggradation.

Between 1990 and 2003, Bernhardt (2005) noted an exponential growth trend as over 37,000 stream restoration projects were undertaken in the U.S alone. With the federal requirement for compensatory mitigation (i.e. no net loss of streams or wetlands due to physical impacts for a project), the field of stream restoration will continue to grow (Cunninghman, 2003). Austin (2007) estimated that over $3 billion is spent annually on wetland and stream restoration projects to meet compensatory mitigation requirements. In addition to compensatory mitigation driven projects, a number of other projects are funded through grants, private and non-profit groups (USEPA, 1995).

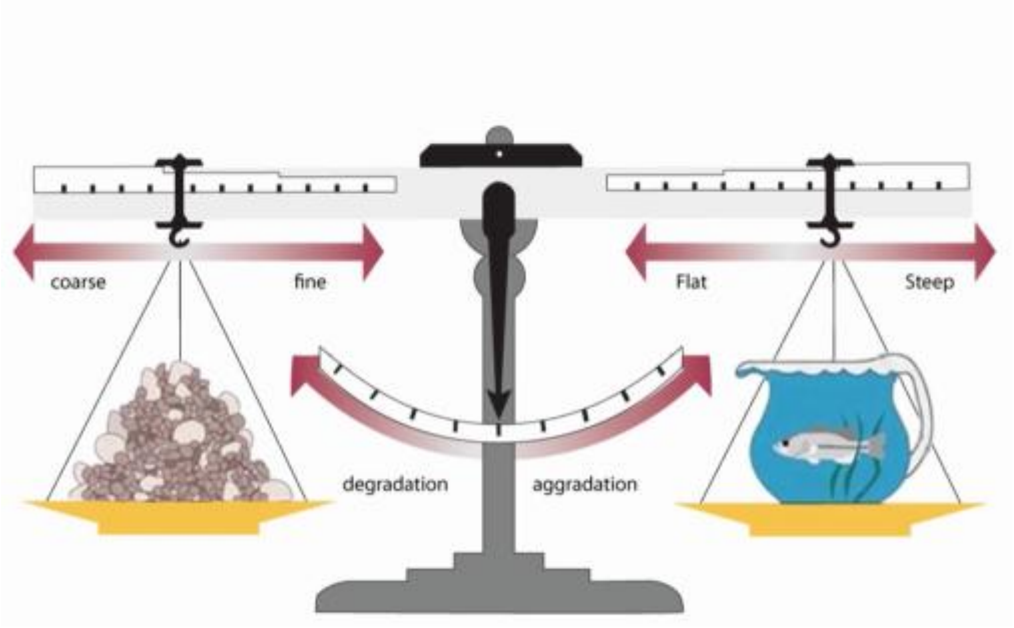

Figure 1.1: Lane (1955) demonstrated that a change in discharge, sediment load, median particle size, and/or slope will lead to stream instability (e.g. degradation or aggradation). Source: Lane (1955). With permission from ASCE.

Historically, engineers focused on straightening and widening streams in an effort to quickly transport water (e.g. alleviate flooding). Increased velocities and shear stresses associated with such efforts resulted in stream degradation whereby channels down cut and widened (Simon, 1994). To counteract streambank erosion, engineers hardened the banks with riprap and concrete. Increased focus on the other functions of streams besides just water transport such as habitat provision has called into question how we as a society should manage our waterways. Rosgen (1994; 1996) brought such concepts mainstream with his work on natural channel design (NCD) whereby designers work with the natural tendencies of streams to create stable and functional systems instead of against them as is the case with channelization and hardening. One of the first steps in the NCD process is correctly identifying bankfull elevation (Hey, 2006). Bankfull is defined as the point or elevation in a stream that divides instream and floodplain processes (e.g. the stream channel stops and the floodplain begins) (USEPA, 2012). Because one can identify bankfull in the field using physical indicators, it is a surrogate for channel forming discharge which is a theoretical discharge that if indefinitely maintained would produce the same channel geometry as the natural long-term hydrograph (Copeland et al., 2000). Bankfull flows typically occur once every 1-2 years (Brockman et al., 2012; Harman et al., 2012).

In degraded streams, which are the target of restoration efforts, identification of bankfull elevation is often difficult because of scarce or even non-existent bankfull indicators. Dunne and Leopold (1978) noted several bankfull identifiers one could use including:

1. Topographic breaks from vertical bank to flat floodplain (e.g. flat depositional areas immediately adjacent to the channel)

2. Topographic break from steep slope to gentle slope
3. Changes in vegetation types (e.g. bare soil to grass, moss to grass, grass to sage, grass to trees, no trees to trees)
4. Textural change of depositional sediment
5. Elevation below which no fine debris occurs
6. Textural change of matrix material between cobble and rocks

While vegetation is a good bankfull indicator in the western part of the U.S., in eastern U.S. vegetation can grow below bankfull elevation and therefore should not be used as an indicator of bankfull.

As the NCD process is dependent on the correct identification of bankfull elevation, an incorrect identification of bankfull elevation will lead to incorrect channel dimensions, patterns and profiles which will in turn affect the dynamic equilibrium of the design channel. One way to minimize errors in identifying bankfull elevation in degraded streams is through the use of regional curves. Regional curves relate the bankfull parameters (width, mean depth, and cross-sectional area) to drainage area. These curves help designers identify bankfull elevation in the field when bankfull indicators are absent or infrequent (Castro and Jackson, 2001; Metcalf et al., 2009; Brockman et al., 2012). Such curves are also used in stream assessment and design (Hey, 2006; USDA-NRCS, 2007). In addition to regional curve, designers can employ hydraulic geometry curves, which are similar to regional curves in that they relate bankfull parameters (cross-sectional area, width, and mean depth) to bankfull discharge instead of drainage area. Because long-term hydrologic data are required, development of hydraulic geometry curves is less frequent as many sites are ungaged. As the name implies, regional curves are developed for streams within the same physiographic region (e.g. similar topography, geology, and climate). To develop a regional curve, one must assess (e.g. survey and compute bankfull dimensions) several stable (e.g. geomorphic reference) streams within the same physiographic region; these streams must encompass a wide range of drainage areas. Preference is given to U.S. Geological Survey (USGS) gaged sites due to their longer term discharge records.

Even though the field of stream restoration has and is expected to continue growing, publically available regional curves are often lacking in many regions of the U.S. This lack of regional curves increases one's chances of incorrectly identifying bankfull elevation. Furthermore, the high levels of anthropogenic impacts to some physiographic regions makes identification of reference streams, from which to develop regional curves, challenging. For example, interest has increased for developing regional curves for the Eastern Kentucky Coalfields (EKC) where past and current mining activities (e.g. data needs of U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, Kentucky Division of Water) and the expansion of the Mountain Parkway (e.g. data needs of Kentucky Transportation Cabinet) has impacted the area's streams and rivers. The EKC are part of the larger Cumberland Plateau region that extends from Pennsylvania down to Alabama. The region contains Kentucky's highest peak, Black Mountain, which is located in Harlan County; the peak reaches 4,145 feet (KGS, 2012). The eastern EKC covers 37 Kentucky counties and over 11,650 square miles. The shale and sandstone in the region dates back to the Pennsylvania Era around 300 million years (Vesley et al., 2008).

Brockman et al. (2012) created regional curves and hydraulic geometry curves for the Inner and Outer Bluegrass regions of Kentucky. While these regions are adjacent to the EKC, they encompass a different geology and topography. Previous work by Vesley (2008) created regional curves (cross-sectional area, width, depth, and discharge) for the rural EKC physiographic region. Parola (2005) work also created regional curves for the EKC. These studies focused on streams located in the physiographic region of the EKC; however, the EKC is subdivided into many hydraulic landscape regions (HLR). While physiographic regions are defined by lands with similar geography, topography, and climate, HLRs are more homogenous units based on water movement as dictated by climate (atmospheric water), landform (surface water) and geology (groundwater) (Winter, 2001). Using HLRs instead of solely physiographic regions may result in improved regional curves (e.g. higher R^2). By using HLR as a basis for identifying appropriate reference streams, stream restoration designers could increase their ability to identify reference streams by examining geographically distant areas, ones which may have experienced lesser levels of anthropogenic disturbances.

1.2 OBJECTIVES

The goal of the thesis was to develop tools to aid in the stream restoration design process for projects located in eastern Kentucky. The objectives are:

- Determine bankfull recurrence intervals and develop regional and hydraulic geometry curves for the Eastern Kentucky Coalfields (EKC)
- Develop and compare regional and hydraulic geometry curves for HLRs 9, 11, and 16 in the EKC
- Compare these curves to theoretical values and results from other such curves developed in the U.S.

1.3 ORGANIZATION OF THESIS

Chapter One of contains the introduction and outlines the objectives of the research. Chapter Two contains a literature review of topics including stream geomorphology, regional curves, hydraulic geometry curves, and hydrologic landscape regions. Chapter Three contains all the methods used to conduct the research. Chapter Four presents and discusses the results. Chapter Five discusses the conclusions of the research, and Chapter 6 presents ideas for future work. Appendix A contains the cross section data for all streams surveyed in this study, and Appendix B contains all the bed material data for each stream surveyed in this study.

CHAPTER 2: LITERATURE REVIEW

2.1 HEADWATER STREAMS

Stream morphology is influenced by a number of factors such as topography, geology, land use, and climate (Leopold and Maddock, 1953; Winter, 2001; Wolock et al., 2004). Other factors such as the type and amount of riparian or streamside vegetation also influence stream morphology (Rosgen, 2001; Hession et al., 2003; Cianfrani et al., 2006). Natural resource extraction/consumption and population growth (e.g. urbanization) negatively impact streams by altering topography, increasing discharge volumes and peaks, and reducing water and habitat quality (Schueler, 1995; Gomi et al., 2002; Villarini et al., 2009; USEPA, 2011). In the EKC, industrialization is limited (Roenker, 2001; Lowrey, 2014) but current and past mining and logging activities along with the expansion of the Mountain Parkway and other such roadways have impacted the region's streams and rivers. Surface coal mining, for which the EKC is known, negatively impacts the health of streams through physical alterations (e.g. stream burial such as with valley fills) as well as water quality impairments (Garcia-Criado et al. 1999, Kennedy et al, 2003, Freund and Petty, 2007, Pond et al., 2008).

Anthropogenic activities in the EKC are particularly impacting to headwater streams, which are often classified as having a Strahler stream order of 3 or less (Vannote et al., 1980; Villines et al., 2015). The USEPA (2011) estimates that between 1992 and 2002, over 1,200 miles of headwater streams were lost due to mining activities in the Appalachian Coalfields of KY, TN, WV and VA. The miles of lost stream are significantly higher when considering the impacts of transportation activities. For instance, in Kentucky, the Kentucky Transportation Cabinet is the largest payee into the Fee In Lieu Of stream mitigation program (KDFWR, 2010). While headwater streams are small in size, they are quite numerous. Lowe and Likens (2005) estimated that headwater streams account for over 70% of the stream length in the U.S., a value that may be higher in the EKC due to the "mature" classification of the area (Davis, 1899; Shreve, 1969). While these small streams are often overlooked or underestimated in databases such as the National Hydrography Dataset (NHD) (Hansen, 2001; Childers et al., 2006; Fritz et al., 2013; Villines et al., 2015), their physical and biological connection to downstream waterbodies is significant (Alexander et al., 2007).

Several studies found that the majority of streams impacted by anthropogenic activities, such as mining, are intermittent or ephemeral; however, these stream types are impacted much less often than higher order ones (Shreve, 1969; Villines, 2013; Palmer and Hondula, 2014; Blackburn-Lynch 2015). How to restore headwater streams in the EKC affected by anthropogenic activities is an ongoing question. One option is to use natural channel design (NCD) techniques.

2.2 NATURAL CHANNEL DESIGN (NCD)

Natural channel design is the most widely used method of restoring streams in the U.S. (Doll et al., 2004). The NCD process seeks to create self-sustaining streams, ones that support diverse and large biologic communities (Doll et al., 2004); working with nature instead of against. In the past, engineers focused on widening and straightening channels to alleviate flooding and used riprap or concrete to stabilize eroding banks. David Rosgen's approach to NCD focuses on using geomorphic principles to changing the dimension, pattern, and profile of the stream (Rosgen, 1994; Rosgen, 1996; Hey, 2006). This NCD methodology is used by many federal, state, and local agencies such as the U.S. Army Corps of Engineers, U.S. Department of Agriculture Natural Resources Conservation Service, U.S. Environmental Protection Agency, and Kentucky Division of Water (Lave, 2009). The NCD process incorporates a fluvial geomorphological approach to stream restoration that was not used in past stream engineering designs (Hey, 2006). This methodology consists of eight main phases (NRCS, 2007; Doll et al., 2004), which are summarized below.

1. Develop clear goals and objectives (e.g. improve streambank stability, improve water quality, reduce flooding, and improve habitat)
2. Identify one or more reference reaches to aid in the determination of stable geomorphic and hydrologic conditions. Ideally, the reference reach will be located in the immediate vicinity of the stream of interest, is physically stable, and has good habitat. During this phase, a morphological characterization of the reference reach and the impaired stream should be conducted. Note if there are any active USGS gages in the watershed.
3. Conduct an analysis of the impacted stream's watershed. Knowing the cause of instability can help in the process of restoring the stream. Use Google Earth or similar platforms to identify land use changes influencing stream stability.
4. Determine whether or not passive (e.g. can the stream recover or its own if the stressor(s) is (are) removed) or active restoration methods are required.
5. Develop design alternatives and conduct hydraulic and sediment transport analyses on each alternative; choose an optimal design.
6. Design instream structures, riparian vegetation, erosion control, and other such stabilization and habitat enhancement measures.
7. Implement the optimal design developed in Steps 5 and 6.

8. Monitor the implemented design to determine its effectiveness in meeting the project goals and objectives.

Correctly identifying bankfull stage is one of the most important steps in the NCD methodology (Hey, 2006; Harman, 2011), a task that is made all the more challenging because many impacted streams, those which are the targets of restoration efforts, often have few if any bankfull indicators (Doll et al. 2004); thus, determining bankfull stage on such streams if often a difficult task. Misidentification of bankfull can result in incorrect channel dimensions, pattern and profile which will in turn affect the dynamic equilibrium of the design channel. One way to minimize errors in identifying bankfull elevation in degraded streams is through the use of regional curves. These curves help designers identify bankfull elevation in the field when bankfull indicators are absent or infrequent (Castro and Jackson, 2001; Metcalf et al., 2009; Brockman et al., 2012). Regional curves as well as hydraulic geometry curves are also useful design tools. As NCD is an iterative process, these curves assist designers in identifying an appropriate starting points for their designs.

2.3 REGIONAL CURVES

Leopold and Maddock (1953) demonstrated the strong relationship between drainage area and channel geomorphology. Regional curves relate drainage area to the bankfull parameters discharge (Q_{bkf}), cross-sectional area (A_{bkf}), width (w_{bkf}), and mean depth (d_{bkf}) as seen in equations 2.1-2.4.

$$Q_{bkf} = aDA^{b} \qquad \text{(eqn. 2.1)}$$

$$A_{bkf} = cDA^{d} \qquad \text{(eqn. 2.2)}$$

$$w_{bkf} = gDA^{h} \quad \text{(eqn. 2.3)}$$

$$d_{bkf} = jDA^{k} \quad \text{(eqn. 2.4)}$$

The variable DA is the drainage area; a, c, g and j are the coefficients (intercepts); and b, d, h and k are the exponents (slopes). Regional curves are powerful tools, because once developed, knowledge of drainage area is all that is needed to estimate bankfull parameters. Programs such as ArcGIS and the USGS's StreamStats allow users to delineate drainage areas for any stream of interest. Regional curves tend to display strongest fits (R^2) for Q_{bkf} and A_{bkf} followed by w_{bkf} and then d_{bkf}.

Regional curves have been developed for numerous regions throughout the U.S. (Blackburn-Lynch, 2015) including the Appalachian Plateaus physiographic region, which is the focus of this study, McCandless (2003), Miller and Davis (2003), Messinger (2009), Westergard et al. (2004). The Appalachian Plateaus physiographic region is vast, stretching from Alabama to New York. In addition to Alabama and New York, the Appalachian Plateaus physiographic region also encompasses parts of Georgia, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia. The Appalachian region is characterized as having high plateaus and deep highly sloped valleys that tend to follow a branched dendritic pattern (Schmidt, 1993).

Prior research by Johnson and Fecko (2008) indicates that regional curves, at least for w_{bkf}, from different physiographic regions largely with in the Appalachian are largely similar. The authors examined curves within the Appalachian Plateaus, Appalachian Valley and Ridge, and New England physiographic provinces and found that one regional curve could describe w_{bkf} for the entire region (i.e. no statistical difference between almost all examined curves). As Q_{bkf}, A_{bkf} and d_{bkf} were not examined in this study, the same conclusion may not hold true.

Table 2.1 contains regional curves developed in the Appalachian Plateau physiographic region. Typical values for b, d, f and h are 0.8-0.9, 0.7-0.8, 0.4-0.5, and 0.3-0.4, respectively (Dunne and Leopold, 1978; Brockman, 2010). The regional curves developed by Babbit (2005) are notably different from the others included in Table 2.1 and may be related to the geology, topography or climate of the area the author studied (southwestern Appalachians in Tennessee). Such differences bring to question whether or not regional curves should be based on hydrologic landscape regions (HLRs) (Wolock et al., 2004), which may produce significant differences in regional curves, rather than just physiographic province.

Table 2.1: Regional curves created across the Appalachian Plateaus physiographic region.

Study	**Location**	$\mathbf{Q_{bkf}}$[1]			$\mathbf{A_{bkf}}$[1]			$\mathbf{w_{bkf}}$[1]			$\mathbf{d_{bkf}}$[1]		
		a	b	R^2	C	d	R^2	e	f	R^2	g	h	R^2
Vesley et al. (2008)	KY	32.7	0.85	0.92	9.5	0.82	0.96	10.9	0.45	0.93	0.88	0.36	0.88
Parola et al. (2005)	KY	60.3	0.61	0.96	19.1	0.57	0.97	20.1	0.3	0.93	0.95	0.28	0.8
Babbit (2005)	TN	150.1	0.75	0.99	32.5	0.70	1.00	18.5	0.44	0.97	1.76	0.26	0.97
Westergard et al. (2004)	NY	45.3	0.86	0.96	10.8	0.82	0.98	13.5	0.45	0.92	0.80	0.37	0.91
McCandless (2003)	MD	34.0	0.94	0.99	10.3	0.75		13.9	0.44		0.95	0.31	
Chaplin (2005)	PA/MD	43.2	0.87	0.92	12.0	0.80	0.92	14.7	0.45	0.81	0.88	0.33	0.72
Messinger (2009)	WV	59.8	0.85	0.96	20.5	0.71	0.98	21.0	0.37	0.95	1.07	0.31	0.88

[1] Q_{bkf} = bankfull dischare (units of ft^2s^{-1})
A_{bkf} = bankfull area (units of ft^2)
w_{bkf} = bankfull width (units of ft)
d_{bkf} = bankfull depth (units of ft)

2.4 HYDRAULIC GEOMETRY CURVES

Hydraulic geometry curves are similar to regional curves except the independent variable is Q_{bkf} instead of drainage area (Leopold and Maddock, 1953) as denoted in equations 2.5-2.7.

$$w_{bkf} = aQ_{bkf}^{b} \qquad \text{(eqn. 2.5)}$$

$$d_{bkf} = cQ_{bkf}^{f} \qquad \text{(eqn. 2.6)}$$

$${}_{vbkf} = kQ_{bkf}^{m} \qquad \text{(eqn. 2.7)}$$

The variable v_{bkf} represents bankfull velocity; the coefficients or intercepts are a, c and k; and the exponents or slopes are b, f and m. The product of the coefficients (a x c x k) equals one, and the sum of the exponents (b + f + m) equals one per the continuity equation (Q=w x d x v) (Leopold et al., 1964). Typical values for b, f and m are 0.53, 0.37 and 0.10, respectively (Langbein, 1947; Leopold et al., 1964).

Since bankfull is identifiable using field indicators, Q_{bkf} serves a surrogate for the channel forming discharge which is a theoretical discharge that if indefinitely maintained would produce the same channel geometry as the natural long-term hydrograph (Copeland et al., 2000). Because Q_{bkf} is required to develop hydraulic geometry curves, and determining Q_{bkf} requires at least 10 years of annual peak flow data, these curves are less frequently developed (USGS, 1982). Although the USGS maintains 9,930 active stream gages across the U.S., many of these gages are located on larger streams and rivers (USGS, 2014) whereas stream restoration projects often occur on smaller streams (Bernhardt et al., 2005).

Identifying active USGS gages on within a relevant range (e.g. drainage areas less than 250 mi^2) is challenging.

2.5 HYDROLOGIC LANDSCAPE REGIONS (HLR)

Hydrologic landscape regions (HLR) are areas separated by similar hydrologic characteristics: land-surface form, geology and climate (Wolock et al., 2004). As defined by Winter (2001), a HLR is described by (1) its land surface form of an upland adjacent to a lowland separated by an intervening steeper slope, (2) its geologic framework, and (3) its climatic setting. Wolock et al. (2004) used geographic information system (GIS) tools with principle components and cluster analyses to separate the U.S. into distinct HLRs based on the afore mentioned hydrologic characteristics. The authors examined 43,931 small (approximately 200 km^2) watersheds which they grouped into 20 HLRs. HLRs with closer numbers are more similar (e.g. HLR 1 is similar to HLR 2 but dissimilar to HLR 20). When creating individual HLRs, the characteristics for land-surface form included relief, total percentage of flat land (<1% slope), percentage flat land in upland area, percentage flat land in lowland areas. The geologic characteristics for each HLR were soil permeability and bedrock permeability. Characteristics for climate included mean annual precipitation minus the mean monthly evapotranspiration. Figure 2.1 shows all of the characteristics that go into play for HLRs.

Wolock et al. (2004) found that the HLRs tended to explain a greater percentage of the variation in land-surface form, geology and climate amongst watershed than ecoregions (the U.S. has nine distinct major ecoregions): 73-83% vs. 33-79%, respectively. Faustini et al. (2009) developed hydraulic geometry curves based on HLRs and found that using HLRs as a grouping mechanism rather than ecoregion "significantly improved equation fit and predictive value." Blackburn-Lynch (2015) created U.S. wide regional curves for each HLR using data from 2,228 sites. Blackburn-Lynch (2015) found that in many cases the regional curves for individual HLRs created a better fit (e.g. higher R^2 value) than previously developed regional curves based on physiographic regions. Of the curves created for A_{bkf}, 75% showed a good fit (e.g. $R^2 \geq 0.6$); for w_{bkf} 65% showed a good fit. Developing regional and hydraulic geometry curves based on HLR and not just physiographic region could result in better fits and could support the use of data from stream sites at locations spatially distant to a project site but within the same HLRs.

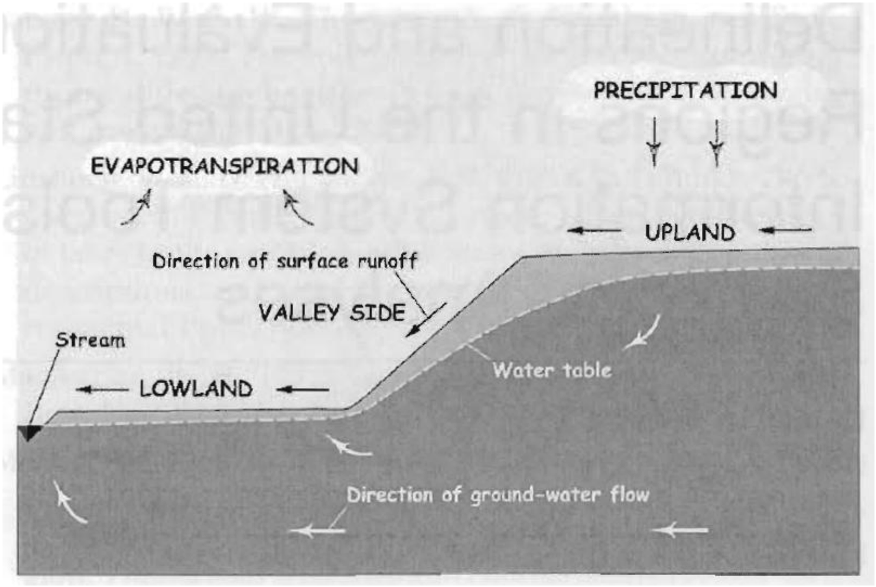

Figure 2.1. Wolock et al. (2004) graphic showing all the hydrologic characteristics that went into the separation of HLRs

CHAPTER 3: METHODS AND MATERIALS

3.1 STUDY AREA

The study area is located in the EKC physiographic region which encompasses the entire eastern portion of Kentucky (includes 37 counties and over 11,650 square miles) (Figure 3.1). The counties within the EKC are: Bell, Boyd, Breathitt, Carter, Clay, Clinton, Elliot, Estill, Floyd, Greenup, Harlan, Jackson, Johnson, Knott, Knox, Lawrence, Lee, Leslie, Letcher, Lewis, Madison, Magoffin, Martin, McCreary, Menifee, Montgomery, Morgan, Owsley, Perry, Pike, Powell, Pulaski, Rockcastle, Rowan, Wayne, Whitley, and Wolfe. The EKC contain more than 80 named coal beds such as the Elkhorn, Hazard, Fire Clay, Path Fork and Pond Creek; coal mining and natural gas extraction are common (Hower et al. 1994). The shale and sandstone in the region date back to the Pennsylvania Era around 300 million years ago (KGS, 2012). The EKC region is characterized by mixed mesophytic forests and supports highly diverse ecosystems (Moore and Wondzell, 2005). The terrain is mountainous with elevations ranging from 500 to over 4,000 ft. The highest peak in the EKC, Black Mountain, is at an elevation of 4,145 ft (KGS, 2012). Agricultural production (non-silviculture) consists predominately of cattle production and is limited with respect to crops with U.S. Department of Agriculture (USDA) county estimates for Kentucky's Eastern/Mountain Region highest for tobacco, hay and pasture (USDA-NASS, 2016). Because of the remoteness of the EKC (no Interstates, rugged terrain), levels of industrialization are low (Roenker, 2001; Lowrey, 2014). The EKC experiences a temperate-humid-continental climate with mild springs and falls. The average annual rainfall is around 47 inches with a high and low temperatures for the summer months ranging between 30 and

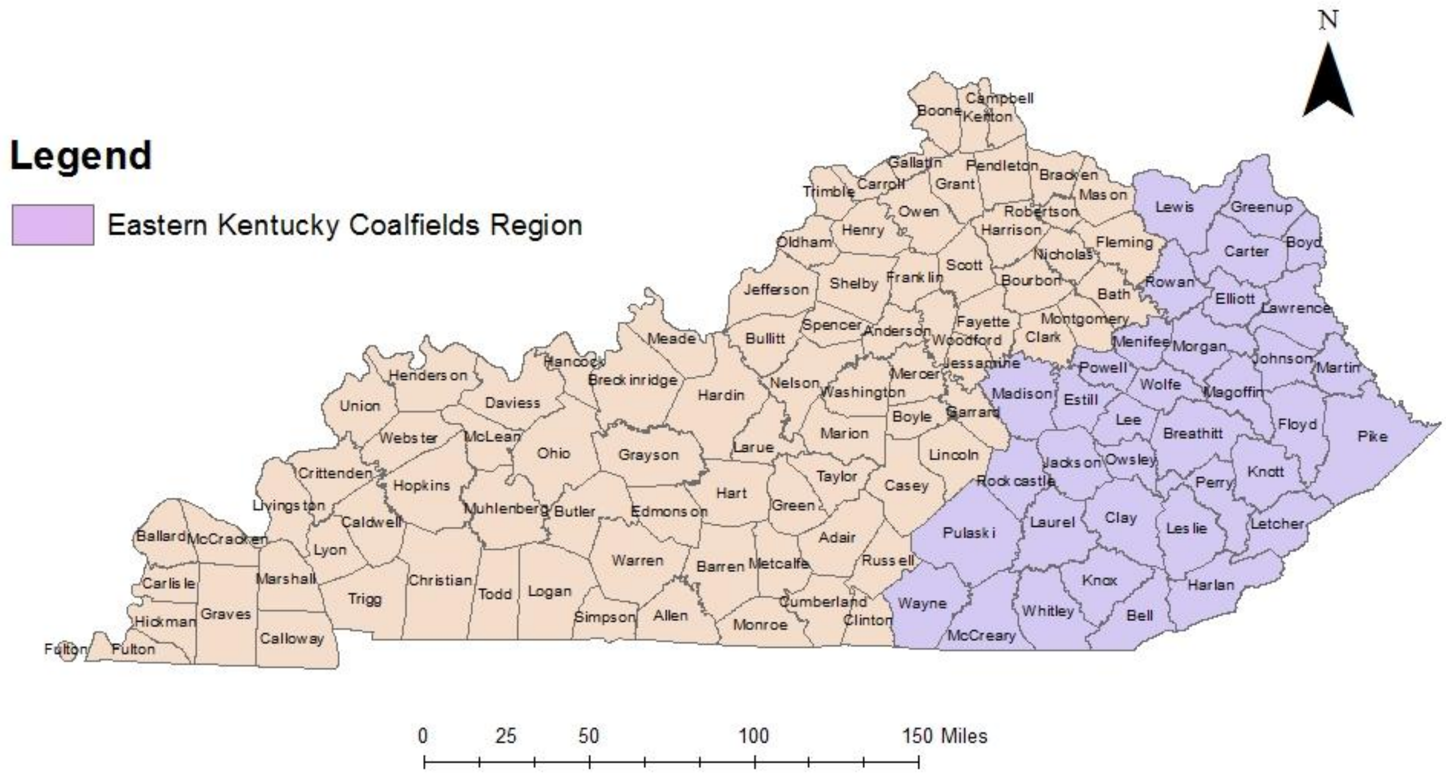

Figure 3.1: The Eastern Kentucky Coalfield (EKC) region encompasses 37 counties within Kentucky.

18°C, respectively; for the winter months, temperatures range between 6°C for a high and -5°C for a low (USDC, 2002).

The EKC contains five HLRs though only three were examined in this study: HLRs 9, 11 and 16 (Figure 3.2). The HLRs 4 and 6 were too small in size. HLR 9 is characterized as having "humid plateaus with impermeable soils and permeable bedrock" (Wolock et al., 2004); it is predominately located in the western portion of the EKC. HLR 9 has overland flow and deep ground water as well as moderate regions of karst landscape. About 10% of the EKC is classified as HLR 9. HLR 11 is characterized as having "humid plateaus with impermeable soils and bedrock" (Wolock et al., 2004). Covering 40% of the EKC, HLR 11 is similar to 9 except the bedrock of HLR 11 is impermeable while it is permeable with HLR 9. Overland flow is predominating in HLR 11. As seen in Figure 3.2, HLR 11 is located primarily in between HLRs 9 and 16. HLR 16 is defined as "humid mountains with permeable soils and impermeable bedrock" (Wolock et al., 2004). The terrain of HLR 16 is steeper than that of HLRs 9 and 11; like HLR 11, the bedrock is impermeable but unlike either HLR 9 or 11, the soils are deemed permeable though shallow. Because of the permeable soils, HLR 16 has shallow groundwater flow. HLR 16 covers the biggest portion of EKC at 47%.

3.2 SITE SELECTION

When identifying stream sites for inclusion in this study, preference was given to USGS gaged sites due to the need for discharge data (≥ 10 years of annual peaks) for developing hydraulic geometry curves. The USGS monitors hydrologic parameters such as water level and discharge at over 9,000 active sites throughout the U.S.; sometimes precipitation and/or water quality data are also collected (USGS, 2016). The USGS currently

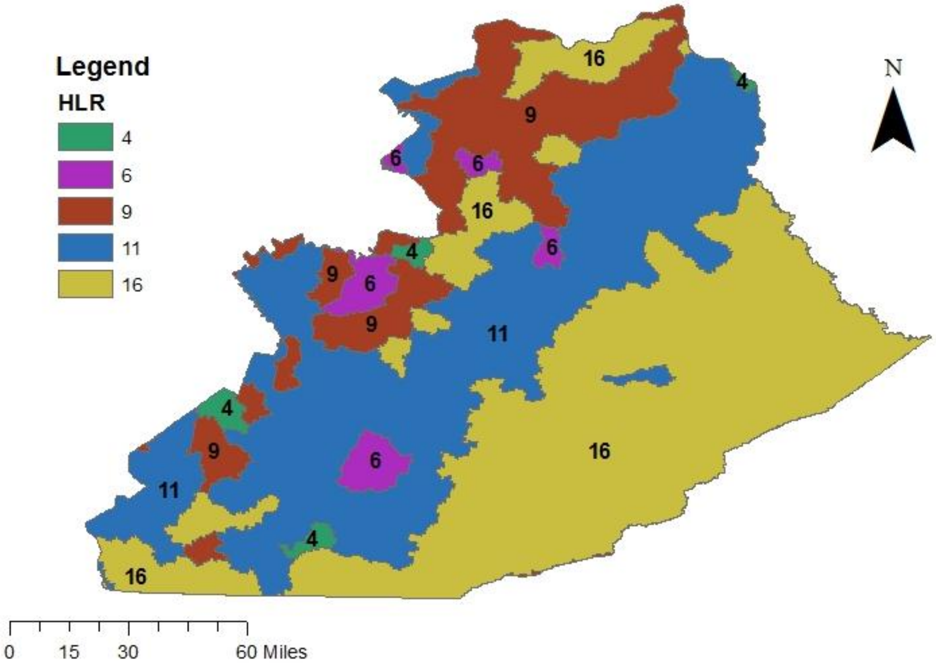

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Figure 3.2: The EKC region contains five hydrologic landscape regions (HLRs); three (HLRs 9, 11, and 16) were examined in this study.

maintains 196 gage stations in Kentucky; 34 are currently active in the EKC region. In the office, Google Earth was used to evaluate these currently active stream sites based on five criteria: (1) drainage area, (2) the number of years of discharge data available, (3) presence/absence of upstream or downstream tributaries, (4) land use change within the watershed, and (5) site accessibility. Streams which were likely unwadeable (e.g. >150 mi^2 or 389 km^2) were largely not considered (Brockman et al., 2012). Sites with less than 10 years of discharge data (e.g. new USGS gage sites) were eliminated as were sites with tributaries immediately upstream or downstream of the gage site. Historic aerial images, which are available on Google Earth were used to assess the level of land use change within the watersheds of the sites. Recent land use changes, such as urbanization, lead to increases in runoff volumes and peaks which often results in stream degradation (Hollis and Luckett, 1976; Schueler, 1995; Hession et al., 2003; Brath et al., 2006; Villarini et al., 2009). Sites were eliminated if notable amounts of land use changes (≥15% by visual inspection) were found within the respective watersheds due to concerns related to stream instability (Schueler, 1995).

The remaining 11 sites in the EKC were visited to evaluate their accessibility, vertical and lateral stability, presence of readily identifiable bankfull indicators, and absence of instream structures (Brockman et al., 2012). Preference was given to readily accessible sites such as those located on public property (e.g. Daniel Boone National Forest and public parks) or adjacent to roads. For sites located on private property, permission was obtained from the landowner. Vertical and lateral stability was assessed by evaluating the bank height ratio (BHR) and riparian vegetation type and density. Sites with BHRs ≤1.3 were not considered (Brockman et al., 2012), and sites with bare, non-vegetated vertical or

Figure 3.3: Example of potential stream site with significant stream bank erosion.

overhanging stream banks were not used (Figure 3.3). As regional and hydraulic geometry curves are based on bankfull dimensions (e.g. cross-sectional area, width, mean depth, and discharge), sites were carefully evaluated for the presence of bankfull indicators such as flat depositional areas immediately adjacent to the channel, breaks in slope, and point bars (Dunne and Leopold, 1978). Sites with instream structures such as weirs or log jams were not considered as these structures can alter channel flow and subsequently channel morphology. Following field visits, a total of six sites met the site selection criteria and were included in the study: 3 in HLR 9, 2 in HLR 11, and 1 in HLR 16 (Table 3.1).

Because the number of active USGS gage station in the EKC is limited, particularly when these active gage sites were further subdivided into the HLRs 9, 11 and 16, inactive USGS gage sites and ungaged sites were also used (Table 3.1). Inactive USGS gage sites were considered if they were maintained until 1985 or later. Google Earth was used to determine if notable land use changes occurred within the watershed since the gage was inactivated until present to minimize potential changes in stream morphology and stability. Unfortunately, none of the inactive USGS gage sites used in this study had an intact staff gage thus prohibiting the determination of bankfull discharge through the use of the respective site's latest USGS stage-discharge rating curve. Published geomorphic and discharge data from Parola et al. (2005) and Vesley et al. (2008) as well as unpublished data from Agouridis (2012) were also used because the number of suitable USGS gage sites (active and inactive) within the EKC region was limited (Table 3.1). Figure 3.4 shows the stream sites used in this study.

3.3 DATA COLLECTION

3.3.1 Equipment

Cross-sectional and longitudinal surveys were conducted using a CST/berger 24X SAL automatic level along with standard equipment such as a tripod, rod, tapes and pins (Harrelson et al., 1994). For bed material analysis (e.g. modified Wolman pebble count), a metric ruler was used (Wolman, 1954; Rosgen, 1996).

Table 3.1: Summary of stream sites used in the development of regional and hydraulic geometry curves for the EKC.

Site ID	USGS Gage	Stream Name	Drainage Area (mi^2)	HLR[1]	Latitude	Longitude
1		Cat Creek 1[2]	1.31	9	37.825	-83.813
2		Rose Creek	1.85	9	38.353	-83.251
3	03250150[3]	Indian Creek near Owingsville	2.43	9	38.157	-83.688
4	03250322	Rock Lick Creek	4.2	9	36.600	-84.745
5		Storey Branch	8.03	9	38.231	-83.634
6	03237900[3]	Cabin Creek near Tollesboro	22.4	9	38.568	-83.537
7	03250000[3]	Triplett Creek at Morehead	45.9	9	38.193	-83.416
8	03216800	Tygarts Creek at Olive Hill[2]	59.6	9	38.299	-83.174
9	03250100	North Fork Triplett near Morehead	84.7	9	38.199	-83.481
10	03217000	Tygarts Creek near Greenup[2]	242	9	38.564	-82.952
11		Stave Branch[2]	0.49	11	37.835	-82.837

Table 3.1: cont'd.

Site ID	USGS Gage	Stream Name	Drainage Area (mi^2)	HLR[1]	Latitude	Longitude
12		UT KY-191 Mile 5	0.76	11	37.734	-83.457
13		Eagle Creek[4]	3.5	11	36.870	-84.369
14		S. Fork Dog Slaughter[4]	3.5	11	36.859	-84.299
15		Dog Slaughter [4]	6.0	11	36.860	-84.301
16		Cane Creek[4]	7.5	11	37.056	-84.241
17	03216370[3]	Big Sinking River	23.4	11	37.639	-83.785
18	03283000	Stillwater Creek at Stillwater[2]	24.0	11	37.757	-83.487
19	03404900	Lynn Camp at Corbin	53.8	11	36.951	-84.094
20		Horse Lick Creek[4]	55.8	11	37.336	-84.137
21	03282500	Red River near Hazel Green[2]	65.8	11	37.812	-83.464
22	03282040	Sturgeon Creek	77.3	11	37.501	-83.810

Table 3.1: cont'd.

Site ID	USGS Gage	Stream Name	Drainage Area (mi^2)	HLR[1]	Latitude	Longitude
23	03281100	Goose Creek at Manchester	163.0	11	37.152	-83.760
24		Buck Creek[4]	175.6	11	37.187	-84.456
25		Davis Upper[5]	0.27	16	36.635	-83.684
26		Line Fork Tributary[2]	0.31	16	37.078	-82.993
27		Glade Branch[2]	0.36	16	37.862	-82.891
28		Bear Hollow Tributary[2]	0.55	16	37.695	-82.798
29		Daniels Creek[2]	0.8	16	37.112	-83.301
30		Shillalah Creek[4]	1.9	16	36.649	-83.580
31	03278000	Bear Branch near Noble[2]	2.21	16	37.451	-83.195
32		Bad Branch[4]	2.6	16	37.068	-82.771
33		Road Fork[2]	2.82	16	37.599	-82.372

Table 3.1: cont'd.

Site ID	USGS Gage	Stream Name	Drainage Area (mi^2)	HLR[1]	Latitude	Longitude
34		Lick Fork[2]	6.78	16	37.779	-82.817
35		Beaver Creek	7.37	16	37.956	-83.619
36		Cat Creek 2[2]	7.81	16	37.776	-83.808
37	03283370[3]	Cat Creek	8.31	16	37.832	-83.811
38		Grapevine Creek[2]	13.85	16	37.353	-83.349
39	03280600	Middle Fork River	16.3	16	37.779	-83.676
40		Rock Creek (Upper)[4]	18.8	16	38.247	-83.589
41		Jenny's Creek[2]	35.6	16	37.813	-82.838
42	03277400[3]	Leatherwood at Daisy	40.9	16	37.113	-83.093
43	03280700	Cutshin Creek	61.3	16	37.165	-83.308
44	03212000[3]	Paint Creek at Staffordsville	103.0	16	37.835	-82.871

Table 3.1: cont'd.

Site ID	**USGS Gage**	**Stream Name**	**Drainage Area (mi^2)**	**HLR**[1]	**Latitude**	**Longitude**
45	03248500[3]	Licking River near Salyersville	107.0	16	37.731	-83.058
46	03281040	Red Bird River near Big Creek[2]	155.0	16	37.179	-83.593
47	03278500	Troublesome Creek at Noble[2]	177.0	16	37.443	-83.218

[1] Hydrologic landscape region
[2] Source: Vesley et al. (2008)
[3] In-active USGS gage
[4] Source: Parola et al. (2005)
[5] Source: Agouridis (2012)

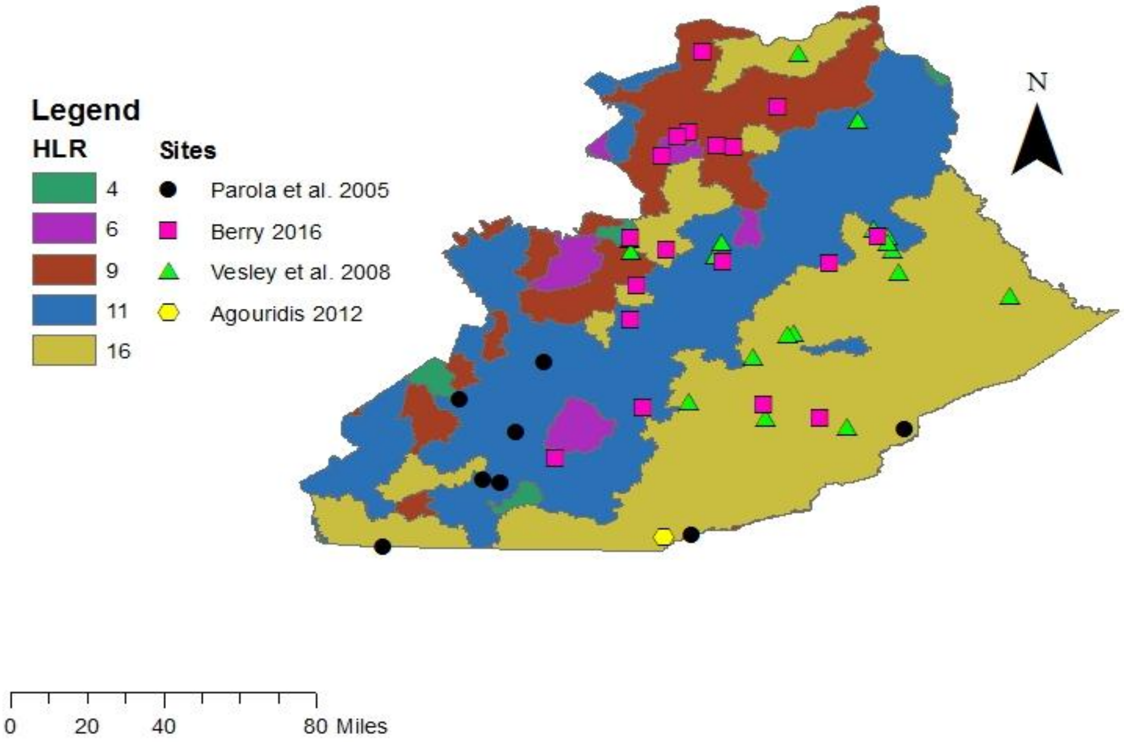

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Figure 3.4: A total of 19 stream sites were surveyed in this study: 7 active USGS gage sites, 8 inactive USGS gage sites, and 4 non-gaged sites. Additionally, data from stream sites from the following studies were used: 9 from Parola et al. (2005), 18 from Vesley et al., (2008), and 1 from Agouridis (2012).

3.3.2 Cross-sectional Surveys

At nearly all stream sites, a total of two riffle cross-sections were surveyed. Inability to survey two riffle cross-sections at select sites (3) was largely due to lack of suitable riffles or inability to access the second riffle. For each cross-sectional survey, data (station and relative elevation) were recorded for the following parameters: bankfull, thalweg, breaks in slopes, water surface, and flood prone extent (if accessible). For instances when the flood prone extent was not accessible, it was visually estimated. All cross-sectional data were analyzed using the RIVERMorph® software. The following bankfull parameters were computed: cross-sectional area (A_{bkf}), width (w_{bkf}), mean depth (d_{bkf}). Refer to Appendix A for cross-sectional survey data and graphs.

3.3.3 Channel Slope

Local channel slopes (S_{bkf}) (approximately 20-30 bankfull widths in length) were determined in accordance with the methods presented in Harrelson et al. (1994).

3.3.4 Bed Material

Modified Wolman pebble counts were conducted at each site. These pebble counts consisted of measuring the intermediate axis of a minimum of 100 sampled pebbles (Wolman, 1954; Rosgen, 1996). These reach-wide pebble counts were conducted by first assessing the percentage of pools and riffle features in the assessed stream reach. Bed material was randomly sampled in these features based on their frequency of occurrence. For example, if 70% of the surveyed stream reach was comprised of riffles, then 70 samples were obtained from riffles while the other 30 samples were obtained in pools. Bed material samples were collected within the wetted perimeter. Bed material data were analyzed using the RIVERMorph® software to determine the median particle size (D_{50}). Refer to Appendix B for bed material data and graphs.

3.3.5 Sinuosity

Due to the difficulty of accurately measuring sinuosity (K) in the field, this parameter was computed for each surveyed stream using Google Earth. Sinuosity was computed by dividing the length of the stream by its respective valley length. The length of the stream used to find sinuosity was 1000 times the bankfull width.

3.3.6 Rosgen Stream Classification

Each stream reach was classified using the Rosgen system of stream classification (Rosgen, 1994; 1996). From the cross-sectional surveys, data regarding floodprone extent (w_{fpa}) and w_{bkf} were used to compute the entrenchment ratio at each site; w_{bkf} and d_{bkf} were used to compute width to depth (w_{bkf}/d_{bkf}) ratios. Longitudinal surveys were used to compute bankfull or water surface slopes (both should be parallel). Google Earth measurements were used to compute K values (channel length divided by valley length). Wolman pebble counts were used to determine the D_{50} of the bed material.

3.3.7 Bankfull Discharge

At stream sites with active USGS gages, bankfull discharge (Q_{bkf}) data were obtained by utilizing the site's stage-discharge relationship as described by Williams (1978). At the start of each cross-sectional survey at active USGS gage sites, the date and time were recorded as were the water surface and bankfull elevations. Using the date and time of the survey, the field surveyed water surface elevation was transformed in the USGS staff gage equivalent for the site (e.g. the field survey data were relevant elevations while the USGS records water level data to a set datum). The difference between the field surveyed water surface and bankfull elevations were computed to relate the relative bankfull elevation to the USGS gage datums. The USGS Rating Depot was used to access to most recent stage-discharge relationships for each actively gaged site. Bankfull discharges were computed using the respective stage-discharge relationships along with the respective USGS gaged site datum-corrected bankfull elevations. As none of the inactive USGG gage sites had intact staff gages present, Q_{bkf} values were not determined for these sites.

Bankfull recurrence intervals (T_{bkf}) were determined using the Log Pearson *Type III method as outlined in the USGS Bulletin* 17B Guidelines for Determining Flood Flow Frequency (1982). Peak flow data were downloaded from the USGS into the RIVERMorph® software for use in determining T_{bkf}. A generalized skew coefficient of 0.011 and a standard error of prediction of 0.520 were used (Hodgkins and Martin, 2003).

3.3.8 Manning's n

When possible, Manning's n values were back-calculated using Equation 3.1, bankfull discharge (Q_{bkf}), the surveyed bankfull dimensions of cross-sectional area (A_{bkf}) and hydraulic radius (R_{bkf}), and main channel slope (S). For data obtained from Parola et al. (2005) and Vesley et al. (2008), hydraulic radius was not provided thus mean bankfull depth (d_{bkf}) values were used instead. This assumption can be made

$$Q_{bkf} = \frac{1.49}{n} {R_{bkf}}^{2/3} S^{1/2} A_{bkf} \qquad \text{(Equation 3.1)}$$

3.3.9 Riparian Vegetation

The riparian vegetation at each stream site was classified as forest (F) or grass (G). A forest classification indicated that the majority of the riparian vegetation consisted of large trees (25-60 ft tall) (Figure 3.5). A grass classification indicated that the majority of the riparian vegetation consisted of grasses or other such short-rooted vegetation (e.g. weeds) (Figure 3.6).

3.3.10 U.S. HLR-based Regional and Hydraulic Geometry Curves

Blackburn-Lynch (2015) created U.S. wide regional curves for all 20 HLRs using data from 2,228 sites. Table 3.2 contains the data sources Blackburn-Lynch (2015) used to create each U.S. wide HLR-based regional curve. Since Blackburn-Lynch (2015) did not develop hydraulic geometry curves, they were created in this study. Table 3.3 contains the modified regional curves (HLR 9, 11 and 16 only) developed using data from Blackburn-Lynch (2015) (only data with DA $\leq$ 250 mi^2 were used) and the hydraulic geometry curves (HLRs 9, 11 and 16 only).

3.3.11 Statistical Analysis

Cross-sectional (e.g. entrenchment ratio, width-to-depth ratio) and bed material (e.g. D_{50}) data were analyzed using RIVERMorph® software. Local S_{bkf} values were computed using Microsoft Excel. Power functions were developed in Microsoft Excel for both regional and hydraulic geometry curves (Leopold et al., 1964). Regional and hydraulic geometry curves were created for all HLRs combined (e.g. HLRs 9, 11 and 16) as well as each individual HLR. For regional curves, the bankfull parameters A_{bkf}, w_{bkf}, d_{bkf}, and Q_{bkf} were the dependent variables while drainage area was the independent variable. For hydraulic

Figure 3.5: Example of a forested riparian stream site (USGS gage 03250000 Triplett Creek at Morehead, Kentucky) located in the EKC.

Figure 3.6: Example of a grassed riparian stream site UT off of KY-191 at Mile Marker 5, located in the EKC.

Table 3.2: All the studies included in the development of regional curves by Blackburn-Lynch (2015). and hydraulic geometry curves (this study) for HLRs 9, 11, and 16.

HLR	**Sample Size**	**Studies**
9	250	Brockman et al. (2012), Castro (2001), Chang et al. (2004), Chaplin (2005), Dutnell (2000), Harman et al. (2000), Keaton et al. (2005), Lawrence (2003), McCandless (2003), Messinger (2009), Mulvihill et al. (2006), Mulvihill et al. (2007), Parola et al. (2005), Robinson (2013), Sherwood and Huitger (2005), USEPA (2006), Vesely et al. (2008)
11	138	Brockman et al. (2012), Chang et al. (2004), Chaplin (2005), Cinotto (2003), Doll et al. (2002), Harman et al. (1999), Lotspeich (2009), McCandless and Everett (2002), Messinger (2009), Mulvihill et al. (2005), Parola et al. (2005), Robinson (2013), Sherwood and Huitger (2005), USEPA (2006), Vesely et al. (2008), White (2001)
16	287	Castro (2001), Chaplin (2005), Cinotto (2003), Dutnell (2000), Harman et al. (2000), Keaton et al. (2005), Lawrence (2003)2, McCandless (2003a), McCandless and Everett (2002), Messinger (2009), Mulvihill et al. (2005), Mulvihill et al. (2006), Mulvihill et al. (2007), Mulvilhill et al. (2009), Robinson (2013), Sherwood and Huitger (2005), USEPA (2006), Vesely et al. (2008), Westergard et al. (2004), White (2001)

Table 3.3: U.S. wide HLR-based regional and hydraulic geometry curves for HLRs 9, 11 and 16. Q_{bkf} is bankfull discharge ($ft^3 s^{-1}$), DA is drainage area (mi^2), A_{bkf} is bankfull cross-sectional area (ft^2), w_{bkf} is bankfull width (ft), d_{bkf} is bankfull mean depth (ft), and v_{bkf} is bankfull velocity ($ft\ s^{-1}$).

HLR	**Regional Curves**[1]	**Hydraulic Geometry Curves**[2]
9	$Q_{bkf}=46.91DA^{0.78}$ $A_{bkf}=14.39DA^{0.69}$ $w_{bkf}=11.27DA^{0.45}$ $d_{bkf}=1.26DA^{0.25}$	$A_{bkf}=0.73Q_{bkf}^{0.83}$ $w_{bkf}=2.12Q_{bkf}^{0.51}$ $d_{bkf}=0.35Q_{bkf}^{0.32}$ $v_{bkf}=1.36Q_{bkf}^{0.17}$
11	$Q_{bkf}=53.98DA^{0.76}$ $A_{bkf}=18.35DA^{0.68}$ $w_{bkf}=14.85DA^{0.38}$ $d_{bkf}=1.24DA^{0.30}$	$A_{bkf}=0.72Q_{bkf}^{0.85}$ $w_{bkf}=2.88Q_{bkf}^{0.46}$ $d_{bkf}=0.25Q_{bkf}^{0.39}$ $v_{bkf}=1.39Q_{bkf}^{0.15}$
16	$Q_{bkf}=51.08DA^{0.86}$ $A_{bkf}=17.89DA^{0.66}$ $w_{bkf}=13.15DA^{0.43}$ $d_{bkf}=1.35DA^{0.22}$	$A_{bkf}=0.65Q_{bkf}^{0.83}$ $w_{bkf}=2.59Q_{bkf}^{0.48}$ $d_{bkf}=0.25Q_{bkf}^{0.35}$ $v_{bkf}=1.55Q_{bkf}^{0.17}$

[1] Developed using data from Blackburn-Lynch (2015) and had a DA of ≤250 mi^2.
[2] Developed using data from Blackburn-Lynch (2015) and had a DA of ≤250 mi^2.

geometry curves, A_{bkf}, w_{bkf}, d_{bkf}, V_{bkf}, S_{bkf}, and n_{bkf} were the dependent variables while Q_{bkf} was the independent variable.

Analyses of covariance (ANCOVAs) were performed in the statistical software package SAS version 9.4 using PROC REG. Regional and hydraulic geometry curves for each bankfull parameter within each HLR were compared (e.g. A_{bkf} for HLR 9 vs. A_{bkf} for HLR 11, A_{bkf} for HLR 9 vs. A_{bkf} for HLR 16, A_{bkf} for HLR 11 vs. A_{bkf} for HLR 16). Comparisons were also made between individual HLRs to the combined regional curves (e.g. A_{bkf} for HLR 9 vs A_{bkf} for HLRs 9, 11 and 16 combined) to determine if subdivision of a physiographic region based on HLR significantly improved the resultant regional and hydraulic geometry curves. Additionally, the regional and hydraulic geometry curves for each HLR were compared to U.S.-wide HLR-based regional curves, for instances when drainage area was less than or equal to 250 mi^2, developed by Blackburn-Lynch (2015). The bankfull parameters S_{bkf} and n_{bkf} from the individual and combined HLRs were not compared to the U.S.-wide HLRs as Blackburn-Lynch (2015) did not provide information on S_{bkf} and n_{bkf}. The coefficient of determination (R^2) was used to classify each fit as strong ($R^2 \geq 0.9$), good ($R^2 \geq 0.75$), moderate ($R^2 \geq 0.5$), and poor ($R^2 < 0.5$).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 REGIONAL CURVES

Bankfull regional curves were created for each assessed stream in the entire EKC region, using stream morphology data from all 47 sites relating bankfull parameters (discharge, cross-sectional area, width, and mean depth) to drainage area. Regional curves were also created for each evaluated individual HLR region within the EKC region. Drainage areas ranged from 0.27 to 242 mi^2; Q_{bkf} ranged from 30.5 to 5,992 $ft^3\ s^{-1}$; A_{bkf} ranged from 3.8 to 1,095 ft^2; w_{bkf} ranged from 5.5 to 147.9 ft, and d_{bkf} from 0.62 to 9.11 ft (Table 4.1).

Each assessed stream was classified according to the Rosgen stream classification system (Rosgen, 1996). Entrenchment ratio (ER) is the first factor computed when using the Rosgen stream classification system. ER is the extent or width of the flood prone area divided by the bankfull width. The ER for the surveyed streams ranged from 1.1 to >2.2 for HLR 9; 1.1 to > 2.2 for HLR 11, and 1.2 to >2.2 for HLR 16 (Table 4.2). The width to depth ratio (w_{bkf}:d_{bkf}) relates bankfull width to mean bankfull depth and is an indication of how deep the channel is as compared to its width. The w_{bkf}:d_{bkf} for HLR 9 ranged from 9.4 to 54.7, 7.8 to 30.0 for HLR 11, and 7.1 to 37.4 for HLR 16. Information on sinuosity (K) was limited, particularly for stream assessed by Parola et al. (2005) and Vesley et al. (2008), but ranged from 1.1 to 1.7 in HLR 9, 1.3 to 2.0 in HLR 11, and 1.1 to 1.4 in HLR 16. Local bankfull slopes ranged from 0.001 to 0.014 ft ft^{-1} in HLR 9, 0.001 to 0.020 ft ft^{-1} in HLR 11, and 0.001 to 0.018 ft ft^{-1} in HLR 16. Bed material (median particle size, D_{50}) was largely gravel or cobble though a few streams were dominated by sand and a few were underlain by bedrock. Refer to Appendix B for bed material data.

Table 4.1: Bankfull summary data for the EKC region.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	Q_{bkf} (ft^3 s^{-1})	A_{bkf} (ft^2)	w_{bkf} (ft)	d_{bkf} (ft)	n_{bkf}	Return Interval (years)
1	Cat Creek[2]	9	1.31	--	12	15	0.8	--	--
2	Rose Creek	9	1.85	--	21.2	21.5	1.0	--	--
3	Indian Creek near Owingsville (03250150[3])	9	2.43	--	23.0	16.9	1.4	--	--
4	Rock Lick Creek (03250322)	9	4.2	67	47.7	21.3	2.3	0.058	1.07
5	Storey Branch	9	8.03	--	23.4	27.9	0.8	--	--
6	Cabin Creek near Tollesboro	9	22.4	--	156.0	49.1	3.2	--	--
7	Triplett Creek at Morehead (03250000[3])	9	45.9	--	248.3	81.4	3.1	--	--
8	Tygarts Creek at Olive Hill[2] (03216800)	9	59.6	818	255.3	82.7	3.1	0.033	1.01

Table 4.1 cont'd.

Site ID	**Stream Site (USGS Gage Number)**	**HLR[1]**	**Drainage Area (mi^2)**	**Q_{bkf} (ft^3 s^{-1})**	**A_{bkf} (ft^2)**	**w_{bkf} (ft)**	**d_{bkf} (ft)**	**n_{bkf}**	**Return Interval (years)**
9	North Fork Triplett near Morehead (03250100)	9	84.7	385	145.9	88.6	1.7	--	1.01
10	Tygarts Creek near Greenup[2] (03217000)	9	242	3,571	1,027.0	112.7	9.1	--	1.11
11	Stave Branch[2]	11	0.49	--	5.9	8.0	0.7	--	--
12	UT KY-191 Mile 5	11	0.76	--	7.6	11.4	0.7	--	--
13	Eagle Creek[4]	11	3.5	135	47.4	31.8	1.5	0.039	--
14	S. Fork Dog Slaughter[4]	11	3.5	150	42.2	26.6	1.6	0.074	--
15	Dog Slaughter[4]	11	6.0	200	56.0	37.5	1.5	0.053	--
16	Cane Creek[4]	11	7.5	153	60.3	33.0	1.8	0.060	--

Table 4.1 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	Q_{bkf} (ft^3 s^{-1})	A_{bkf} (ft^2)	w_{bkf} (ft)	d_{bkf} (ft)	n_{bkf}	Return Interval (years)
17	Big Sinking River (03216370[3])	11	23.4	--	91.7	44.8	2.1	--	-
18	Stillwater Creek at Stillwater[2] (03283000)	11	24.0	194	66.5	32.6	2.0	0.042	1.01
19	Lynn Camp at Corbin (03404900)	11	53.8	473	163.3	70.1	2.3	0.024	1.01
20	Horse Lick Creek[4]	11	55.8	750	210.0	62.6	3.4	0.039	--
21	Red River near Hazel Green[2] (03282500)	11	65.8	1,710	400.0	56.0	7.1	--	--
22	Sturgeon Creek (03282040)	11	77.3	427	173.6	68.5	2.6	0.043	1.01

Table 4.1 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	Q_{bkf} (ft^3 s^{-1})	A_{bkf} (ft^2)	w_{bkf} (ft)	d_{bkf} (ft)	n_{bkf}	Return Interval (years)
23	Goose Creek at Manchester (03281100)	11	163.0	1,160	330.7	86.3	3.8	0.066	1.01
24	Buck Creek[4]	11	175.6	2,200	504.7	115.5	4.4	0.030	--
25	Davis Upper[5]	16	0.27	--	6.0	8.4	0.7	--	--
26	Line Fork Tributary[2]	16	0.31	--	3.8	7.0	0.6	--	--
27	Glade Branch[2]	16	0.36	--	4.0	5.5	0.7	--	-
28	Bear Hollow Tributary[2]	16	0.55	--	6.4	6.7	1.0	-	--
29	Daniels Creek[2]	16	0.8	31	9.1	9.3	1.0	0.046	--
30	Shillalah Creek[4]	16	1.9	85	26.4	25.4	1.0	0.062	--
31	Bear Branch near Noble (03278000)[2]	16	2.21	61	15.8	14.5	1.1	0.043	1.02

Table 4.1 cont'd.

Site ID	**Stream Site (USGS Gage Number)**	**HLR[1]**	**Drainage Area (mi^2)**	**Q_{bkf} ($ft^3\ s^{-1}$)**	**A_{bkf} (ft^2)**	**w_{bkf} (ft)**	**d_{bkf} (ft)**	**n_{bkf}**	**Return Interval (years)**
32	Bad Branch[4]	16	2.6	110	29.0	24.7	1.2	0.059	--
33	Road Fork[2]	16	2.82	70	11.5	9.8	1.2	0.032	--
34	Lick Fork[2]	16	6.78	--	33.0	23.0	1.4	-	--
35	Beaver Creek	16	7.37	--	55.9	32.3	1.8	--	--
36	Cat Creek 2[2]	16	7.81	--	35.2	22.0	1.6	--	--
37	Cat Creek (03283370[3])	16	8.31	--	44.6	26.4	1.7	--	--
38	Grapevine Creek[2]	16	13.85	--	44.0	25.5	1.7	--	--
39	Middle Fork River (03280600)	16	16.3	--	70.1	51.5	1.4	--	--
40	Rock Creek (Upper)[4]	16	18.8	350	85.4	53.0	1.6	0.044	--
41	Jenny's Creek[2]	16	35.6	--	141.6	59.0	2.4	--	--

Table 4.1 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	Q_{bkf} (ft^3 s^{-1})	A_{bkf} (ft^2)	w_{bkf} (ft)	d_{bkf} (ft)	n_{bkf}	Return Interval (years)
42	Leatherwood at Daisy (03277400[3])	16	40.9	--	163.2	52.8	3.1	--	1.01
43	Cutshin Creek (03280700)	16	61.3	1,100	198.6	64.9	3.1	0.054	1.02
44	Paint Creek at Staffordsville (03212000[3])	16	103.0	--	237.4	59.6	4.0	--	--
45	Licking River near Salyersville (03248500[3])	16	107.0	--	260.3	52.6	5.0	--	--
46	Red Bird River near Big Creek[2] (03281040)	16	155.0	5,992	1,095.0	147.9	7.4	--	1.06

Table 4.1 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	Q_{bkf} (ft^3 s^{-1})	A_{bkf} (ft^2)	w_{bkf} (ft)	d_{bkf} (ft)	n_{bkf}	Return Interval (years)
47	Troublesome Creek at Noble[2] (03278500)	16	177.0	3,800	775.1	94.1	8.2	--	1.10

[1] Hydrologic landscape region
[2] Source: Vesley et al. (2008)
[3] In-active USGS gage
[4] Source: Parola et al. (2005)
[5] Source: Agouridis (2012)

Table 4.2: Stream type (Rosgen) and streamside (riparian) vegetation for the EKC region.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	ER	w_{bkf}:d_{bkf}	K (ft ft^{-1})	S_{bkf} (ft ft^{-1})	D_{50} (mm)[6]	Rosgen Stream Type	Streamside (Riparian) Vegetation Type[7]
1	Cat Creek[2]	9	1.31	1.5	18.8	--	0.013	C	B3/1c	--
2	Rose Creek	9	1.85	1.7	22.4	1.1	0.014	19	B4	G/F
3	Indian Creek near Owingsville (03250150[3])	9	2.43	>2.2	12.3	1.2	0.006	59	C4	G/F
4	Rock Lick Creek (03250322)	9	4.2	>2.2	9.4	1.3	0.001	21	E4	G
5	Storey Branch	9	8.03	1.1	33.2	1.1	--	29	F4	G/F
6	Cabin Creek near Tollesboro	9	22.4	1.4-2.2	15.5	1.1	0.004	28	B4c	--

Table 4.2 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	ER	w_{bkf}:d_{bkf}	K (ft ft^{-1})	S_{bkf} (ft ft^{-1})	D_{50} (mm)[6]	Rosgen Stream Type	Streamside (Riparian) Vegetation Type[7]
7	Triplett Creek at Morehead (03250000[3])	9	45.9	1.4-2.2	26.6	1.2	0.005	58	B4c	F
8	Tygarts Creek at Olive Hill[2] (03216800)	9	59.6	1.7	45.5	--	0.001	27	B4/1c	--
9	North Fork Triplett near Morehead (03250100)	9	84.7	1.2	53.7	1.7	--	75	B3	G/F
10	Tygarts Creek near Greenup[2] (03217000)	9	242	>2.2	12.4	--	--	37	E4	--
11	Stave Branch[2]	11	0.49	4.5	11.0	--	0.008	16	C4	--
12	UT KY-191 Mile 5	11	0.76	1.3	17.3	1.3	0.008	30	B4c	G

Table 4.2 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	ER	w_{bkf}:d_{bkf}	K (ft ft^{-1})	S_{bkf} (ft ft^{-1})	D_{50} (mm)[6]	Rosgen Stream Type	Streamside (Riparian) Vegetation Type[7]
13	Eagle Creek[4]	11	3.5	1.1	21.3	--	0.003	37	F4/1	--
14	S. Fork Dog Slaughter[4]	11	3.5	1.7	16.3	--	0.016	135	B3c	--
15	Dog Slaughter[4]	11	6.0	1.2	25.2	--	0.010	91	B3c	--
16	Cane Creek[4]	11	7.5	1.4	18.03	--	0.005	46	B4c	--
17	Big Sinking River (03216370[3])	11	23.4	>2.2	21.9	1.7	0.020	61	B4	F
18	Stillwater Creek at Stillwater[2] (03283000)	11	24.0	1.4	16.0	--	0.003	51	B4c	--
19	Lynn Camp at Corbin (03404900)	11	53.8	1.3	30.0	1.7	0.001	63	B4c	--

Table 4.2 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	ER	w_{bkf}:d_{bkf}	K (ft ft^{-1})	S_{bkf} (ft ft^{-1})	D_{50} (mm)[6]	Rosgen Stream Type	Streamside (Riparian) Vegetation Type[7]
20	Horse Lick Creek[4]	11	55.8	1.7	18.7	--	0.002	28	B4c	--
21	Red River near Hazel Green[2] (03282500)	11	65.8	>2.2	7.8	--	--	G	E4	--
22	Sturgeon Creek (03282040)	11	77.3	1.4-2.2	26.7	2.0	0.001	84	B3	F
23	Goose Creek at Manchester (03281100)	11	163.0	>2.2	22.5	1.5	0.004	71	C3	F
24	Buck Creek[4]	11	175.6	>2.2	26.4	--	0.001	41	C4	--
25	Davis Upper[5]	16	0.27	>2.2	15.6	--	0.017	16	C4	F
26	Line Fork Tributary[2]	16	0.31	2.4	11.3	--	--	G	C4	--

Table 4.2 cont'd.

Site ID	**Stream Site (USGS Gage Number)**	**HLR**[1]	**Drainage Area (mi^2)**	**ER**	**w_{bkf}:d_{bkf}**	**K ($ft\ ft^{-1}$)**	**S_{bkf} ($ft\ ft^{-1}$)**	**D_{50} (mm)**[6]	**Rosgen Stream Type**	**Streamside (Riparian) Vegetation Type**[7]
27	Glade Branch[2]	16	0.36	2.3	7.5	--	--	G	E4	--
28	Bear Hollow Tributary[2]	16	0.55	3.4	7.0	--	0.012	C	E3	--
29	Daniels Creek[2]	16	0.8	2.2	9.5	--	0.011	37	C4/1	--
30	Shillalah Creek[4]	16	1.9	1.7	24.3	--	0.017	64	B4c	--
31	Bear Branch near Noble (03278000)[2]	16	2.21	2.3	13.3	--	0.011	46	C4/1	--
32	Bad Branch[4]	16	2.6	1.3	21.1	--	0.018	78	B3c	--
33	Road Fork[2]	16	2.82	3.5	8.4	--	0.014	42	E4	--
34	Lick Fork[2]	16	6.78	1.7	16	--	0.004	G	B4/1c	--
35	Beaver Creek	16	7.37	1.3	18.1	1.1	--	33	B4	G/F

Table 4.2 cont'd.

Site ID	Stream Site (USGS Gage Number)	HLR[1]	Drainage Area (mi^2)	ER	w_{bkf}:d_{bkf}	K ($ft\ ft^{-1}$)	S_{bkf} ($ft\ ft^{-1}$)	D_{50} (mm)[6]	Rosgen Stream Type	Streamside (Riparian) Vegetation Type[7]
36	Cat Creek 2[2]	16	7.81	1.4	13.8	--	0.005	40	B4c	--
37	Cat Creek (03283370[3])	16	8.31	>2.2	15.7	1.2	0.010	23	C4	F
38	Grapevine Creek[2]	16	13.85	1.6	14.8	--	--	S	B5c	--
39	Middle Fork River (03280600)	16	16.3	>2.2	37.4	1.2	--	79	C3	G
40	Rock Creek (Upper)[4]	16	18.8	1.2	32.9	--	0.008	46	B4/1c	--
41	Jenny's Creek[2]	16	35.6	1.2	24.6	--	0.002	S	F5	--
42	Leatherwood at Daisy (03277400[3])	16	40.9	1.4	17.1	1.4	0.001	23	B4	F

Table 4.2 cont'd.

Site ID	**Stream Site (USGS Gage Number)**	**HLR**[1]	**Drainage Area (mi^2)**	**ER**	**w_{bkf}:d_{bkf}**	**K (ft ft^{-1})**	**S_{bkf} (ft ft^{-1})**	**D_{50} (mm)**[6]	**Rosgen Stream Type**	**Streamside (Riparian) Vegetation Type**[7]
43	Cutshin Creek (03280700)	16	61.3	1.4-2.2	21.2	1.4	0.009	70	B3	G
44	Paint Creek at Staffordsville (03212000[3])	16	103.0	>2.2	14.9	--	0.004	18	C4	--
45	Licking River near Salyersville (03248500[3])	16	107.0	1.4-2.2	10.6	1.2	--	0.2	B5	G/F
46	Red Bird River near Big Creek[2] (03281040)	16	155.0	2.1	20.0	--	--	28	E4	--

Table 4.2 cont'd.

Site ID	**Stream Site (USGS Gage Number)**	**HLR**[1]	**Drainage Area (mi^2)**	**ER**	**w_{bkf}:d_{bkf}**	**K ($ft\ ft^{-1}$)**	**S_{bkf} ($ft\ ft^{-1}$)**	**D_{50} (mm)**[6]	**Rosgen Stream Type**	**Streamside (Riparian) Vegetation Type**[7]
47	Troublesome Creek at Noble[2] (03278500)	16	177.0	2.1	11.4	--	--	18	E4	--

[1] Hydrologic landscape region
[2] Source: Vesley et al. (2008)
[3] In-active USGS gage
[4] Source: Parola et al. (2005)
[5] Source: Agouridis (2012)
[6] C=cobble, G=gravel, and S=sand
[7] G=grass dominated, F=forest dominated, G/F=equal mixture of grass and forest

HLR 9 contained the following Rosgen stream types: 6 B, 1 C, 1 E, and 1 F. HLR 11 contained the following Rosgen stream types: 9B, 3 C, 1 E, and 1 F. HLR 16 contained the following Rosgen stream types: 10 B, 7 C, 5 E and 1 F.

4.1.1 Bankfull Discharge

For 24 of the 47 sites (51.1%) with long-term flow data, Q_{bkf} was determined and used to develop regional curves (e.g. bankfull discharge versus drainage area). Table 4.3 contains the resultant bankfull discharge regional curves for the EKC region (Combined HLRs of 9, 11 and 16) and the individual HLR regions of 9, 11 and 16. Figure 4.1 is a graphical representation of the data points and regression equations for the Combined HLRs and each individual HLR. Based on the coefficients of determination (R^2), good to strong relationships exist for the bankfull discharge regional curves. Drainage area explained 87% of the variance in bankfull discharge for the EKC region (Combined HLRs). Separating the EKC region into individual HLRs generally improved the R^2 value. For HLR 9 and 16, the R^2 increased to 0.88 and 0.97, respectively, while it decreased to 0.80 for HLR 11. The exponents for the regional curves developed in this study (b=0.62-0.90) are within the ranges of those found by other researchers for the Appalachian region (b=0.61-0.94) (Table 4.4). Excluding Babbit (2005), coefficients for the combined and individual HLRs examined in this study (a=16.14-54.49) were within the range of those found for the Appalachian region (a=32.70-62.96).

Table 4.3: Bankfull regional curve relationships for bankfull discharge ($ft^3 s^{-1}$) and drainage area (mi^2).

HLR	**Regression Equation**	**R^2**
Combined HLRs (9, 11 and 16)	$Q_{bkf}=37.54DA^{0.77}$	0.87
HLR 9	$Q_{bkf}=16.14DA^{0.90}$	0.88
HLR 11	$Q_{bkf}=54.49DA^{0.62}$	0.80
HLR 16	$Q_{bkf}=34.88DA^{0.76}$	0.97

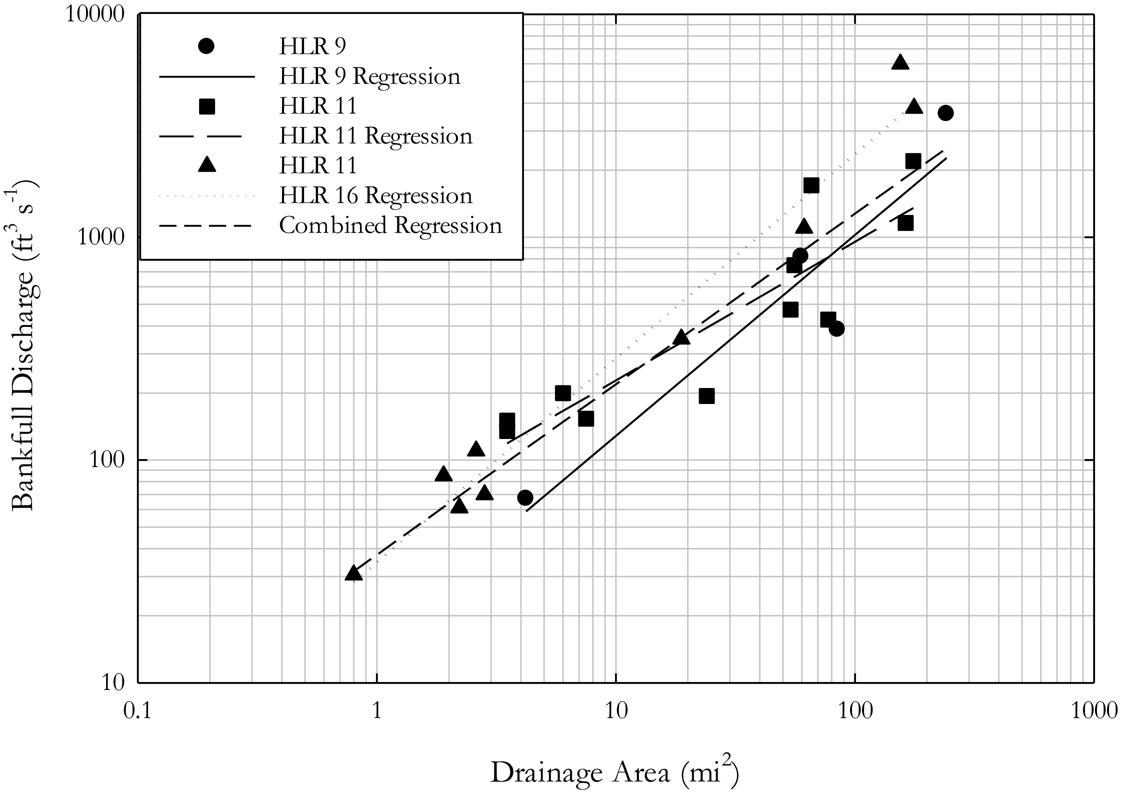


Figure 4.1: Bankfull discharge ($ft^3 s^{-1}$) as a function of drainage area (mi^2) for the Combined HLRs and individual ones of HLR 9, HLR 11, and HLR 16.

Table 4.4: Comparison of regional curves in the Eastern United States and Appalachian Region where $Q_{bkf}=aDA^{b}$, $A_{bkf}=cDA^{d}$, $w_{bkf}=gDA^{h}$, and $d_{bkf}=jDA^{k}$. DA is drainage area (mi^{2}), Q_{bkf} is bankfull discharge (ft^{3} s^{-1}), A_{bkf} is bankfull cross-sectional area (ft^{2}), w_{bkf} is bankfull width (ft), and d_{bkf} is bankfull mean depth (ft).

Study	Q_{bkf}			A_{bkf}			w_{bkf}			d_{bkf}		
	a	B	R^2	c	d	R^2	g	h	R^2	j	k	R^2
Combined HLRs	37.54	0.77	0.87	10.59	0.74	0.94	12.16	0.42	0.91	0.88	0.32	0.82
HLR 9	16.14	0.90	0.88	10.90	0.76	0.91	13.32	0.42	0.97	0.82	0.34	0.65
HLR 11	54.49	0.62	0.80	12.63	0.69	0.94	14.11	0.38	0.92	0.89	0.31	0.83
HLR 16	34.88	0.92	0.97	9.81	0.76	0.95	11.18	0.42	0.90	0.89	0.33	0.89
U.S. HLR 9	46.91	0.78	0.88	14.39	0.69	0.81	11.27	0.45	0.80	1.26	0.25	0.58
U.S. HLR 11	53.95	0.76	0.78	18.35	0.68	0.80	14.85	0.38	0.69	1.24	0.30	0.63
U.S. HLR 16	51.08	0.86	0.88	17.89	0.66	0.80	13.15	0.43	0.79	1.35	0.22	0.52
Babbit (2005)	150.06	0.75	0.99	32.48	0.70	1.00	18.51	0.44	0.97	1.76	0.26	0.97
Brockman (2010)[2]	35.07	0.91	0.92	15.08	0.82	0.96	14.23	0.46	0.94	1.06	0.36	0.90
Chaplin (2005)[3]	43.21	0.87	0.92	12.04	0.80	0.92	14.65	0.45	0.81	0.88	0.33	0.72
Dunne and Leopold (1978)[4]	--	--	--	21.17	0.70	--	14.00	0.40	--	1.50	0.29	--
McCandless (2003)[5]	34.02	0.94	0.99	13.17	0.75	0.93	13.87	0.44	0.92	0.95	0.31	0.91

Table 4.4 cont'd.

Study	Q_{bkf}			A_{bkf}			w_{bkf}			d_{bkf}		
	a	B	R^2	c	d	R^2	g	h	R^2	j	k	R^2
Messinger (2009)[6]	59.81	0.85	0.96	20.49	0.71	0.98	20.99	0.37	0.95	1.07	0.31	0.88
Miller and Davis (2003)[7]	62.96	0.87	0.81	12.67	0.81	0.90	12.51	0.51	0.88	1.01	0.31	0.85
Parola et al. (2005)[8]	60.30	0.61	0.96	19.10	0.57	0.97	20.10	0.30	0.93	0.95	0.28	0.80
Vesley et al. (2008)[9]	32.70	0.85	0.92	9.45	0.82	0.96	10.88	0.45	0.93	0.88	0.36	0.88
Westergard et al. (2004)[10]	45.30	0.86	0.96	10.80	0.82	0.98	13.50	0.45	0.92	0.80	0.37	0.91

[1] Southwestern Appalachians of East Tennessee
[2] Combined Inner and Outer Bluegrass Regions of Kentucky
[3] Pennsylvania and Maryland
[4] Eastern United States
[5] Appalachian Plateau and Valley and Ridge of Maryland
[6] Appalachian Plateaus of West Virginia
[7] Catskill Mountains of New York
[8] Four Rivers and Upper Cumberland of Kentucky
[9] Eastern Kentucky Coalfields
[10] Central New York

4.1.2 Bankfull Cross-sectional Area

Bankfull cross-sectional area was determined for all 47 sites. Regional curves for A_{bkf} were created using all the surveyed sites and subdivided in to each individual HLR region. Table 4.5 contains the resultant bankfull cross-sectional area regional curves for the EKC region (Combined HLRs of 9, 11 and 16) and the individual HLR regions of 9, 11 and 16. Figure 4.2 is a graphical representation of the data points and regression equations for the Combined HLRs and each individual HLR. Based on the coefficients of determination (R^2), strong relationships exist for the bankfull cross-sectional area regional curves. Drainage area explained 94% of the variance in bankfull cross-sectional area for the EKC region (Combined HLRs). Separating the EKC region into individual HLRs generally maintained or improved the R^2 values. For HLR 16, the R^2 value increased to 0.95 while it was maintained for HLR 11 (R^2=0.94) and decreased for HLR 9 (R^2=0.91). The exponents for the regional curves developed in this study (d=0.69-0.76) are within the ranges of those found by other researchers for the Appalachian region (d=0.57-0.82) (Table 4.4). The coefficients for the combined and individual HLRs examined in this study (c=9.81-12.63) were within the range, though the lower end, of those found for the Appalachian region (c=9.45-32.48).

Table 4.5: Bankfull regional curve relationships for bankfull cross-sectional area (ft2) and drainage area (mi^2).

HLR	**Regression Equation**	**R^2**
Combined HLRs (9, 11 and 16)	A_{bkf}=10.59DA$^{0.74}$	0.94
HLR 9	A_{bkf}=10.90DA$^{0.76}$	0.91
HLR 11	A_{bkf}=12.63DA$^{0.69}$	0.94
HLR 16	A_{bkf}=9.81DA$^{0.76}$	0.95

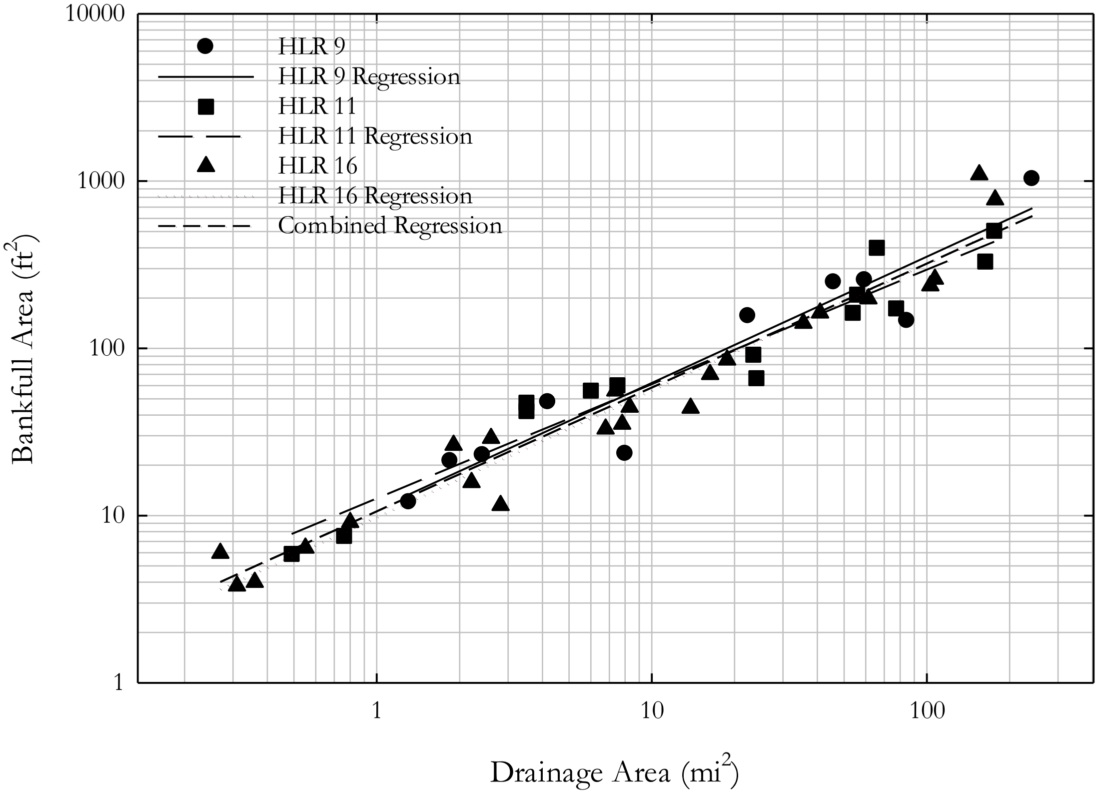


Figure 4.2: Bankfull cross-sectional area (ft^2) as a function of drainage area (mi^2) for the Combined HLRs and individual ones of HLR 9, HLR 11, and HLR 16.

4.1.3 Bankfull Width

Bankfull width was determined for all 47 sites. Bankfull width regional curves were created using all the surveyed sites and subdivided in to each individual HLR region. Table 4.6 contains the resultant bankfull width regional curves for the EKC region (Combined HLRs of 9, 11 and 16) and the individual HLR regions of 9, 11 and 16. Figure 4.3 is a graphical representation of the data points and regression equations for the Combined HLRs and each individual HLR. Based on the coefficients of determination (R^2), strong relationships exist for the bankfull width regional curves. Drainage area explained 91% of the variance in bankfull width for the EKC region (Combined HLRs). Separating the EKC region into individual HLRs generally improved the R^2 values. For HLRs 9 and 11, the R^2 values increased to 0.97 and 0.92, respectively, while it decreased for HLR 16 (R^2=0.90). The exponents for the regional curves developed in this study (h=0.38-0.42) are within the ranges of those found by other researchers for the Appalachian region (h=0.30-0.51) (Table 4.4). The coefficients for the combined and individual HLRs examined in this study (g=11.18-14.11) were generally within the range, though the lower end, of those found for the Appalachian region (g=12.51-20.99).

Table 4.6: Bankfull regional curve relationships for bankfull width (ft) and drainage area (mi^2).

HLR	Regression Equation	R^2
Combined HLRs (9, 11 and 16)	$w_{bkf}=12.16DA^{0.42}$	0.91
HLR 9	$w_{bkf}=13.32DA^{0.42}$	0.97
HLR 11	$w_{bkf}=14.11DA^{0.38}$	0.92
HLR 16	$w_{bkf}=11.18DA^{0.42}$	0.90

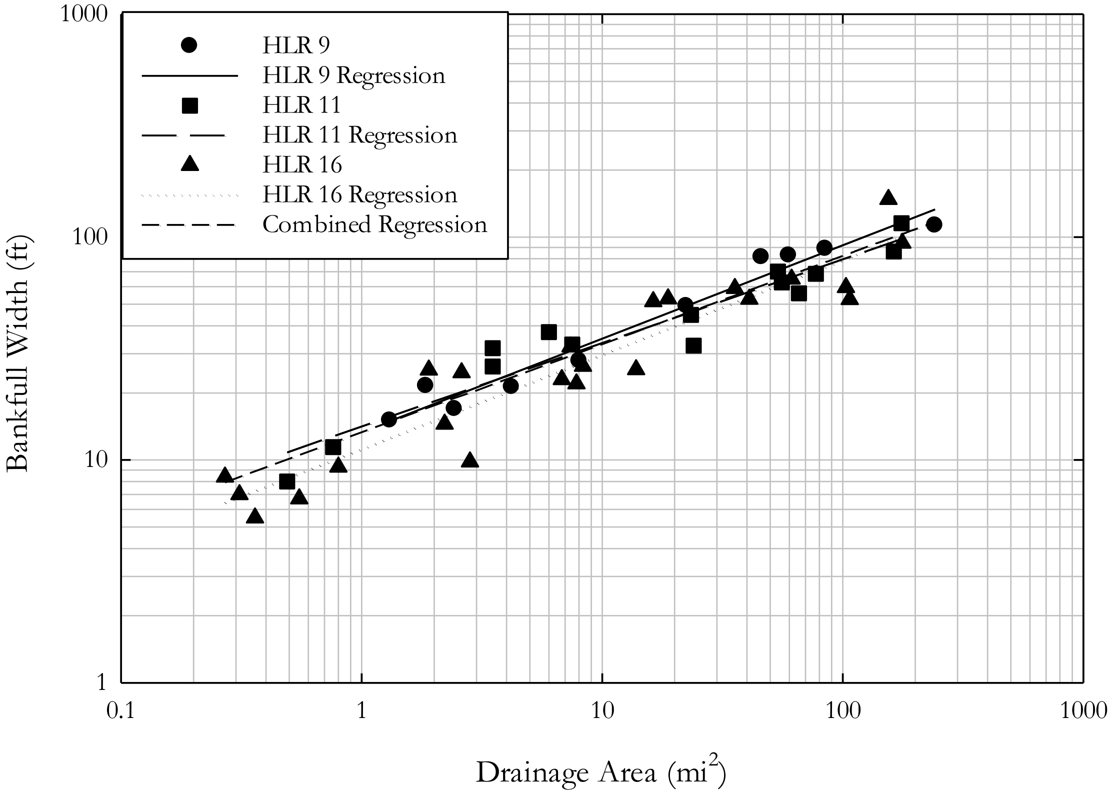


Figure 4.3: Bankfull width (ft) as a function of drainage area (mi^2) for the Combined HLRs and individual ones of HLR 9, HLR 11, and HLR 16.

4.1.4 Bankfull Mean Depth

Bankfull mean depth was determined for all 47 sites. Bankfull mean depth regional curves were created using all the surveyed sites and subdivided in to each individual HLR region. Table 4.7 contains the resultant bankfull mean depth regional curves for the EKC region (Combined HLRs of 9, 11 and 16) and the individual HLR regions of 9, 11 and 16. Figure 4.4 is a graphical representation of the data points and regression equations for the Combined HLRs and each individual HLR. Based on the coefficients of determination (R^2), moderate to strong relationships exist for the bankfull mean depth regional curves. Drainage area explained 82% of the variance in bankfull mean depth for the EKC region (Combined HLRs). Separating the EKC region into individual HLRs generally improved the R^2 values in almost all cases. For HLRs 11 and 16, the R^2 values increased to 0.83 and 0.89, respectively, while it decreased for HLR 9 (R^2=0.65). The exponents for the regional curves developed in this study (k=0.31-0.34) are within the ranges of those found by other researchers for the Appalachian region (k=0.26-0.32) (Table 4.4). The coefficients for the combined and individual HLRs examined in this study (j=0.82-0.89) were generally within the range, though the lower end, of those found for the Appalachian region (j=0.80-1.76).

Table 4.7: Bankfull regional curve relationships for bankfull mean depth (ft) and drainage area (mi^2).

HLR	**Regression Equation**	**R^2**
Combined HLRs (9, 11 and 16)	$d_{bkf}=0.88DA^{0.32}$	0.82
HLR 9	$d_{bkf}=0.82DA^{0.34}$	0.65
HLR 11	$d_{bkf}=0.89DA^{0.31}$	0.83
HLR 16	$d_{bkf}=0.89DA^{0.33}$	0.89

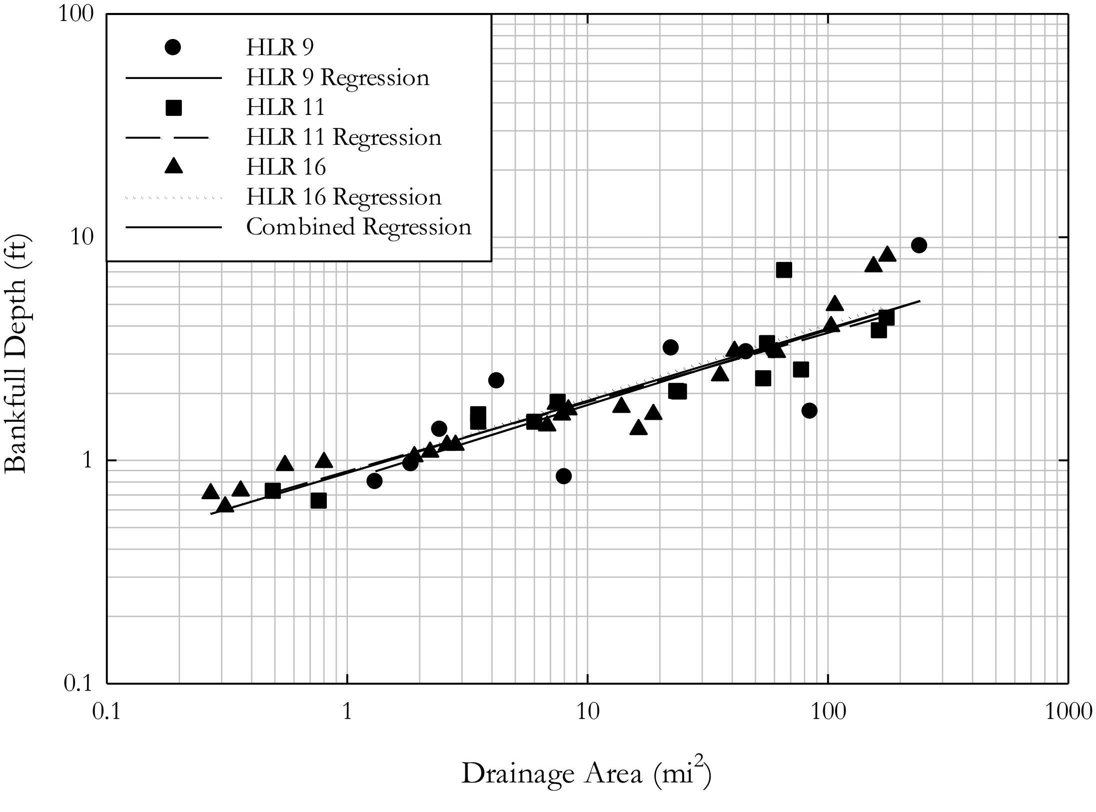


Figure 4.4: Bankfull mean depth (ft) as a function of drainage area (mi^2) for the Combined HLRs and individual ones of HLR 9, HLR 11, and HLR 16.

4.1.5 Statistical Comparison

Results of the statistical comparisons of regional curves between HLRs are presented in Table 4.8.

4.1.5.1 Bankfull Discharge

HLR 16 significantly differed from HLR 9, HLR 11, and Combined HLRs (Figure 4.5) (Table 4.8). The exponent (b=0.92) of the HRL 16 regional curve was larger than the exponents from HLR 11 (b=0.62) and Combined HLRs (b=0.77) while the intercept (a=34.88) for HLR 16 was larger than that for HRL 9 (a=16.14) but smaller than the one for HLR 11 (a=54.49) (Table 4.4). No significant differences were noted between HLR 16 and U.S. HLR 16. The regional curve for HLR 16 predicted larger Q_{bkf} values then the regional curves for HLR 9, HRL 11, and Combined HLRs for nearly the entire range of drainage areas (Table 4.9). At a drainage area of 25 mi^2, the predicted value of Q_{bkf} for HLR 16 is 674.0 ft^3 s^{-1} versus 292.5 ft^3 s^{-1} for HLR 9, 400.9 ft^3 s^{-1} for HLR 11, and 447.6 ft^3 s^{-1} for Combined HLRs. Surprisingly, no significant differences were noted between HLR 9 and U.S. HLR 9; HLR 9 predicted lower Q_{bkf} values for a wide range of drainage areas (Table 4.9). Similarly, no difference was noted between HLR 9 and HLR 11 though a cross-over was present with HLR 9 predicting lower Q_{bkf} values below 100 mi^2 but higher ones for larger drainage areas.

Table 4.8: Results of the comparison of regional curves based on HLR. H_o: No significant differences in slopes or intercepts amongst regional curves. H_a: Significant differences in slopes or intercepts amongst regional curves.

Comparison	**Q_{bkf}**		**A_{bkf}**		**w_{bkf}**		**d_{bkf}**	
	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**
HLR 9 vs. Combined HLRs	0.75	No	0.66	No	0.36	No	0.97	No
HLR 11 vs. Combined HLRs	0.12	No	0.02	Yes	0.82	No	0.05	No
HLR 16 vs. Combined HLRs	0.03	Yes	0.10	No	0.40	No	0.04	Yes
HLR 9 vs. U.S. HLR 9	0.91	No	0.27	No	0.07	No	0.02	Yes
HLR 11 vs. U.S. HLR 11	0.05	No	0.02	Yes	0.29	No	0.46	No
HLR 16 vs. U.S. HLR 16	0.42	No	0.95	No	0.02	Yes	0.00	Yes
HLR 9 vs. HLR 11	0.12	No	0.00	Yes	0.55	No	0.16	No
HLR 9 vs. HLR 16	0.01	Yes	0.32	No	0.19	No	0.03	Yes
HLR 11 vs. HLR 16	0.00	Yes	0.00	Yes	0.37	No	0.00	Yes

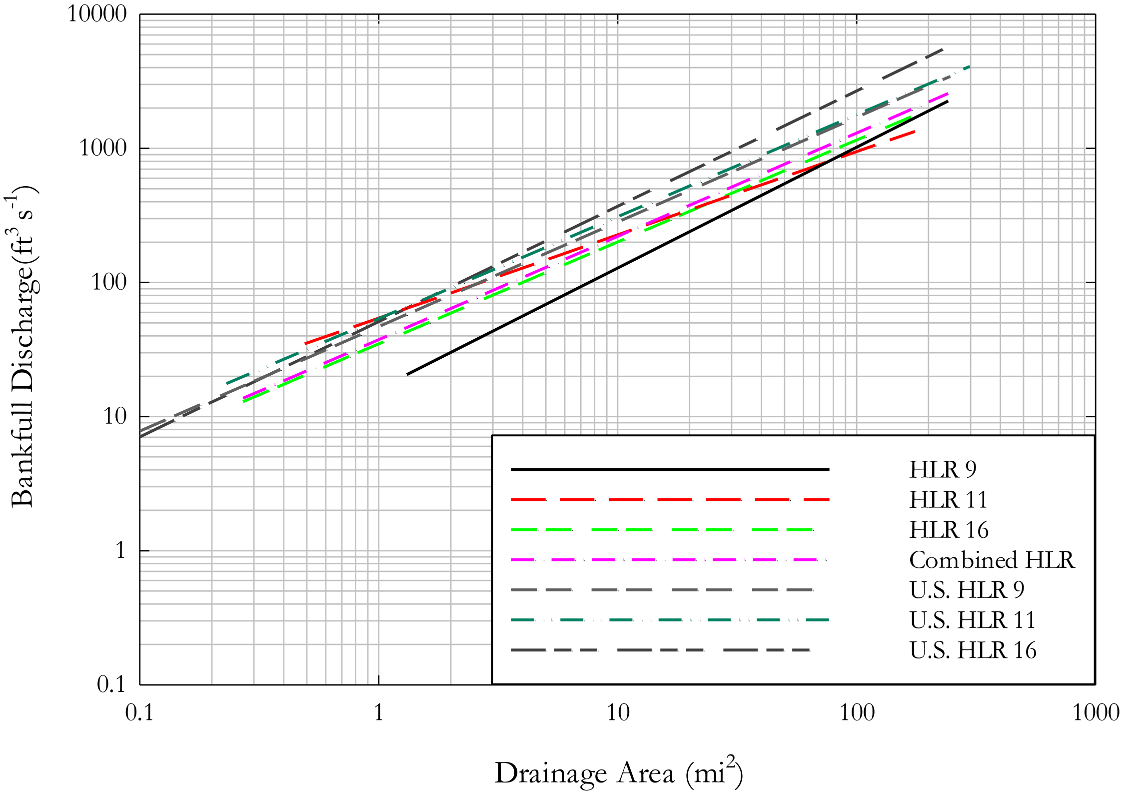


Figure 4.5: Comparison of regional curves for bankfull discharge.

Table 4.9 Comparison of HLR-based hydraulic geometry curves developed for the EKC and U.S. wide.

Bankfull Parameters	**HLR**	**Drainage Area (mi^2)**							
		1	5	10	25	50	100	150	200
Q_{bkf}	Combined HLRs	37.5	129.6	221.1	447.6	763.3	1,301.7	1,778.6	2,219.7
	HLR 9	16.1	68.7	128.2	292.5	545.7	1,018.4	1,466.9	1,900.3
	HLR 11	54.5	147.8	227.2	400.9	616.1	946.9	1,217.6	1,455.3
	HLR 16	34.5	153.3	290.0	674.0	1,275.4	2,413.1	3,504.1	4,565.9
	U.S. HLR 9	46.9	164.6	282.7	577.6	991.9	1,703.2	2,336.8	2,924.6
	U.S. HLR 11	54.0	183.3	310.5	622.9	1,054.9	1,786.5	2,431.2	3,025.3
	U.S. HLR 16	51.0	203.9	370.0	813.7	1,477.0	2,680.7	3,799.2	4,865.6
A_{bkf}	Combined HLRs	10.6	34.8	58.2	114.7	191.5	319.8	431.7	534.1
	HLR 9	10.9	37.0	62.7	125.9	213.1	360.9	491.2	611.2
	HLR 11	12.6	38.3	61.9	116.4	187.8	303.0	400.8	488.8
	HLR 16	9.8	33.3	56.5	113.3	191.8	324.8	442.1	550.1
	U.S. HLR 9	14.4	43.7	70.5	132.6	214.0	345.2	456.6	556.9
	U.S. HLR 11	18.4	54.8	87.8	163.8	262.4	420.4	553.8	673.5
	U.S. HLR 16	17.9	51.8	81.7	149.7	236.6	373.8	488.5	590.6

Table 4.9 cont'd.

Bankfull Parameters	**HLR**	**Drainage Area (mi^2)**							
		1	5	10	25	50	100	150	200
w_{bkf}	Combined HLRs	12.2	23.9	32.0	47.0	62.9	84.1	99.8	112.6
	HLR 9	13.3	26.2	35.0	51.5	68.9	92.2	109.3	123.3
	HLR 11	14.1	26.0	33.9	48.0	62.4	81.2	94.7	105.7
	HLR 16	11.2	22.0	29.4	43.2	57.8	77.4	91.7	103.5
	U.S. HLR 9	11.3	23.3	31.8	48.0	65.3	89.5	107.4	122.3
	U.S. HLR 11	14.9	27.4	35.6	50.5	65.7	85.5	99.7	111.2
	U.S. HLR 16	13.2	26.3	35.4	52.5	70.7	95.3	113.4	128.3
d_{bkf}	Combined HLRs	0.9	1.5	1.8	2.5	3.1	3.8	4.4	4.8
	HLR 9	0.8	1.4	1.8	2.5	3.1	3.9	4.5	5.0
	HLR 11	0.9	1.5	1.8	2.4	3.0	3.7	4.2	4.6
	HLR 16	0.9	1.5	1.9	2.6	3.2	4.1	4.7	5.1
	U.S. HLR 9	1.3	1.9	2.2	2.8	3.4	4.0	4.4	4.7
	U.S. HLR 11	1.2	2.0	2.5	3.3	4.0	4.9	5.6	6.1
	U.S. HLR 16	1.4	1.9	2.2	2.7	3.2	3.7	4.1	4.3

4.1.5.2 Bankfull Cross-sectional Area

HLR 11 significantly differed from HLR 9, HLR 16, Combined HLRs, and U.S. HLR 11 (Figure 4.6) (Table 4.8). The exponent (d=0.69) of the HLR 11 regional curve was smaller than the exponents for HLR 9 (d=0.76), HLR 16 (d=0.76), and Combined HLRs (d=0.74) while the coefficient (c=12.63) was larger than that for HLR 9 (c=10.90), HLR 16 (c=9.81), and Combined HLRs (c=10.59) but smaller than the coefficient for U.S. HLR 11 (c=18.35) (Table 4.4). At a drainage area of 25 mi^2, the predicted value of A_{bkf} for HLR 11 is 116.4 ft^2 versus 125.9 ft^2 for HLR 9, 113.3 ft^2 for HLR 16, 114.7 ft^2 for Combined HLRs, and 163.8 ft^2 for U.S. HLR 11. As seen in Figure 4.6, differences in A_{bkf} are more pronounced at lower drainage areas, which are typical of many stream restoration projects (Alexander and Allan, 2006; Mecklenburg and Fay, 2011). Thus, separation of the EKC based upon HLR is likely warranted for projects with smaller drainage areas.

4.1.5.3 Bankfull Width

Generally, the exponents from the regional curves developed for the EKC (HLR 9, HLR 11, and HLR 16) displayed little variation with respect to slope indicating changes in bankfull width due to changes in drainage area were similar across the HLRs (Figure 4.7) (Table 4.4). Based on work by Johnson and Fecko (2008), it was expected that the fewest differences between HLRs would occur for w_{bkf}. Significant differences were noted only between HLR 16 and U.S. HLR 16 (Table 4.8). The exponents between the two regional curves were nearly the same while the coefficient for HLR 16 (g=11.18) was lower than the coefficient for U.S. HLR 16 (g=13.15). At a drainage area of 25 mi^2, the predicted value of w_{bkf} for HLR 16 is 43.2 ft while it is 52.5 ft for U.S. HLR 16 (Table 4.9).

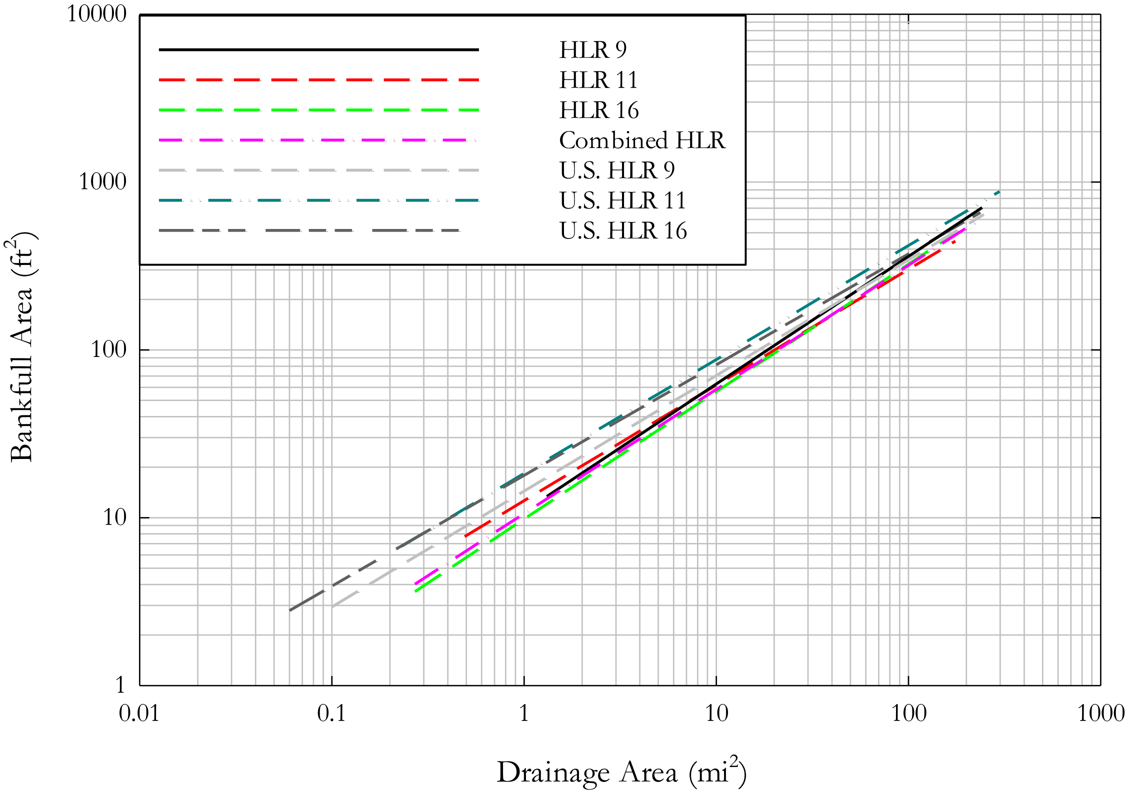


Figure 4.6: Comparison of regional curves for bankfull cross-sectional area.

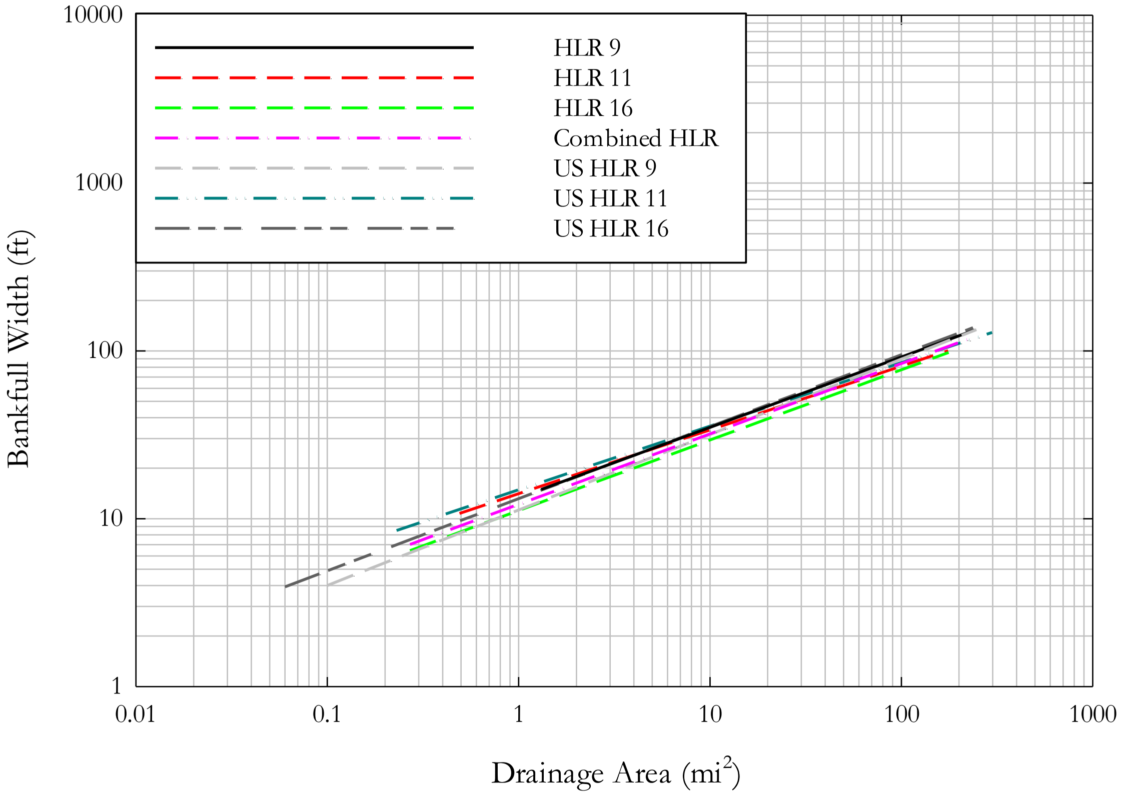


Figure 4.7: Comparison of regional curves for bankfull width.

4.1.5.4 Bankfull Mean Depth

Significant differences were present with regards to HLR 9 and HLR 16. HLR 9 differed significantly from HLR 16 and U.S. HLR 9 while HLR 16 differed significantly from HLR 11, Combined HLRs, and U.S. HLR 16 in addition to HLR 9 (Figure 4.8) (Table 4.8). As shown in Table 4.4, the exponent for HLR 9 (k=0.34) was larger than the exponent for U.S. HLR 9 (k=0.25) while the coefficient for HLR 9 (j=0.82) was smaller than the coefficient for U.S. HLR 9 (j=1.26). The exponent for HLR 16 (k=0.33) was larger than the exponent for U.S. HLR 16 (k=0.22) but similar to the exponents for HLR 9, HLR 11 (k=0.31), and Combined HLRs (k=0.32). The coefficient for HLR 16 (j=0.89) was smaller than the coefficient for U.S. HLR 16 (j=1.35), larger than the coefficient for HLR 9 (j=0.82), but was the same or similar to the coefficients for HLR 11 (j=0.89) and Combined HLRs (0.88). Thus, the finding of statistically significant differences between HLR 16 and HLR 11 and Combined HLR was surprising. At a drainage area of 25 mi^2, the predicted d_{bkf} for HLR 9 is 2.5 ft, 2.4 ft for HLR 11, 2.6 ft for HLR 16, 2.5 ft for Combined HLRs, 2.8 ft for U.S. HLR 9, and 2.7 ft for U.S. HLR 16 (Table 4.z). At lower drainage areas, the differences in d_{bkf} between the EKC and U.S. wide regional curves are more pronounced while differences between regional curves within the EKC, though significant at times, are small and generally on the order of 0.1-0.2 ft.

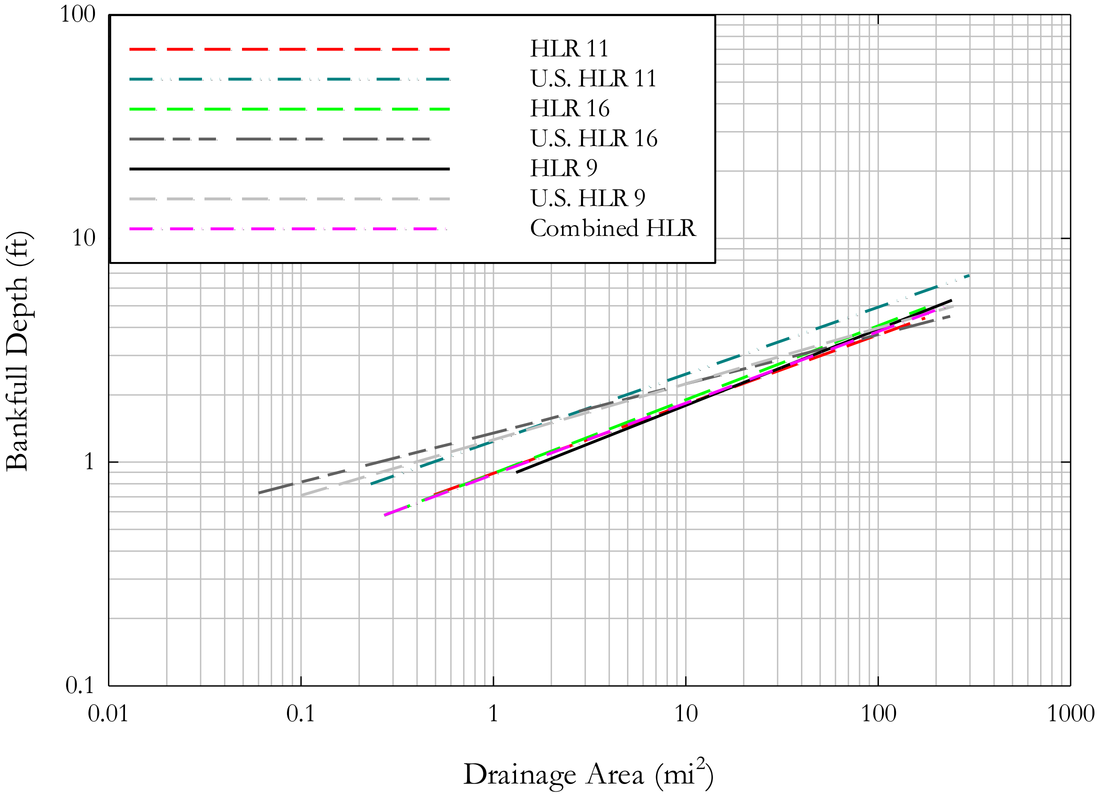


Figure 4.8: Comparison of regional curves for bankfull mean depth.

4.1.5.5 Regional Curve Comparison Summary

Results indicate that separating the EKC based on HLR for the development of regional curves was beneficial as in most instances R^2 improved over the Combined HLRs and significant differences were present between one or more of the HLR regions within the EKC (i.e. why R^2 of individual HLRs was generally higher than Combined HLRs). For Q_{bkf}, HLR 16 differed significantly from HLR 9 and HLR 11. For A_{bkf}, HLR 11 differed significantly from HLR 9 and HLR 16. Little variation (i.e. no significant differences) were present between the HLRs in the EKC for w_{bkf}. For d_{bkf}, significant differences were noted between HLR 9 and HLR 16 as well as HLR 11 and HLR 16.

As seen in Figures 4.5-4.8, differences between the HLRs within the EKC were greatest for smaller drainage areas, which are more characteristic of the size of watersheds in which stream restoration projects occur (Alexander and Allan, 2006; Mecklenburg and Fay, 2011). Based on the Combined HLR, a stream located in a 10 mi^2 watershed is expected to have a Q_{bkf} of 221.1 ft^3 s^{-1} and the following dimensions: A_{bkf}=52.8 ft^2, w_{bkf}=32 ft, and d_{bkf}=1.8 ft. Using the HLR specific regional curves would yield channels of different sizes and dimensions. The HLR 9 regional curves would generate a larger (A_{bkf}=62.7 ft^2) and wider (w_{bkf}=35.0 ft) channel with a similar depth (d_{bkf}=1.8 ft) even though the predicted Q_{bkf} of 128.2 ft_3 s^{-1} is much lower. The impermeable soils of HLR 9 are ideal for overland flow production and the permeable bedrock (i.e. karst) means groundwater and surface waters are closely connected (Wolock et al., 2004). While Parola et al. (2007) postulated that streams in karst-influenced areas would have smaller dimensions as a result of predicted smaller discharges, Agouridis et al. (2011) found this was not the case for the Inner and Outer Bluegrass regions of Kentucky, areas dominated by karst.

As compared to the regional curves for the Combined HLRs, the HLR 11 regional curves would also generate a larger (A_{bkf}=61.9 ft^2) channel with a slightly greater width (w_{bkf}=33.9 ft) channel with a similar depth (d_{bkf}=1.8 ft) even though the predicted Q_{bkf} of 227.2 ft^3 s^{-1} is about the same. Like HLR 9, the soils of HLR 11 are impermeable but so is the bedrock (Wolock et al., 2004) which explains the larger expected Q_{bkf} value for a 10 mi^2 watershed for HLR 11 as compared to HLR 9. Lastly, compared to the regional curves for the Combined HLRs, the HLR 16 regional curves would generate a similar sized channel (A_{bkf}=56.5 ft^2) that is narrower (w_{bkf}=29.4 ft) and slightly deeper (d_{bkf}=1.8 ft). HLR 16 is characterized by impermeable soils like HLR but bedrock like HLR 11; it has steeper topography than HLR 9 or HLR 11 (Wolock et al., 2004). As expected, the predicted Q_{bkf} is largest for HLR 16 at 290 ft^3 s^{-1} for a 10 mi^2 watershed, and the steeper slopes produce larger v_{bkf}. values (v_{bkf}=1.8 ft s^{-1} for HLR 9, 3.12 ft s^{-1} for HLR 11, and 4.36 ft s^{-1} for HLR 16) resulting in deeper channels due to scouring (Schumm and Khan, 1972).

Comparison of the regional curves for the three HLRs examined in the EKC to those same HLRs on a U.S. wide basis found few statistical differences. No statistical differences were found for Q_{bkf} but were for A_{bkf}, $w_{\mathbf{bkf}}$ and d_{bkf}. For A_{bkf}, significant differences were noted between HLR 11 and U.S. HLR 11. For w_{bkf}, differences were present between HLR 16 and U.S. 16. For d_{bkf}, differences were present between HLR 9 and U.S. HLR 9 as well as HLR 16 and U.S. HLR 16. In each of these cases, for a 10 mi^2 watershed, the U.S. wide HLRs predicted larger channel dimensions as compared to the HLRs in the EKC (Table 4.9). The lack of statistical significance between some HLRs for some bankfull parameters suggests designers who are challenged with finding acceptable reference stream sites may look to the same type of HLRs in other parts of the U.S. to supplement their datasets for certain bankfull parameters but not all.

4.2 HYDRAULIC GEOMETRY CURVES

Hydraulic geometry curves relating bankfull parameters A_{bkf}, w_{bkf}, and d_{bkf} to Q_{bkf} were created for the entire EKC region (HLR 9, 11 and 16 combined) and each individual HLR region examined in the study (HLR 9, 11 and 16 separately). Due to the low number of available active USGS gaged sites, only 24 of the 47 sites (51%) were used: 4 in HLR 9, 11 in HRL 11 and 9 in HLR 16 (Table 4.1). For HLR 9, the following sites were used: Site IDs 4, 8, 9 and 10. Q_{bkf} for these sites ranged from 67 to 3,571 ft^3 s^{-1} with an average value of 1,210 ft^3 s^{-1} and a median value of 602 ft^3 s^{-1}. For HLR 11, the following sites were used: Site IDs 13, 14, 15, 16, 18, 19, 20, 21, 22, 23 and 24. Q_{bkf} for these sites ranged from 135 to 2,200 ft^3 s^{-1} with an average value of 687 ft^3 s^{-1} and a median value of 427 ft^3 s^{-1}. For HLR 16, the following sites were used: Site IDs 29, 30, 31, 32, 33, 40, 43, 46 and 47. Q_{bkf} for these sites ranged from 31 to 5,992 ft^3 s^{-1} with an average value of 1,289 ft^3 s^{-1} and a median value of 110 ft^3 s^{-1}. In all instances, the majority of the sites in each individual HLR had smaller drainage areas and hence smaller Q_{bkf} values; few sites had large drainage areas and hence large Q_{bkf} values. Checking for continuity, the product of the coefficients for w_{bkf}, d_{bkf} and v_{bkf} for the combined HLR, HLR 9, HLR 11, and HLR 16 equaled 1.003, 1.020, 1.003, and 0.999, respectively. The sum of the exponents of w_{bkf}, d_{bkf} and v_{bkf} summed to 1.000, 0.997, 1.000, and 1.000, respectively.

4.2.1 Bankfull Cross-sectional Area

Table 4.10: Hydraulic geometry curves for bankfull area (A_{bkf}). A_{bkf} is in units of ft^2 and Q_{bkf} is in units of $ft^3\ s^{-1}$.

HLR	Regression Equation	R^2
Combined HLR (9, 11 and 16)	$A_{bkf}=0.47Q_{bkf}^{0.92}$	0.96
HLR 9	$A_{bkf}=1.69Q_{bkf}^{0.77}$	0.99
HLR 11	$A_{bkf}=0.65Q_{bkf}^{0.88}$	0.97
HLR 16	$A_{bkf}=0.34Q_{bkf}^{0.93}$	0.99

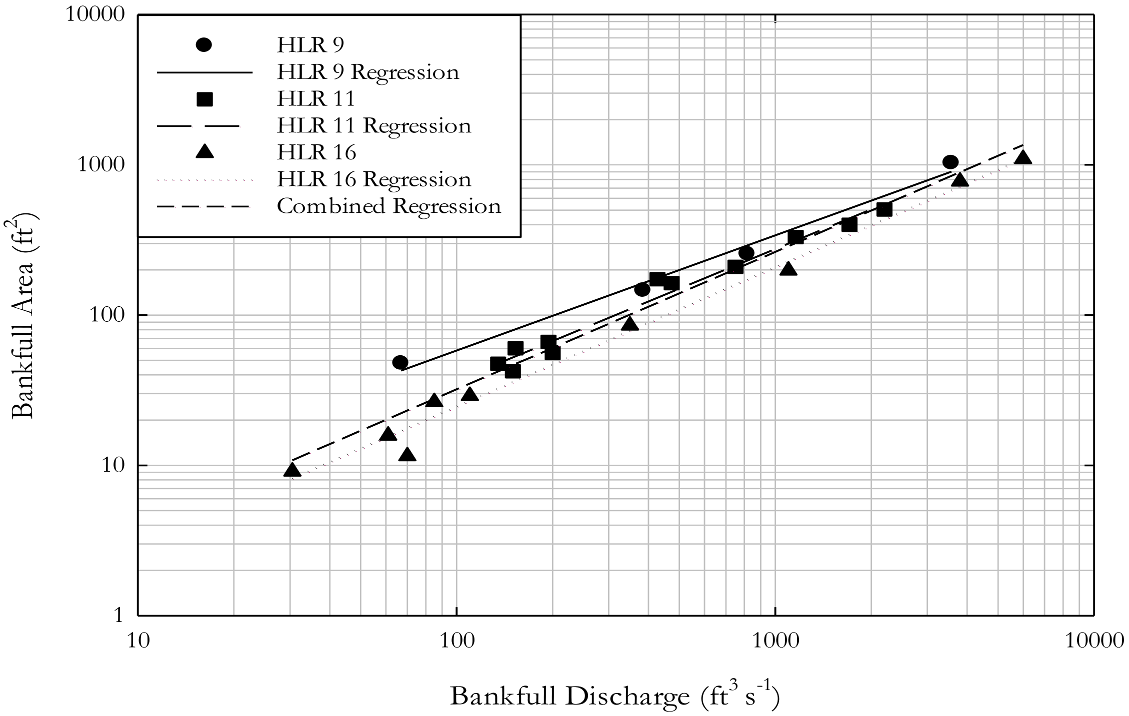


Figure 4.9: Bankfull area as a function of bankfull discharge for the combined HLR (9, 16 and 11), HLR 9, HLR 11, and HLR 16.

The hydraulic geometry curves for A_{bkf} are presented in Table 4.10 while Figure 4.9 contains a graphical representation of the data. All curves exhibited a strong fit with R^2 values ranging from 0.96 for the combined HLR curve to 0.99 for HLR 9 and 16, individually, indicating that Q_{bkf} explains almost all of the variation in A_{bkf}. The combined HLR hydraulic geometry curve has an exponent of 0.92. Exponents for the individual HLR hydraulic geometry curves (0.77 for HLR 9, 0.88 for HLR 11, and 0.93 for HLR 16) are similar to the 0.8 value found by McCandless (2003) for the Alleghany Plateaus and Ridge and Valley and the 0.83 to 0.89 range found by Brockman (2010) for the Inner and Outer Bluegrass regions of Kentucky.

4.2.2 Bankfull Width

The hydraulic geometry curves for w_{bkf} are presented in Table 4.11 while Figure 4.10 contains a graphical representation of the data. These curves exhibited a good to strong fit with R^2 values ranging from 0.79 for HLR 11 to 0.92 for HLR 16 indicating that Q_{bkf} explains much of the variation in w_{bkf}. The combined HLR hydraulic geometry curve has an exponent of 0.48. Exponents for the individual HLR hydraulic geometry curves (0.41 for HLR 9, 0.42 for HLR 11, and 0.50 for HLR 16) are similar to the 0.5 value found by Leopold et al. (1964) for the U.S., the 0.44 to 0.52 range reported by Brockman (2010), 0.47 noted by McCandless (2003) for the Allegany Plateau and Valley and Ridge regions of the eastern U.S., and 0.52 reported by Hey and Thorne (1986) for gravel bed rivers in the United Kingdom.

4.2.3 Bankfull Mean Depth

The hydraulic geometry curves for d_{bkf} are presented in Table 4.12 while Figure 4.11 contains a graphical representation of the data. These curves exhibited a moderate to strong

Table 4.11: Hydraulic geometry curves for bankfull width (w_{bkf}). w_{bkf} is in units of ft and Q_{bkf} is in units of $ft^3 s^{-1}$.

HLR	Regression Equation	R^2
Combined HLR (9, 11 and 16)	$w_{bkf}=2.56Q_{bkf}^{0.48}$	0.85
HLR 9	$w_{bkf}=4.96Q_{bkf}^{0.41}$	0.81
HLR 11	$w_{bkf}=4.09Q_{bkf}^{0.42}$	0.79
HLR 16	$w_{bkf}=1.97Q_{bkf}^{0.50}$	0.92

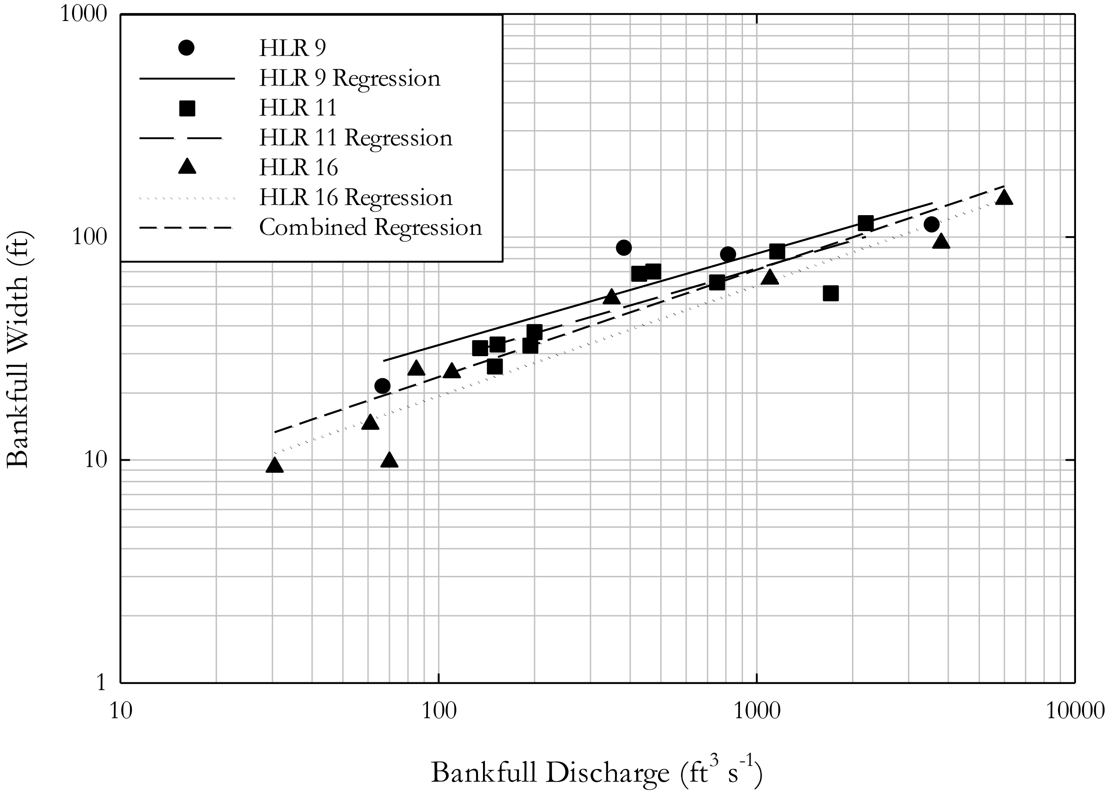


Figure 4.10: Bankfull width as a function of bankfull discharge for the combined HLR (9, 16 and 11), HLR 9, HLR 11, and HLR 16.

Table 4.12: Hydraulic geometry curves for bankfull mean depth (d_{bkf}). d_{bkf} is in units of ft and Q_{bkf} is in units of $ft^3\ s^{-1}$.

HLR	Regression Equation	R^2
Combined HLR (9, 11 and 16)	$d_{bkf}=0.19Q_{bkf}^{0.43}$	0.87
HLR 9	$d_{bkf}=0.35Q_{bkf}^{0.35}$	0.62
HLR 11	$d_{bkf}=0.16Q_{bkf}^{0.46}$	0.88
HLR 16	$d_{bkf}=0.17Q_{bkf}^{0.43}$	0.95

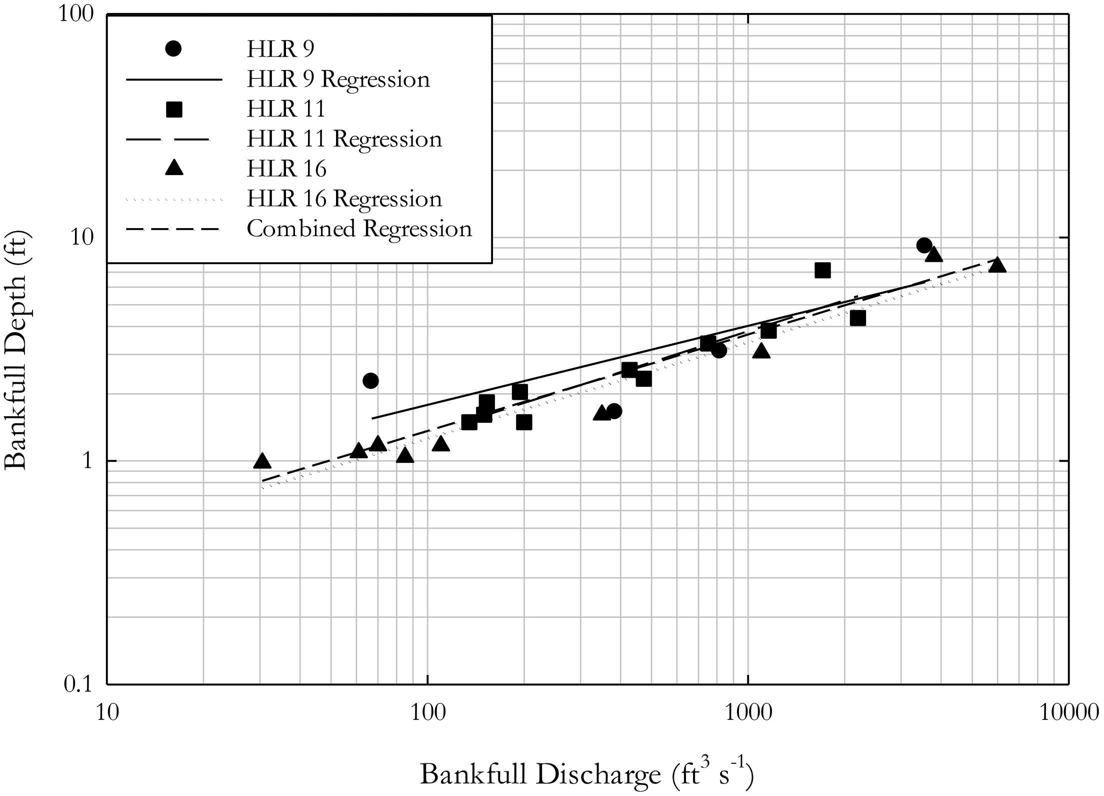


Figure 4.11: Bankfull depth as a function of bankfull discharge for the combined HLR (9, 16 and 11), HLR 9, HLR 11, and HLR 16.

fit with R^2 values ranging from 0.62 for HLR 9 to 0.95 for HLR 16 indicating that Q_{bkf} explains a moderate amount to much of the variation in d_{bkf} depending on the HLR. The combined HLR hydraulic geometry curve has an exponent of 0.43. Exponents for the individual HLR hydraulic geometry curves (0.35 for HLR 9, 0.46 for HLR 11, and 0.43 for HLR 16) are similar though slightly higher in some instances to the 0.33 to 0.40 values reported by Miller and Davis (2003), 0.40 value reported by Leopold et al. (1964), 0.36 to 0.39 range reported by Brockman (2010), 0.33 value provided by McCandless (2003), and 0.39 value noted by Hey and Thorne (1986).

4.2.4 Bankfull Velocity

The hydraulic geometry curves for v_{bkf} are presented in Table 4.13 while Figure 4.12 contains a graphical representation of the data. These curves generally exhibited a poor fit with R^2 values ranging from 0.16 for the combined HLR 9 to 0.43 for HLR 11; HLR 9 had a good fit with an R^2 value of 0.88. In all but one case, Q_{bkf} explained a minimal amount of the variation in v_{bkf}. The combined HLR hydraulic geometry curve has an exponent of 0.09. Exponents for the individual HLR hydraulic geometry curves (0.23 for HLR 9, 0.12 for HLR 11, and 0.07 for HLR 16) are similar to the 0.10 value reported by both Hey and Thorne (1986) and Leopold et al. (1964) and the 0.11 to 0.17 range reported by Brockman (2010); however, the exponents computed in this study show more variation. This variation is likely due to other factors that affect v_{bkf} such as slope and channel roughness.

4.2.5 Bankfull Slope

The hydraulic geometry curves for bankfull (local) slope, S_{bkf}, are presented in Table 4.14 while Figure 4.13 contains a graphical representation of the data. All curves exhibited a

Table 4.13 Hydraulic geometry curves for bankfull velocity (v_{bkf}). v_{bkf} is in units of ft s^{-1} and Q_{bkf} is in units of ft^3 s^{-1}.

HLR	Regression Equation	R^2
Combined HLR (9, 11 and 16)	$v_{bkf}=2.11Q_{bkf}^{0.08}$	0.16
HLR 9	$v_{bkf}=0.59Q_{bkf}^{0.23}$	0.88
HLR 11	$v_{bkf}=1.55Q_{bkf}^{0.12}$	0.43
HLR 16	$v_{bkf}=2.92Q_{bkf}^{0.07}$	0.35

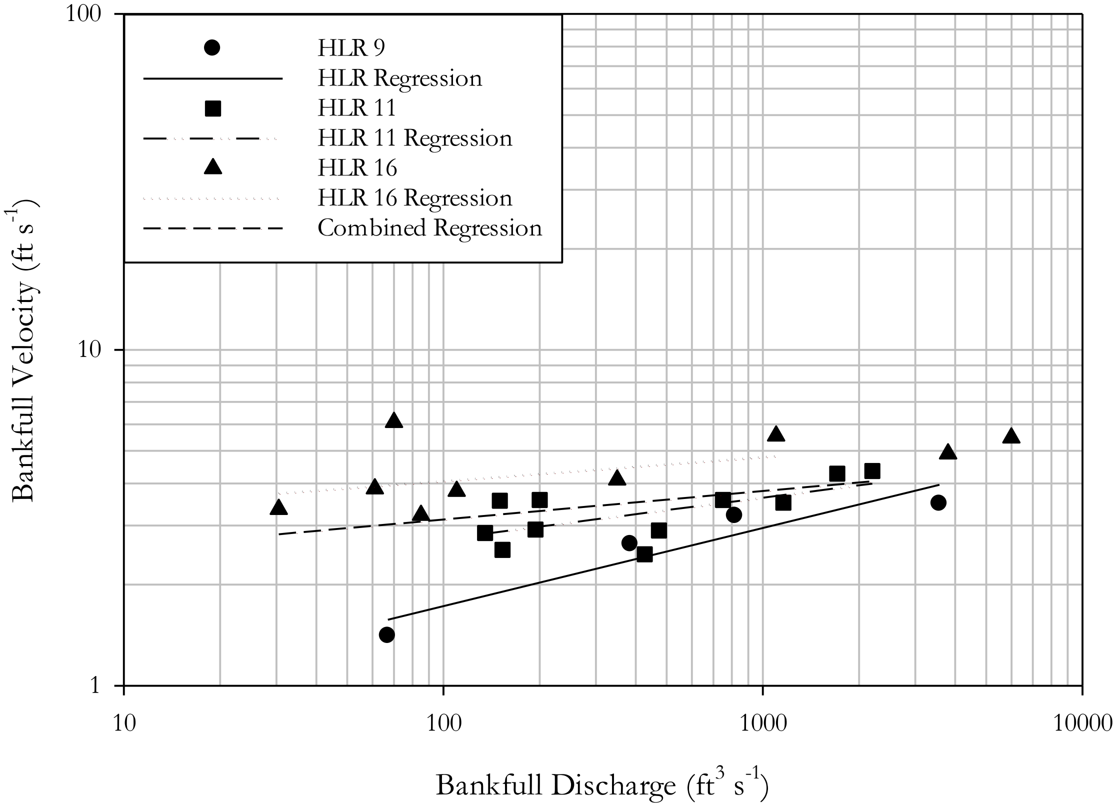


Figure 4.12: Bankfull velocity as a function of bankfull discharge for the combined HLR (9, 16 and 11), HLR 9, HLR 11, and HLR 16.

Table 4.14: Hydraulic geometry curves for bankfull slope (S_{bkf}). S_{bkf} is in units of ft ft^{-1} and Q_{bkf} is in units of ft^3 s^{-1}.

HLR	Regression Equation	R^2
Combined HLR (9, 11 and 16)	$S_{bkf}=0.06Q_{bkf}^{-0.49}$	0.27
HLR 9	$S_{bkf}=0.00Q_{bkf}^{0.04}$	1.00
HLR 11	$S_{bkf}=0.09Q_{bkf}^{-0.58}$	0.34
HLR 16	$S_{bkf}=0.02Q_{bkf}^{-0.13}$	0.25

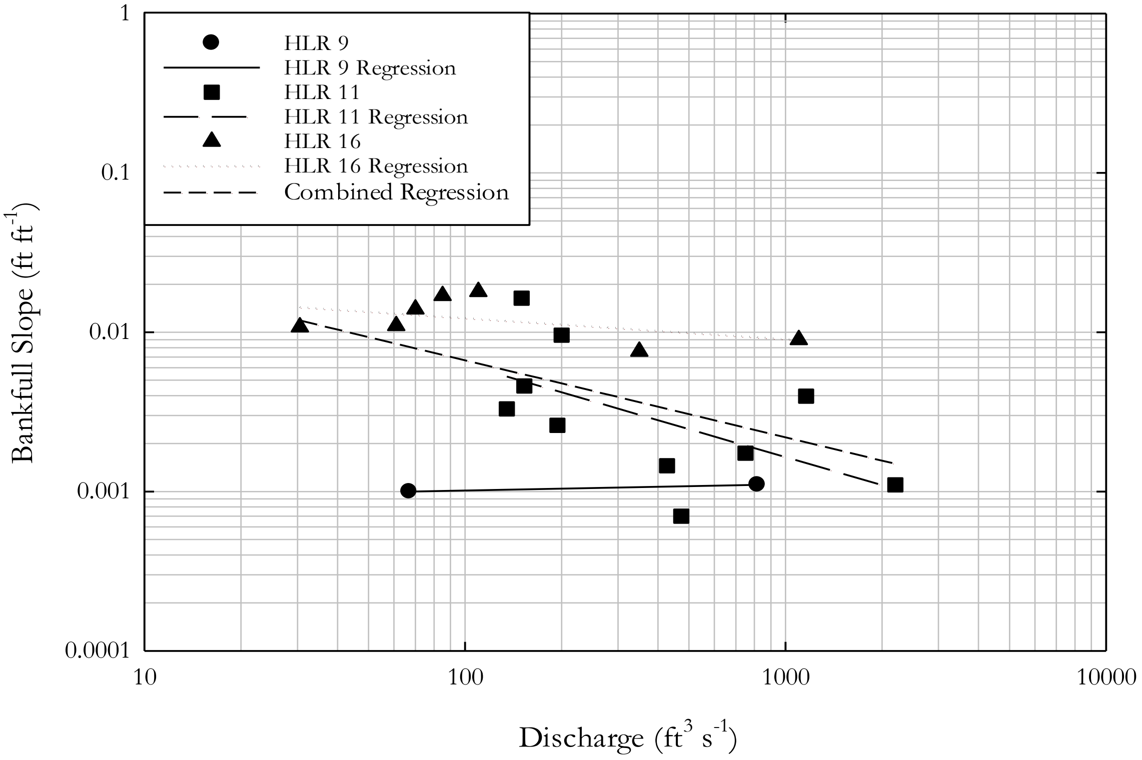


Figure 4.13: Bankfull (local) slope as a function of bankfull discharge for the combined HLR (9, 16 and 11), HLR 9, HLR 11, and HLR 16.

poor fit, except HLR 9 which only had two data points yielding an R^2 of 1.00, indicating that bankfull slope explains little variance in bankfull discharge. HLR 11 had the best fit with a R^2 value of 0.34 while the combined HLR and HLR 16 had R^2 values of 0.27 and 0.25, respectively. The combined HLR hydraulic geometry curve had an exponent of -0.49 while exponents for the individual HLR hydraulic geometry curves were 0.04, -0.58, and -0.13 for HLR 9, HLR 11, HLR 16, respectively. The combined HLR and HLR 11 had exponents similar to those found by Hey and Thorne (1986), -0.43, and Brockman (2010), -0.35 to -0.48, while HLR 16 was notably lower. As seen in Figure 4.13, the data are quite scattered but display the expected trend of a decrease in slope with an increase in drainage area (Schumm, 1977).

4.2.6 Bankfull Manning's n

Table 4.15 shows the equations computed for the combined (HLR 9, 11 and 16), and for each individual HLR. A graphical representation is shown in Figure 4.14. All equations, with the exception of HLR 9, which had only two data points, had a poor fit, meaning Manning's n explains little variance in bankfull discharge. The combined HLR exhibited an R^2 of 0.07 while HLR 9, HLR 11, and HLR 16 had R^2 values of 1.00, 0.14, and 0.06, respectively. The combined HLR hydraulic geometry curve has an exponent of -0.07 while exponents for the individual HLR hydraulic geometry curves were 0.23, -0.14, and -0.05 for HLR 9, HLR 11, HLR 16, respectively. The exponent for HLR 11 is similar to the value of -0.2 provided by Leopold et al. (1964) but is lower than the value of -0.8 provided by Brockman et al. (2010). The exponents for the combined HLR and HLR 16 are much lower than both of these studies. Neither Parola et al. (2005) nor Vesley et al. (2008) included information on riparian vegetation thus an evaluation of its influence on the resultant bankfull Manning's n trends was not performed.

Table 4.15: Hydraulic geometry curves for Manning's n at bankfull (n_{bkf}). n_{bkf} is dimensionless. Q_{bkf} is in units of ft^3 s^{-1}.

HLR	Regression Equation	R^2
Combined HLR (9, 11 and 16)	$n_{bkf}=0.07Q_{bkf}^{-0.07}$	0.07
HLR 9	$n_{bkf}=0.15Q_{bkf}^{0.23}$	1.00
HLR 11	$n_{bkf}=0.10Q_{bkf}^{-0.14}$	0.14
HLR 16	$n_{bkf}=0.04Q_{bkf}^{0.05}$	0.06

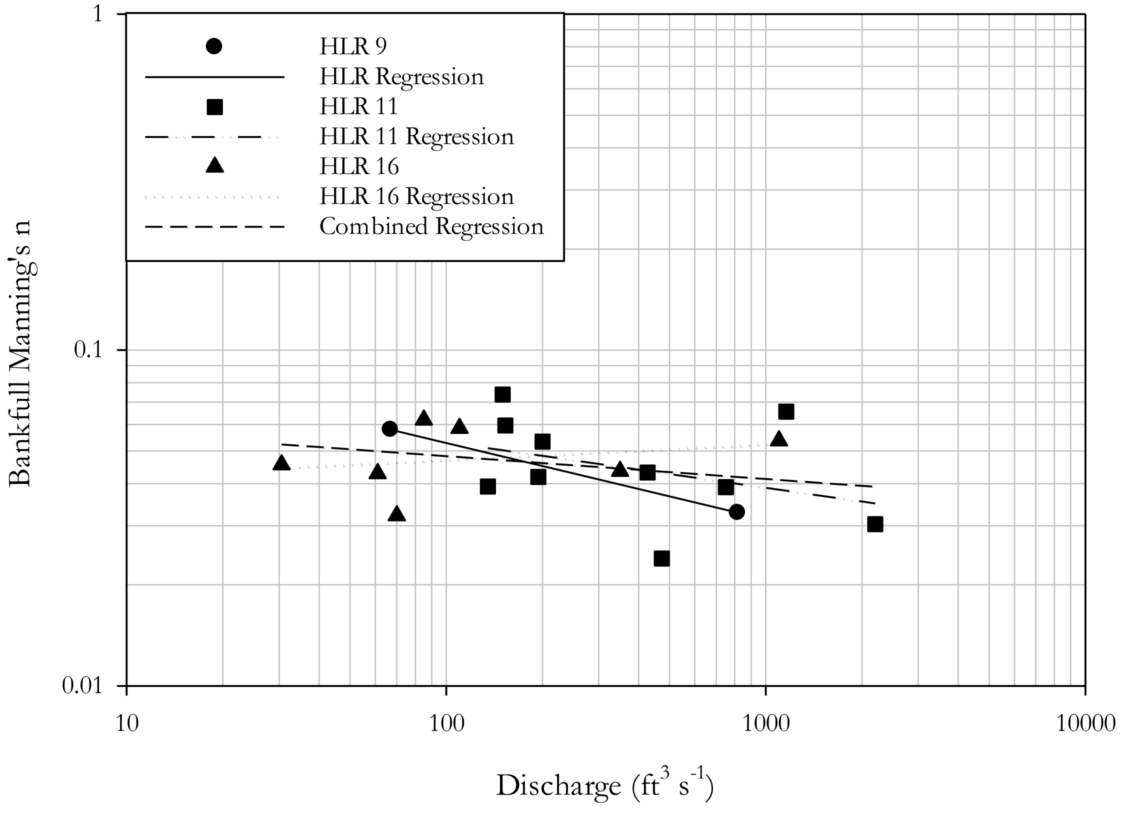


Figure 4.14: Bankfull Manning's n as a function of bankfull discharge for the combined HLR (9, 16 and 11), HLR 9*, HLR 11, and HLR 16. HLR 9 only had data available for two points.

4.2.7 Statistical Comparison

Results of the statistical comparisons of hydraulic geometry curves between HLRs are presented in Table 4.16.

4.2.7.1 Bankfull Cross-sectional Area

HLR 9 significantly differed from HLR 11, HLR 16, Combined HLRs, and U.S. HLR 9 (Figure 4.15) (Table 4.16). The exponent (h=0.77) of the HLR 9 hydraulic geometry curve was smaller than the exponents from HLR 11 (h=0.88), HLR 16 (h=0.93), Combined HLRs (h=0.92), and U.S. HLR 9 (h=0.83) while the intercept was between 2-5 times larger for HLR 9 (g=1.69) than all the other hydraulic geometry curves from the EKC region and the U.S. curved developed using data from Blackburn-Lynch (2015) (Table 4.17). As seen in Figure 4.15 and Table 4.18, the hydraulic geometry curve for HLR 9 predicted larger values for A_{bkf} as compared to the other curves, particularly for Q_{bkf} values less than 1,000 ft^3 s^{-1}. At 250 ft^3 s^{-1}, for example, the predicted value of A_{bkf} for HLR 9 is 119 ft^2 versus 82 ft^2 for HLR 11, 58 ft^2 for HLR 16, 76 ft^2 for Combined HLRs, and 71 ft^2 for U.S. HLR 9. Caution is recommended when interpreting these results as only four data points were used to develop the A_{bkf} hydraulic geometry curves for HLR 9.

4.2.7.2 Bankfull Width

For w_{bkf}, HLR 9 differed significantly from U.S. HLR 9; no other significant differences were found amongst the hydraulic geometry curves (Figure 4.16) (Table 4.16). HLR 9 had the smallest exponent (b=0.41) while U.S. HLR 9 had the largest (h=0.51) (Table 4.17).

Table 4.16: Results of the comparison of hydraulic geometry curves based on HLR. H_o: No significant differences in slopes or intercepts amongst hydraulic geometry equations. H_a: Significant differences in slopes or intercepts amongst hydraulic geometry equations.

Comparison	**A_{bkf}**		**w_{bkf}**		**d_{bkf}**		**v_{bkf}**		**S_{bkf}**		**n_{bkf}**	
	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**
HLR 9 vs. Combined HLRs	0.01	Yes	0.73	No	0.13	No	0.86	No	--[1]	--	--[1]	--
HLR 11 vs. Combined HLRs	0.51	No	0.24	No	0.23	No	0.91	No	0.59	No	0.92	No
HLR 16 vs. Combined HLRs	0.26	No	0.95	No	0.49	No	0.59	No	0.96	No	0.42	No
HLR 9 vs. U.S. HLR 9	0.05	Yes	0.05	Yes	0.00	Yes	0.79	No	--	--	--	--

Comparison	**A_{bkf}**		**w_{bkf}**		**d_{bkf}**		**v_{bkf}**		**S_{bkf}**		**n_{bkf}**	
	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**	***p*-value**	**Reject H_o?**
HLR 11 vs. U.S. HLR 11	0.28	No	0.40	No	0.04	Yes	0.95	No	--	--	--	--
HLR 16 vs. U.S. HLR 16	0.34	No	0.34	No	0.08	No	0.45	No	--	--	--	--
HLR 9 vs. HLR 11	0.00	Yes	0.26	No	0.92	No	0.10	No	--	--	--	--
HLR 9 vs. HLR 16	0.00	Yes	0.69	No	0.05	Yes	0.05	Yes	--	--	--	--
HLR 11 vs. HLR 16	0.01	Yes	0.17	No	0.11	No	0.64	No	0.67	No	0.45	No

Table 4.16 cont'd.

[1] Only two data points were available for HLR 9, so comparisons were not made.

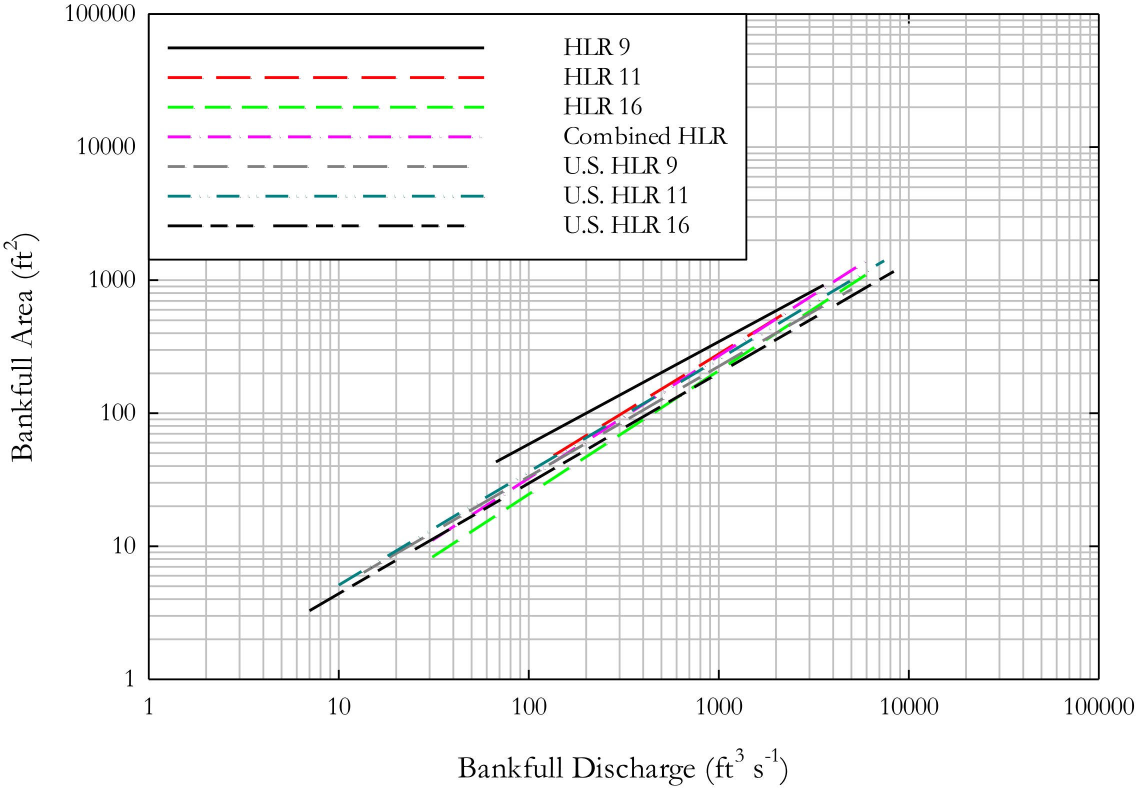


Figure 4.15: Comparison of hydraulic geometry relationships for bankfull cross-sectional area.

Table 4.17: Comparison of hydraulic geometry curves in the Eastern United States and Appalachian Region where $A_{bkf}=gQ_{bkf}^{h}$, $w_{bkf}=aQ_{bkf}^{b}$, $d_{bkf}=Q_{bkf}^{f}$, $v_{bkf}=kQ_{bkf}^{m}$, $S_{bkf}=tQ_{bkf}^{z}$, and $n_{bkf}=xQ_{bkf}^{y}$. Q_{bkf} is bankfull discharge (ft^{3} s^{-1}), A_{bkf} is bankfull cross-sectional area (ft^{2}), w_{bkf} is bankfull width (ft), d_{bkf} is bankfull mean depth (ft), v_{bkf} is bankfull velocity (ft s^{-1}), S_{bkf} is bankfull slope (ft ft^{-1}), and n_{bkf} is bankfull Manning's roughness coefficient (dimensionless).

Study	**A_{bkf}**			**w_{bkf}**			**d_{bkf}**			**v_{bkf}**			**S_{bkf}**			**n_{bkf}**		
	g	**h**	**R^2**	**a**	**B**	**R^2**	**c**	**f**	**R^2**	**k**	**m**	**R^2**	**t**	**z**	**R^2**	**x**	**y**	**R^2**
Combined HLRs	0.47	0.92	0.96	2.56	0.48	0.85	0.19	0.43	0.87	2.11	0.08	0.16	0.06	-0.49	0.27	0.07	-0.07	0.07
HLR 9	1.69	0.77	0.99	4.96	0.41	0.81	0.35	0.35	0.62	0.59	0.23	0.88	0.00	0.04	1.00	0.15	-0.23	1.00
HLR 11	0.64	0.88	0.97	4.09	0.42	0.79	0.16	0.46	0.88	1.55	0.12	0.43	0.09	-0.58	0.34	0.10	-0.14	0.14
HLR 16	0.34	0.93	0.99	1.97	0.50	0.92	0.17	0.43	0.95	2.92	0.07	0.35	0.02	-0.13	0.25	0.04	0.05	0.06
U.S. HLR 9	0.73	0.83	0.91	2.12	0.51	0.90	0.35	0.32	0.72	1.36	0.17	0.29	--	--	--	--	--	--

Table 4.17 cont'd.

Study	**A_{bkf}**			**w_{bkf}**			**d_{bkf}**			**v_{bkf}**			**S_{bkf}**			**n_{bkf}**		
	g	**h**	**R^2**	**a**	**B**	**R^2**	**c**	**f**	**R^2**	**k**	**m**	**R^2**	**t**	**z**	**R^2**	**x**	**y**	**R^2**
U.S. HLR 11	0.72	0.85	0.93	2.88	0.46	0.87	0.25	0.39	0.79	1.39	0.15	0.31	--	--	--	--	--	--
U.S. HLR 16	0.65	0.83	0.93	2.59	0.48	0.88	0.25	0.35	0.80	1.55	0.17	0.35	--	--	--	--	--	--
Brockman (2010)[1]	0.82	0.85	0.94	2.64	0.49	0.94	0.31	0.36	0.84	1.21	0.15	0.32	0.03	-0.35	0.42	0.1	-0.8	0.09
McCandless (2003)[2]	0.79	0.80	0.95	2.65	0.47	0.94	0.3	0.33	0.91	--	--	--	--	--	--	--	--	--
Leopold et. al (1964)[3]	--	--	--	--	0.53	--	--	0.37	--	--	0.10	--	--	-0.70	--	--	-0.2	--
Leopold et al. (1964)[4]	--	--	--	--	0.50	--	--	0.40	--	--	0.10	--	--	--	--	--	--	--

Table 4.17 cont'd.

Study	**A_{bkf}**			**w_{bkf}**			**d_{bkf}**			**v_{bkf}**			**S_{bkf}**			**n_{bkf}**		
	g	**h**	**R^2**	**a**	**B**	**R^2**	**c**	**f**	**R^2**	**k**	**m**	**R^2**	**t**	**z**	**R^2**	**x**	**y**	**R^2**
Hey and Thorne (1986)[5]	--	--	--	2.17	0.52	0.96	0.20	0.39	0.86	2.54	0.10	0.79	--	--	--	--	--	--

[1] Combined Inner and Outer Bluegrass Regions of Kentucky
[2] Bedrock, cobble and gravel streams in Allegheny Plateau and Valley and Ridge Regions
[3] Theoretical equations
[4] River in downstream direction
[5] Equations developed in metric system. Gravel bed rivers in the United Kingdom with >50% tree cover.

Table 4.18: Comparison of HLR-based hydraulic geometry curves developed for the EKC and U.S. wide.

Bankfull Parameters	**Study**	**Discharge ($ft^3\ s^{-1}$)**						
		50	**100**	**250**	**500**	**1,000**	**2,500**	**5,000**
A_{bkf}	Combined HLRs	17	33	76	143	270	628	1,189
	HLR 9	34	59	119	202	345	699	1,192
	HLR 11	20	37	82	152	279	626	1,152
	HLR 16	13	25	58	110	210	492	937
	U.S. HLR 9	19	33	71	127	226	483	858
	U.S. HLR 11	20	36	79	142	255	557	1,003
	U.S. HLR 16	17	30	64	113	201	430	764
w_{bkf}	Combined HLRs	17	33	36	51	71	109	153
	HLR 9	25	33	48	63	84	123	163
	HLR 11	21	28	42	56	74	109	146
	HLR 16	14	20	31	44	62	99	139
	U.S. HLR 9	16	22	35	50	72	115	163
	U.S. HLR 11	17	24	37	50	69	105	145
	U.S. HLR 16	17	24	37	51	71	111	154

Table 4.18 cont'd.

Bankfull Parameters	**Study**	**Discharge (ft^3 s^{-1})**						
		50	**100**	**250**	**500**	**1,000**	**2,500**	**5,000**
d_{bkf}	Combined HLRs	1.0	1.4	2.0	2.8	3.7	5.5	7.4
	HLR 9	1.4	1.8	2.4	3.1	3.9	5.4	6.9
	HLR 11	1.0	1.3	2.0	2.8	3.8	5.9	8.1
	HLR 16	0.9	1.2	1.8	2.5	3.3	4.9	6.6
	U.S. HLR 9	1.2	1.5	2.1	2.6	3.2	4.3	5.3
	U.S. HLR 11	1.2	1.5	2.2	2.8	3.7	5.3	6.9
	U.S. HLR 16	1.0	1.3	1.7	2.2	2.8	3.9	4.9
v_{bkf}	Combined HLRs	2.9	3.1	3.3	3.5	3.7	4.0	4.2
	HLR 9	1.5	1.7	2.1	2.5	2.9	3.6	4.2
	HLR 11	2.5	2.7	3.0	3.3	3.6	4.0	4.3
	HLR 16	3.8	4.0	4.3	4.5	4.7	5.1	5.3
	U.S. HLR 9	2.6	3.0	3.5	3.9	4.4	5.1	5.8
	U.S. HLR 11	2.5	2.8	3.2	3.5	3.9	4.5	5.0
	U.S. HLR 16	3.1	3.4	4.0	4.5	5.0	5.9	6.6

Table 4.18 cont'd.

Bankfull Parameters	**Study**	**Discharge (ft^3 s^{-1})**						
		50	**100**	**250**	**500**	**1,000**	**2,500**	**5,000**
S_{bkf}	Combined HLRs	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	HLR 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	HLR 11	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	HLR 16	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	U.S. HLR 9	--	--	--	--	--	--	--
	U.S. HLR 11	--	--	--	--	--	--	--
	U.S. HLR 16	--	--	--	--	--	--	--
n_{bkf}	Combined HLRs	0.05	0.05	0.05	0.05	0.04	0.04	0.04
	HLR 9	0.06	0.05	0.04	0.04	0.03	0.02	0.02
	HLR 11	0.06	0.05	0.05	0.04	0.04	0.03	0.03
	HLR 16	0.05	0.05	0.05	0.05	0.06	0.06	0.06
	U.S. HLR 9	--	--	--	--	--	--	--
	U.S. HLR 11	--	--	--	--	--	--	--
	U.S HLR 16	--	--	--	--	--	--	--

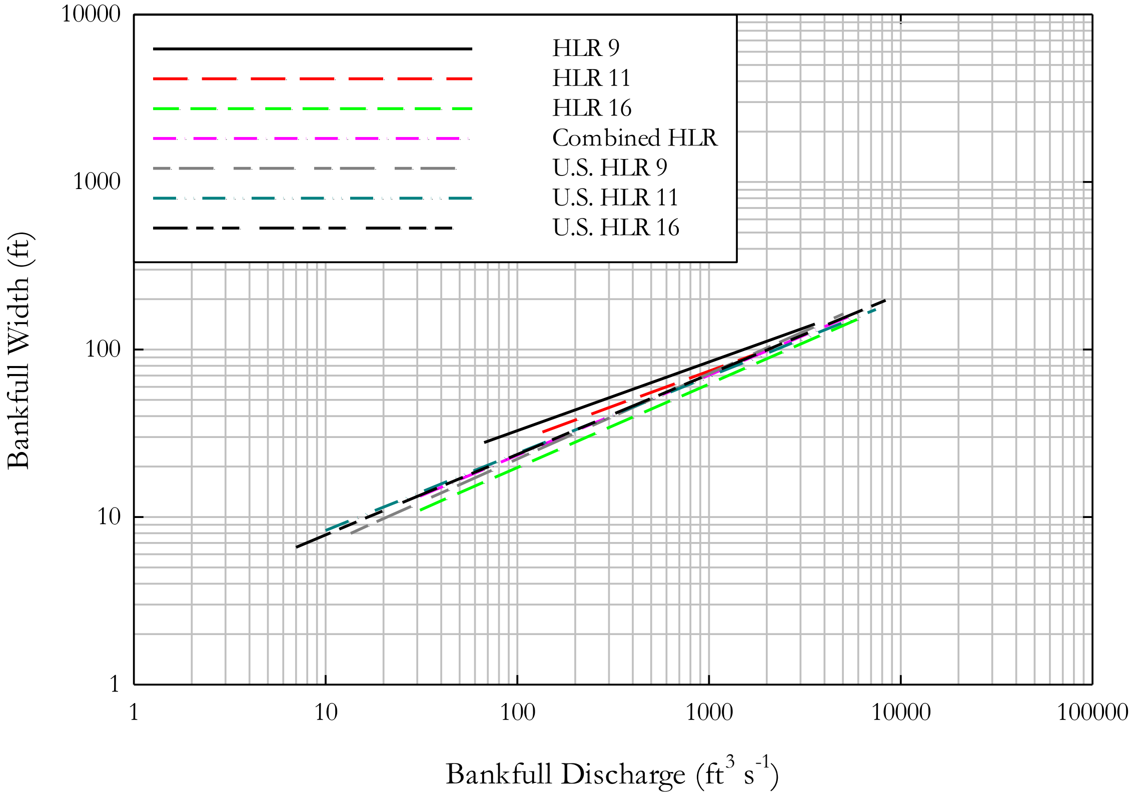


Figure 4.16: Comparison of hydraulic geometry relationships for bankfull width.

HLR 9 had the largest coefficient (a=4.96) of the produced curves. As with A_{bkf}, caution is recommended as only four data points were used to construct the HLR 9 hydraulic geometry curves. While significant differences were noted between HLR 9 and U.S. HLR 9, these differences may be the result of low amounts of data rather than physically based differences with HLR 9 (e.g. geology and topography) that could influence bankfull characteristics. The lack of significant differences between HLR 9, HLR 11, and HLR 16 indicates that separation of the EKC region based on hydrologic landscape units was not warranted. This result was not surprising as Johnson and Fecko (2008) found regional equations, which were developed within the same physiographic region, were statistically similar.

4.2.7.3 Bankfull Mean Depth

Significant differences were found between HLR 9 and HLR 16, HLR 9 and U.S. HLR 9, and HLR 11 and U.S. HLR 11 for the parameter d_{bkf} (Figure 4.17) (Table 4.16). HLR 9 had a smaller exponent than HLR 16 (f=0.35 vs f=0.43, respectively) while HLR 16 had a smaller coefficient than HLR 9 (c=0.17 vs c=0.35, respectively) (Table 4.17). As seen in Figure 4.19, the two curves differed more for lower values of Q_{bkf} but began to converge above 1,000 ft^3 s^{-1}. Significant differences were noted between HLR 9 and U.S. HLR 9, largely with respect to

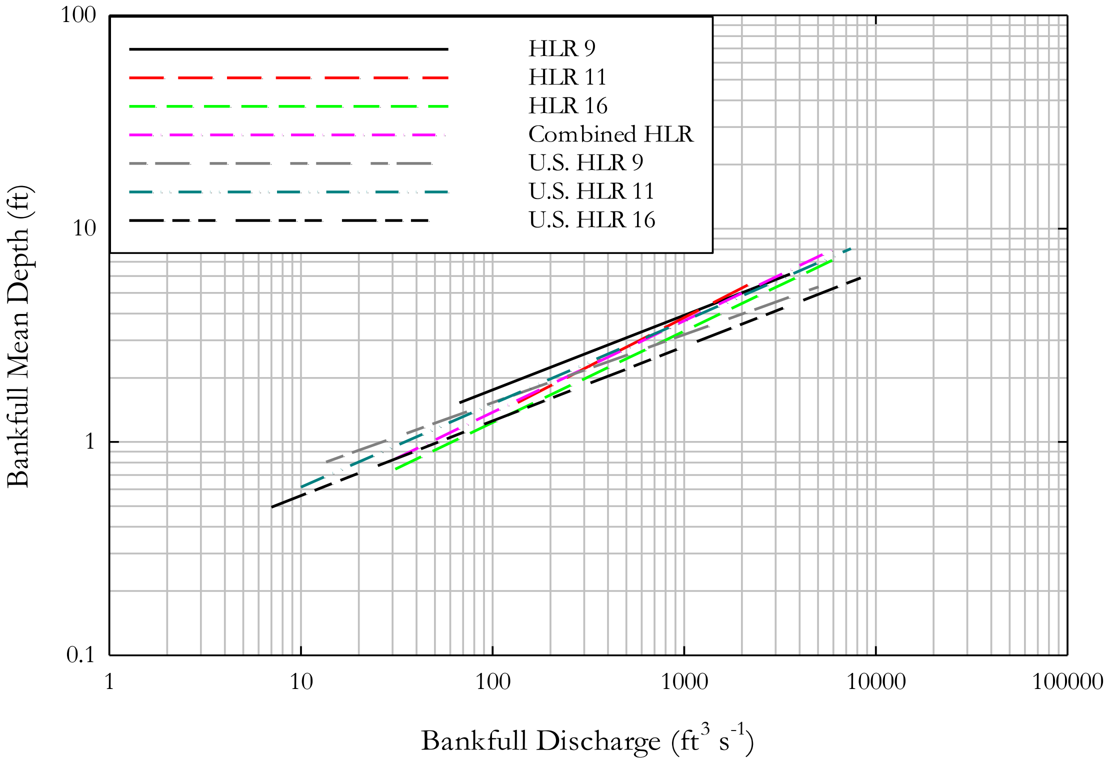


Figure 4.17: Comparison of hydraulic geometry relationships for bankfull mean depth.

exponent values. Differences associated with HLR 9, as with A_{bkf} and w_{bkf}, may be the result of few data points. HLR 11 had a larger exponent (f=0.46) and smaller coefficient (c=0.16) as compared to U.S. HLR 11 (f=0.39, c=0.25). At 250 $ft^3\ s^{-1}$, values for d_{bkf} were 2.4 ft for HLR 9, 2.0 ft for HLR 11, 1.8 ft for HLR 16, and 2.1 ft for U.S. HLR 9 (Table 4.17).

4.2.7.4 Bankfull Velocity

Significant differences were noted only between HLR 9 and HLR 16 for the parameter $v_{bkf..}$ As seen in Figure 4.18 and Table 4.16, the HLR 16 hydraulic geometry curve has a lower slope (m=0.07) and a large coefficient (k=2.92) than HLR 9 (m=0.23, k=0.59). The larger A_{bkf} values for HLR 9 resulted in smaller v_{bkf} values (i.e. continuity equation). Differences between HLR 9 and HLR 16 were more pronounced at lower Q_{bkf} flows (Table 4.18). For a Q_{bkf} of 250 $ft^3\ s^{-1}$, the predicted v_{bkf} for HLR 9 is 2.1 ft s^{-1} and 4.3 ft s^{-1} for HLR 16. As previously noted, only four data points were used to develop the hydraulic geometry curves for HLR 9, so results should be interpreted cautiously.

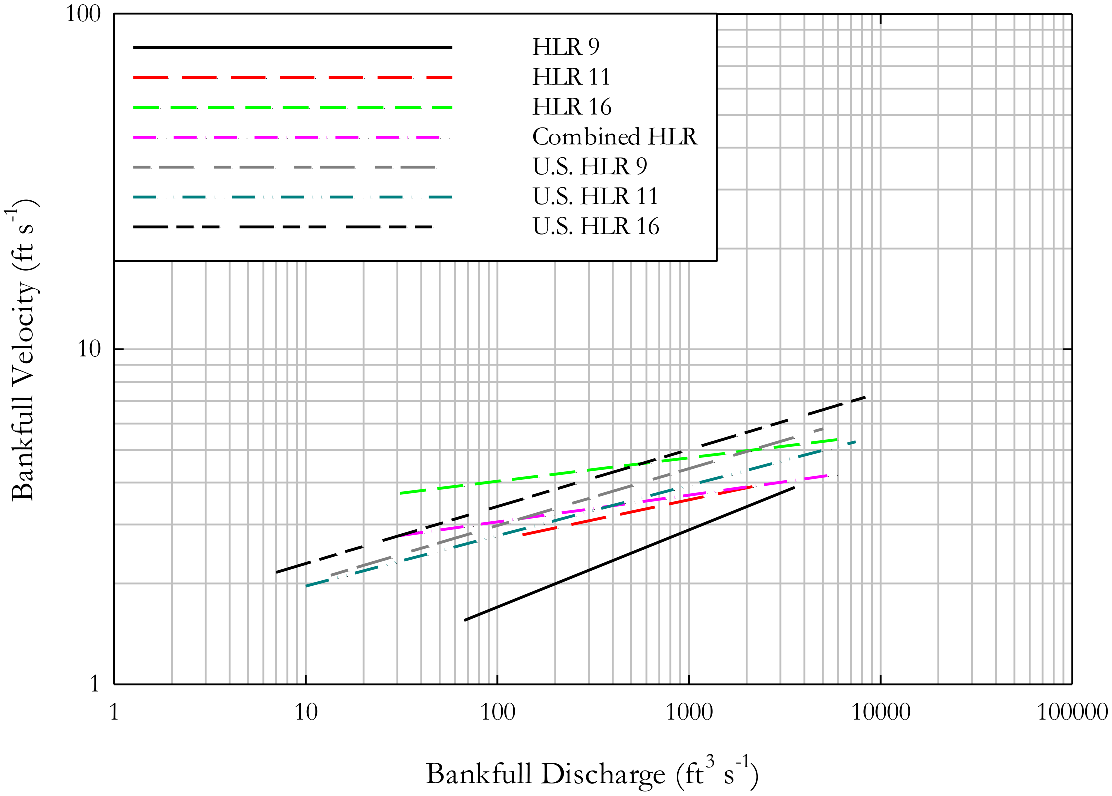


Figure 4.18: Comparison of hydraulic geometry relationships for bankfull velocity.

4.2.7.5 Bankfull Slope

Blackburn-Lynch (2015) did not report S_{bkf} values, therefore U.S.-wide hydraulic geometry curves for this parameter were not determined. Because HLR 9 had only two S_{bkf} data points, comparisons were not made to HLR 9. No significant differences were noted between HLR 11, HLR 16, or Combined HLR (Figure 4.19) (Table 4.16).

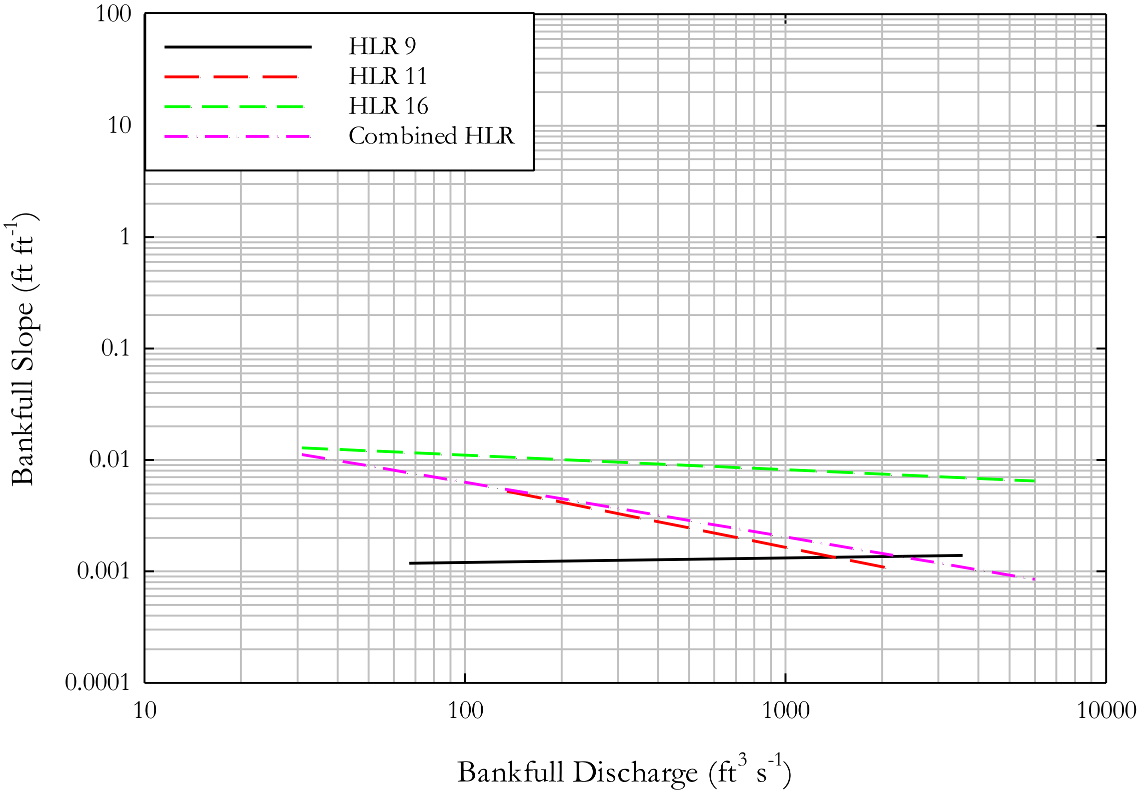


Figure 4.19: Comparison of hydraulic geometry relationships for bankfull slope.

4.2.7.6 Manning's n

As with S_{bkf}, Blackburn-Lynch (2015) did not report n_{bkf} values nor the necessary data to compute n_{bkf} using Manning's equation, therefore U.S.-wide hydraulic geometry curves for n_{bkf} were not determined. Because HLR 9 had only two n_{bkf} data points, comparisons were not made to HLR 9. No significant differences were noted between HLR 11, HLR 16, or Combined HLR (Figure 4.20) (Table 4.16).

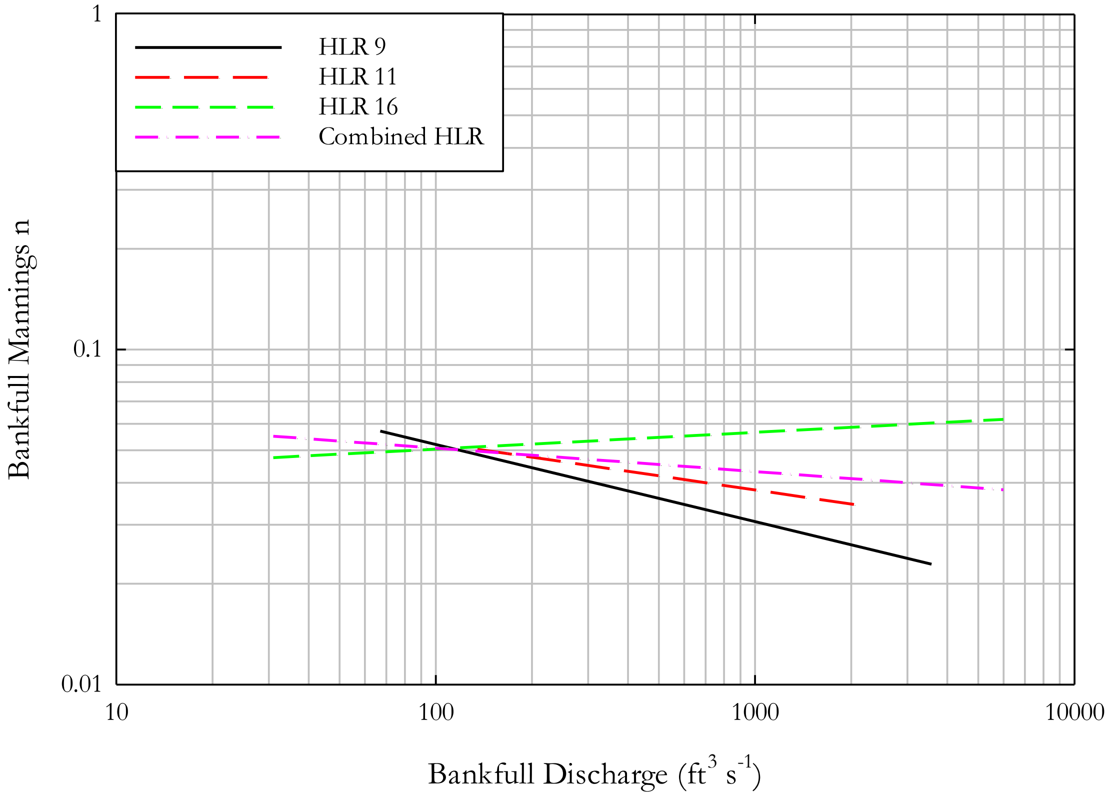


Figure 4.20: Comparison of hydraulic geometry relationships for bankfull Manning's n.

4.2.7.7 Hydraulic Geometry Curve Comparison Summary

Excluding HLR 9, which had only four data points and the results surrounding which should be interpreted with caution, statistical differences between hydraulic geometry curves for HLRs in the EKC as well as the U.S. wide HLRs were limited to A_{bkf} for HLR 11 and HLR 16 as well as d_{bkf} for HLR 11 and U.S. HLR 11. The lack of significant differences between HLRs in the EKC region indicates that one hydraulic geometry curve for the entire region (e.g. Combined HLRs) may be sufficient for stream assessment and natural channel design purposes. However, as seen in Table 4.18, the differences in predicted channel dimensions between the different

HLRs in the EKC region may be unacceptable to the designer, depending on the size of the stream system of interest. For example, at a Q_{bkf} of 50 ft^3 s^{-1}, the predicted A_{bkf} for a stream in HLR 9 is 34 ft^2, 20 ft^2 for HLR 11, and 13 ft^2 for HLR 16. Hence, the size of a stream in HLR 9 is 1.7 times larger than one in HLR 11 and 2.6 times larger than one in HLR 16; HLR 11 is 1.5 times larger than HLR 16. At a Q_{bkf} of 5,000 ft^3 s^{-1}, these differences are smaller particularly between the closer HLR units of 9 and 11. HLR 9 is only 1.03 times larger than HLR 11 but is 1.3 times larger than HLR 16; HLR 11 is 1.2 times larger than HLR 16.

Also important were the lack of statistical differences between the same HLR regions using data only within the EKC region and using data throughout the contiguous U.S., exempting HLR 9 from the EKC region. The results of this study suggest that designers challenged with finding acceptable reference streams within a HLR region, such as in the case of significant anthropogenic (e.g. mining, agriculture, urbanization) or natural impacts (e.g. fires, volcanic eruptions, floods), may look to the same type of HLR regions located in other geographic areas throughout the U.S. for acceptable data. As seen in Table 4.18, the predicted A_{bkf} of a stream with a Q_{bkf} of 50 ft^3 s^{-1} is 20 ft^2 for both HLR 11 and U.S. HLR 11 and is 13 ft^2 for HLR 16 and 17 ft^2 for U.S. HLR 16 (1.3 times larger). At 5,000 ft^3 s^{-1}, HLR 11 is 1,152 ft^2 compared to 1,003 ft^2 for U.S. HLR 11 (0.87 times smaller) and is 937 ft^2 for HLR 16 and 764 ft^2 for U.S. HLR 16 (0.82 times smaller). Important to note is that this study did not conduct a statistical comparison between U.S.-wide HLRs. Therefore, utilizing data from non-similar HLRs to supplement hydraulic geometry curve datasets is not recommended at this time.

CHAPTER 5: CONCLUSIONS

Within the EKC, 27 streams were surveyed, in the field, to determine their bankfull parameters of cross-sectional area, width, and mean depth. This dataset was supplemented using bankfull parameter values from Parola et al. (2005), Vesely et al. (2008), and Agouridis (2012). These data were used to develop regional curves and hydraulic geometry curves for three individual HLRs within the EKC (HLR 9, HLR 11, and HLR 16) as well as one for the entire EKC (Combined HLRs). U.S. wide regional curves and hydraulic geometry curves were also created using data from Blackburn-Lynch (2015); only sites with drainage areas less than 250 mi^2 were used as this was the upper range for the sites examined in the EKC.

5.1 REGIONAL CURVES

Results indicate that separating the EKC based on HLR for the development of regional curves was beneficial as in most instances R^2 improved over the Combined HLRs and significant differences were present between one or more of the HLR regions within the EKC (i.e. why R^2 of individual HLRs was generally higher than Combined HLRs). For Q_{bkf}, HLR 16 differed significantly from HLR 9 and HLR 11. For A_{bkf}, HLR 11 differed significantly from HLR 9 and HLR 16. Little variation (i.e. no significant differences) were present between the HLRs in the EKC for w_{bkf}. For d_{bkf}, significant differences were noted between HLR 9 and HLR 16 as well as HLR 11 and HLR 16. Differences between the HLRs within the EKC were greatest for smaller drainage areas, which are more characteristic of the size of watersheds in which stream restoration projects occur (Alexander and Allan, 2006; Mecklenburg and Fay, 2011).

Using the HLR specific regional curves predicted different channel sizes and dimensions. The HLR 9 regional curves would generate a larger and wider channel, then an average of all three HLRs, even for the lowest predicted Q_{bkf} of the HLRs. The impermeable soils of HLR 9 are ideal for overland flow production, and the permeable bedrock (i.e. karst) means groundwater and surface waters are closely connected (Wolock et al., 2004). The HLR 11 regional curves would also generate a larger channel with a slightly greater width even though the predicted Q_{bkf} is about the same as the average for the EKC. Like HLR 9, the soils of HLR 11 are impermeable but so is the bedrock (Wolock et al., 2004) which explains the larger expected Q_{bkf} value for HLR 11 as compared to HLR 9. Lastly, the HLR 16 regional curves would generate a similar sized channel to the average for the EKC but one that is narrower and slightly deeper. HLR 16 is characterized by impermeable soils like HLR but bedrock like HLR 11; it has steeper topography than HLR 9 or HLR 11 (Wolock et al., 2004). As expected, the predicted Q_{bkf} is largest for HLR 16, and the steeper slopes produce larger v_{bkf}. values as compared to the other EKC HLRs resulting in deeper channels due to scouring (Schumm and Khan, 1972).

Comparison of the regional curves for the three HLRs examined in the EKC to those same HLRs on a U.S. wide basis found few statistical differences. No statistical differences were found for Q_{bkf} but were for A_{bkf}, $w_{\mathbf{bkf}}$ and d_{bkf}. For A_{bkf}, significant differences were noted between HLR 11 and U.S. HLR 11. For w_{bkf}, differences were present between HLR 16 and U.S. 16. For d_{bkf}, differences were present between HLR 9 and U.S. HLR 9 as well as HLR 16 and U.S. HLR 16. In each of these cases, the U.S. wide HLRs predicted larger channel dimensions as compared to the HLRs in the EKC. The lack of statistical significance between some HLRs for some bankfull parameters suggests designers who are challenged with finding acceptable reference stream sites may look to the same type of HLRs in other parts of the U.S. to supplement their datasets for certain bankfull parameters but not all.

5.2 HYDRAULIC GEOMETRY CURVES

Excluding HLR 9, which had only four data points and the results surrounding which should be interpreted with caution, statistical differences between hydraulic geometry curves for HLRs in the EKC as well as the U.S. wide HLRs were limited to A_{bkf} for HLR 11 and HLR 16 as well as d_{bkf} for HLR 11 and U.S. HLR 11. The lack of significant differences between HLRs in the EKC region indicates that one hydraulic geometry curve for the entire region (e.g. Combined HLRs) may be sufficient for stream assessment and natural channel design purposes. However, the differences in predicted channel dimensions between the different HLRs in the EKC region may be unacceptable to the designer, depending on the size of the stream system of interest.

Also important were the lack of statistical differences between the same HLR regions using data only within the EKC region and using data throughout the contiguous U.S., exempting HLR 9 from the EKC region. The results of this study suggest that designers challenged with finding acceptable reference streams within a HLR region, such as in the case of significant anthropogenic (e.g. mining, agriculture, urbanization) or natural impacts (e.g. fires, volcanic eruptions, floods), may look to the same type of HLR regions located in other geographic areas throughout the U.S. for acceptable data. Important to note is that this study did not conduct a statistical comparison between U.S.-wide HLRs. Therefore, utilizing data from non-similar HLRs to supplement hydraulic geometry curve datasets is not recommended at this time.

CHAPTER 6: FUTURE WORK

This research was challenged by the lack of long-term active USGS gages in the EKC. Development of hydrologic geometry curves requires the development of a robust stream gaging network that encompassing a wide range of stream sizes (e.g. small headwater streams to rivers). When determining where to place a stream gage, consideration should be given to the HLR in which the gage will be located. For instance, HLR 9 had quite limited discharge data. Future work should also consider the effect of riparian vegetation type (e.g. grass, forested, mixture of grass and forest) on bankfull channel dimensions as grouped by HLR. Because of the different nature of soil and bedrock permeability between the examined HLRs, as well as general topographic slope, it is possible that the influence of vegetation differs between the HLRs.

APPENDIX A: CROSS-SECTIONAL DATA

(a) (b)

Figure A.1: (a) Upstream and (b) downstream views of Site ID 2: Rose Creek (HLR 9).

Elevations in all tables are relative to HI=105 ft.

Table A.1: Cross-sectional survey data for Site ID 2: Rose Creek, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	0.46	104.54	
2	0.66	104.34	
2.5	2.40	102.60	
3	2.65	102.35	
3.5	3.37	101.63	
4	3.64	101.36	
4.5	4.37	100.63	
5	4.80	100.20	
6	5.10	99.90	
7	4.88	100.12	
8	4.86	100.14	
9	4.84	100.16	BKF
10	5.09	99.91	
10.5	5.43	99.57	LEW
11	5.92	99.08	
12	6.11	98.89	
13.5	6.01	98.99	
15	6.08	98.92	
17	6.03	98.97	
19	5.84	99.16	
20	5.65	99.35	REW
22	5.52	99.48	
24	5.26	99.74	
26	5.00	100.00	
28	4.78	100.22	
30	4.75	100.25	
32	4.56	100.44	
34	4.90	100.10	
35	4.41	100.59	
36	4.00	101.00	
38	3.76	101.24	
40	3.53	101.47	
42	3.35	101.65	
44	3.00	102.00	
45	2.85	102.15	

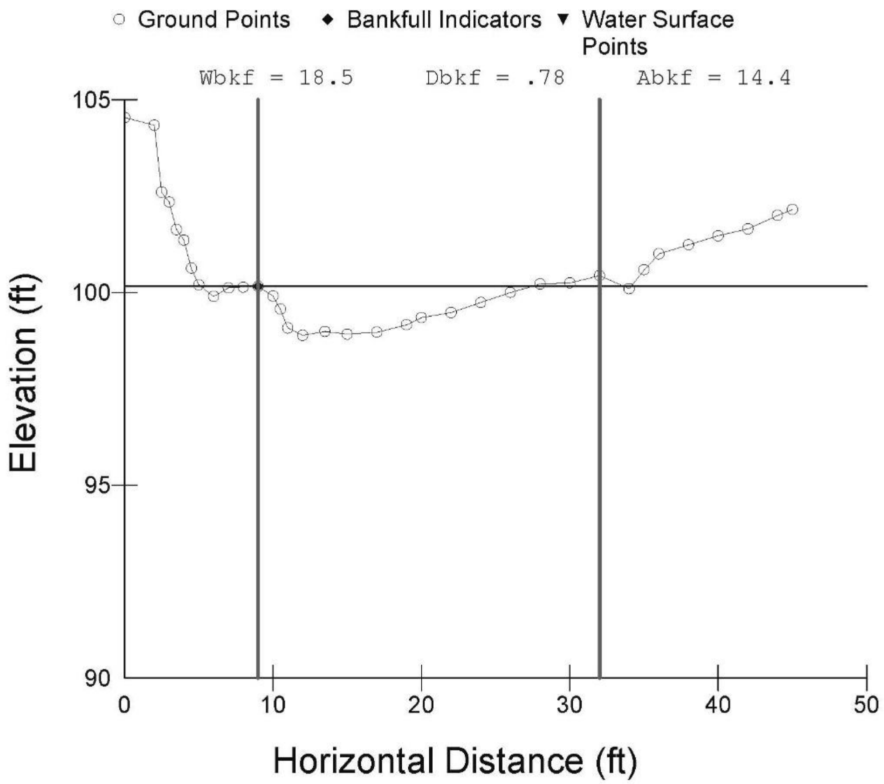


Figure A.2: Site ID 2, Rose Creek, XSEC 1 (HLR 9).

Table A.2: Cross-sectional survey data for Site ID 2: Rose Creek, XSEC 2 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	0.05	104.95	
2	0.57	104.43	
3	0.98	104.02	
4	1.55	103.45	
5	2.14	102.86	
6	2.74	102.26	
7	3.21	101.79	
8	3.59	101.41	
9	3.85	101.15	
10	4.18	100.82	
11	4.76	100.24	
12	5.61	99.39	LEW
13	5.95	99.05	
14.5	6.08	98.92	
16.5	5.91	99.09	
18.5	5.58	99.42	
20.5	5.40	99.60	
22.5	5.23	99.77	
24.5	5.28	99.72	
26.5	5.21	99.79	
28.5	5.11	99.89	
30.5	5.02	99.98	
32.5	5.06	99.94	
33.5	4.64	100.36	
34.5	4.18	100.82	BKF
36	3.88	101.12	
37	3.21	101.79	
38	2.91	102.09	
39	2.72	102.28	
40	2.67	102.33	
41	2.35	102.65	

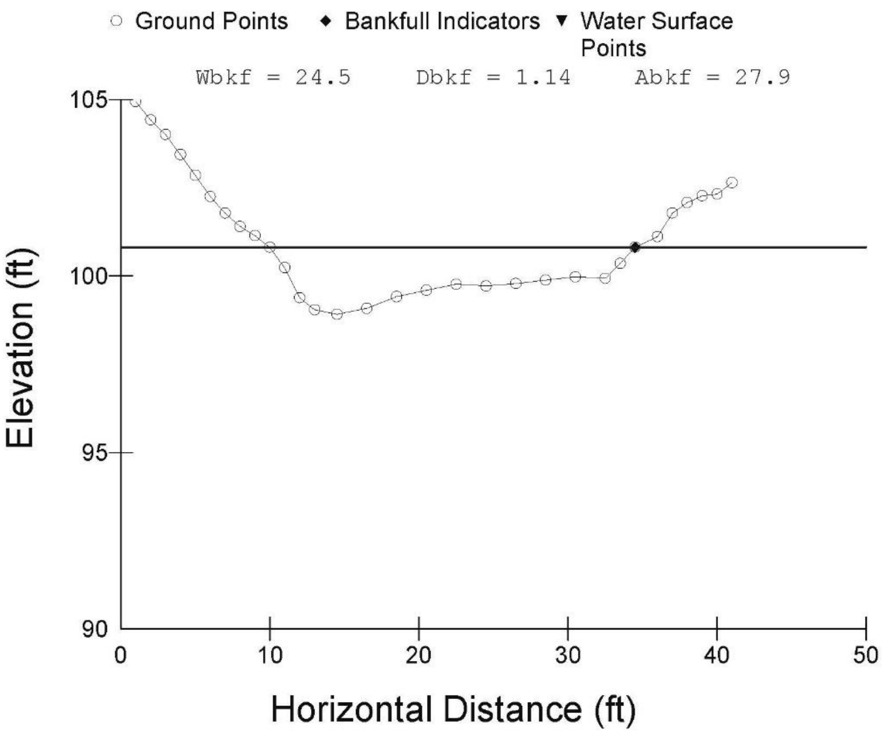


Figure A.3: Site ID 2, Rose Creek, XSEC 2 (HLR 9).

Figure A.4: Downstream view of Site ID 3: USGS gage 03250150 Indian Creek (HLR 9).

Table A.3: Cross-sectional survey data for Site ID 3: USGS gage 03250150 Indian Creek near Owingsville, KY, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	6.08	98.92	
2	6.92	98.08	
4	7.35	97.65	
6	7.67	97.33	
8	8.10	96.90	
8.4	8.49	96.51	
8.8	8.75	96.25	
10.3	8.33	96.67	
11.3	8.19	96.81	
12	8.72	96.28	
14	9.13	95.87	
15	9.41	95.59	
16	9.50	95.50	
17	9.56	95.44	
18	9.59	95.41	
19	9.66	95.34	
20	9.65	95.35	
21	9.56	95.44	
22	9.59	95.41	
23	9.59	95.41	
24	9.49	95.51	
25	9.35	95.65	
26	9.01	95.99	
27	9.05	95.95	
28	8.96	96.04	
29	8.8	96.2	
29.6	8.03	96.97	BKF
31	8.17	96.83	
32	8.02	96.98	
33	7.76	97.24	
34	7.36	97.64	
35	6.58	98.42	
36	6.25	98.75	
37	6.02	98.98	

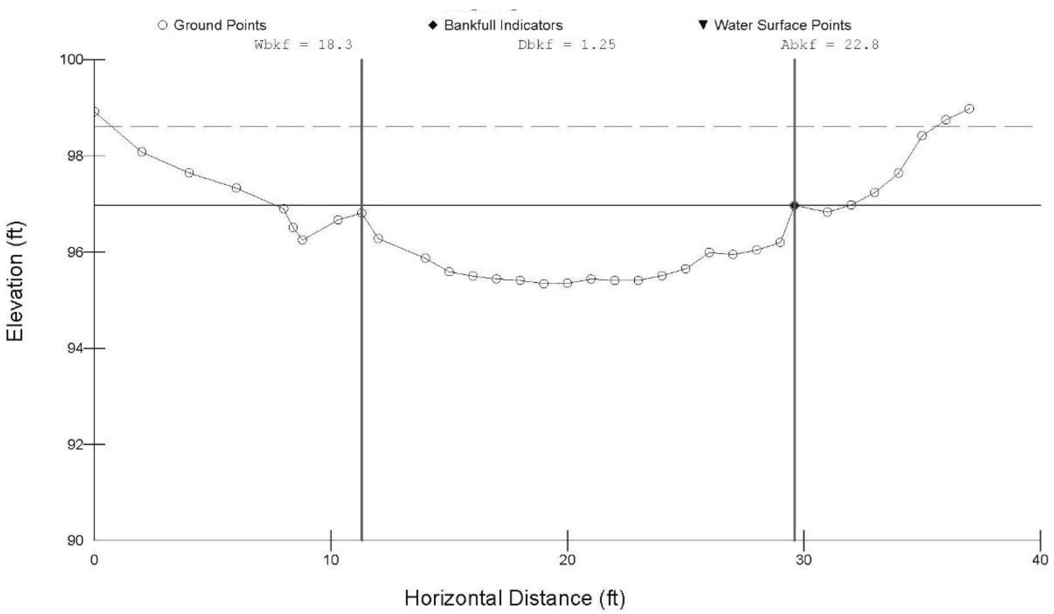


Figure A.5: Site ID 3, USGS gage 03250150 Indian Creek, XSEC 1 (HLR 9).

Table A.4: Cross-sectional survey data for Site ID 3: USGS gage 03250150 Indian Creek near Owingsville, KY, XSEC 2 (HLR 9).

Station (ft)	**FS (ft)**	**Elevation (ft)**	**Notes**
0	3.58	101.42	
1	3.67	101.33	
1.5	3.83	101.17	
2	4.36	100.64	
2.5	4.60	100.40	BKF
3	5.34	99.66	
3.2	6.08	98.92	
3.8	6.33	98.67	
4	6.47	98.53	
5	6.62	98.38	
6	6.61	98.39	
7	6.57	98.43	
7.5	6.60	98.40	
8	6.59	98.41	
9	6.62	98.38	
10	6.67	98.33	
11	6.69	98.31	
12	6.57	98.43	
13	6.59	98.41	
13.5	5.56	99.44	
14	5.32	99.68	
15	5.40	99.60	
16	5.30	99.70	
17	4.82	100.18	
18	4.61	100.39	BKF
20	4.76	100.24	
22	4.68	100.32	
23	4.81	100.19	
24	4.90	100.10	
26	4.74	100.26	
28	4.75	100.25	
30	4.23	100.77	
32	4.93	100.07	
34	4.95	100.05	
36	5.11	99.89	
38	5.34	99.66	
40	5.38	99.62	

Table A,4: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
42	5.29	99.71	
44	4.74	100.26	
45	4.57	100.43	

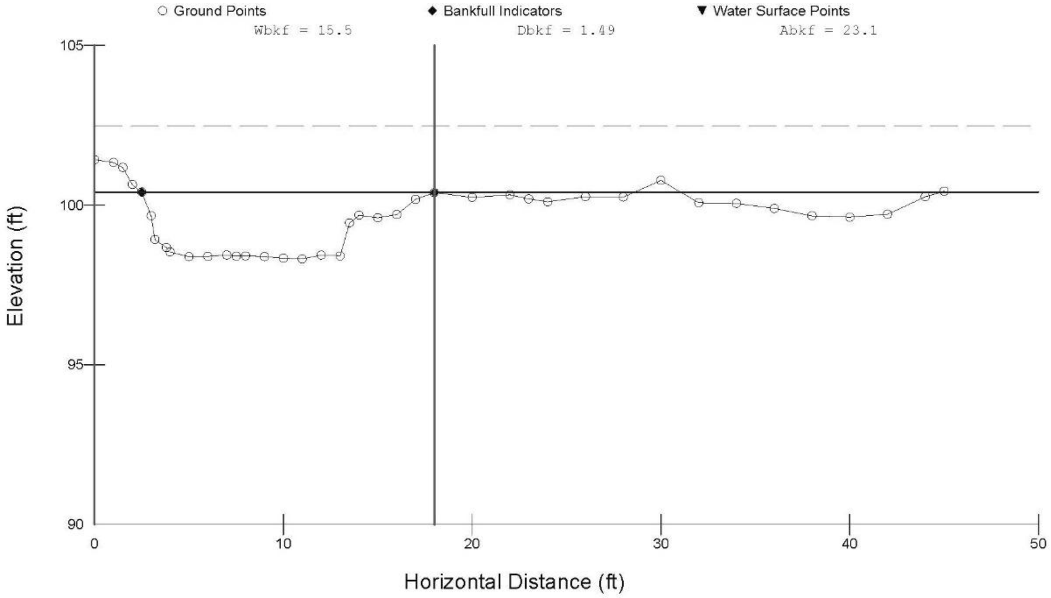


Figure A.6: Site ID 3, USGS gage 03250150 Indian Creek, XSEC 2 (HLR 9).

Figure A.7: (a) Upstream and (b) downstream views of Site ID 4: USGS gage 03250322 Rock Lick Creek (HLR 9).

Table A.5: Cross-sectional survey data for Site ID 4: USGS gage 03250322 Rock Lick Creek near Sharkey, KY, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	3.32	101.68	
2.5	3.56	101.44	
4	4.89	100.11	
5	5.82	99.18	
6	6.32	98.68	
7	6.64	98.36	
8	6.78	98.22	
9	7.01	97.99	
10	7.36	97.64	
11	7.41	97.59	
12	7.43	97.57	
12.5	7.46	97.54	
13	7.76	97.24	
14	8.33	96.67	
15	8.66	96.34	
15.4	9.30	95.70	
17	9.45	95.55	
18	9.46	95.54	
19	9.63	95.37	
20	10.30	94.70	
21	9.99	95.01	
22	9.98	95.02	
23	10.40	94.60	
24	10.38	94.62	
25	10.32	94.68	
26	10.15	94.85	
27	9.77	95.23	
28	9.60	95.40	
28.8	9.31	95.69	
29.8	8.53	96.47	
31	7.40	97.60	
32	7.11	97.89	BKF
33	7.18	97.82	
34	7.22	97.78	
35	6.91	98.09	
36	6.54	98.46	
37	6.04	98.96	

Table A.5: cont'd.

Station (ft)	**FS (ft)**	**Elevation (ft)**	**Notes**
38	5.83	99.17	
39	5.71	99.29	
40	5.56	99.44	
41	5.35	99.65	
42	5.03	99.97	
43	4.89	100.11	
44	4.54	100.46	
45	4.41	100.59	
46	4.09	100.91	

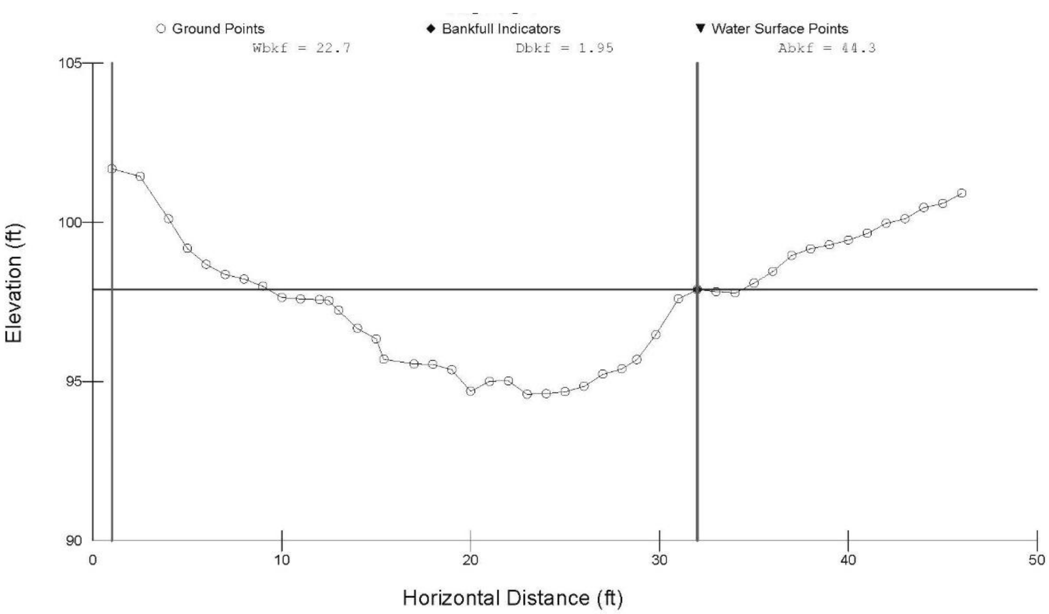


Figure A.8: Site ID 4, USGS gage 03250322 Rock Lick Creek, XSEC 1 (HLR 9).

Table A.6: Cross-sectional survey data for Site ID 4: USGS gage 03250322 Rock Lick Creek near Sharkey, KY, XSEC 2 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	5.45	99.55	
2	5.53	99.47	
3	5.92	99.08	
4	6.40	98.60	
5	6.74	98.26	
6	7.25	97.75	
7	7.57	97.43	
8	7.86	97.14	
9	8.20	96.80	BKF
9.5	8.79	96.21	
10	9.15	95.85	
11	10.30	94.70	
12	11.25	93.75	
13	11.69	93.31	
14	11.68	93.32	
15	11.69	93.31	
16	11.52	93.48	
17	11.46	93.54	
18	11.29	93.71	
19	11.56	93.44	
20	11.57	93.43	
21	11.60	93.40	
22	11.66	93.34	
23	11.62	93.38	
24	11.38	93.62	
24.5	10.76	94.24	
25.5	9.53	95.47	
27	9.21	95.79	
28	8.75	96.25	
29	8.05	96.95	
30	7.61	97.39	
31	7.35	97.65	
32	6.97	98.03	
33	6.88	98.12	
34	6.51	98.49	
35	6.33	98.67	
36	6.10	98.90	

Table A.6: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
37	5.85	99.15	
38	5.66	99.34	
39	5.22	99.78	
40	5.03	99.97	

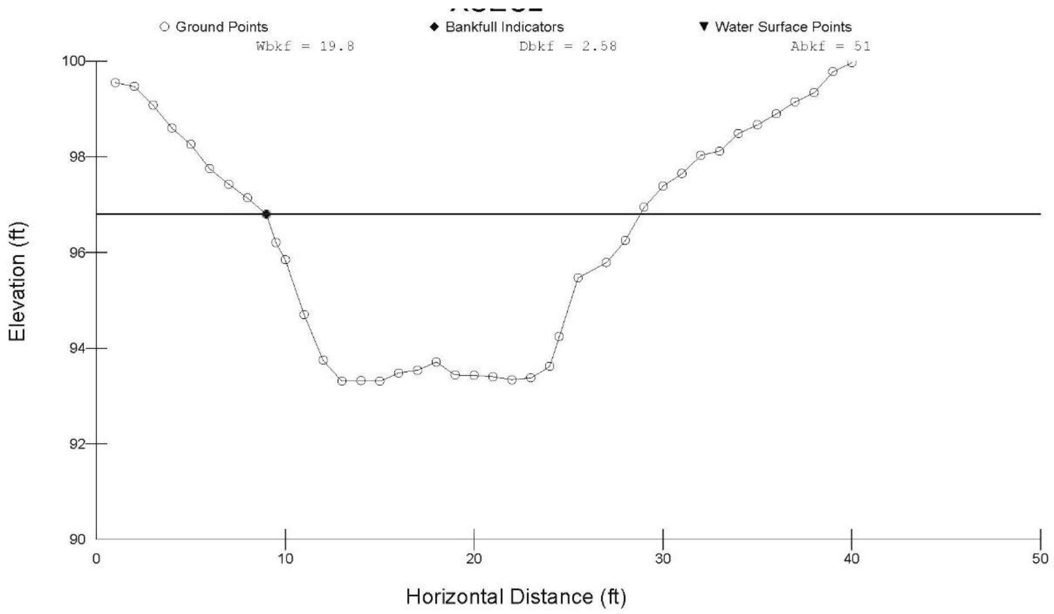


Figure A.9: Site ID 4, USGS gage 03250322 Rock Lick Creek, XSEC 2 (HLR 9).


(a) (b)

Figure A.10: (a) Upstream and (b) downstream views of Site ID 5: Storey Branch (HLR 9).

Table A.7: Cross-sectional survey data for Site ID 5: Storey Branch, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	5.00	100.00	
3	5.23	99.77	
4	5.37	99.63	
5	6.71	98.29	
6	7.25	97.75	
7	8.09	96.91	
8	8.64	96.36	
9	9.84	95.16	
10	11.64	93.36	BKF
11.5	11.97	93.03	
13	11.96	93.04	
15	12.14	92.86	
17	12.36	92.64	
19	12.54	92.46	
21	12.61	92.39	
23	12.67	92.33	
25	12.71	92.29	
27	12.68	92.32	
29	12.75	92.25	
31	12.51	92.49	
33	12.40	92.60	
37	12.39	92.61	
39	11.45	93.55	REW
40	10.20	94.80	
41	8.83	96.17	
42	5.99	99.01	

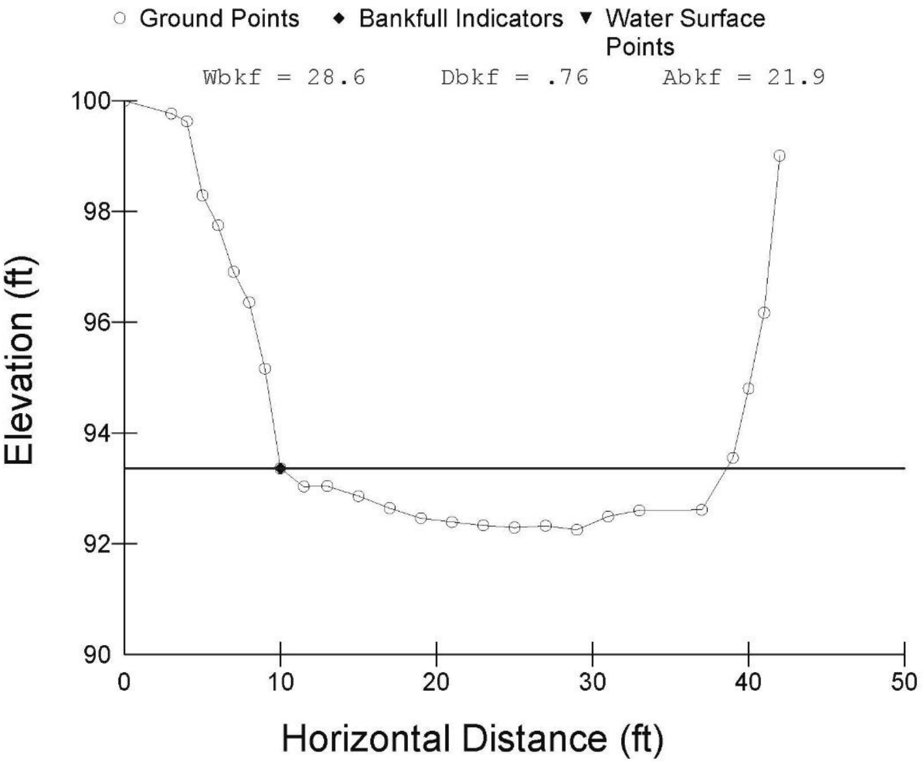


Figure A.11: Site ID 5, Storey Branch, XSEC 1 (HLR 9).

Table A.8: Cross-sectional survey data for Site ID 5: Storey Branch, XSEC 2 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	4.94	100.06	
2	4.75	100.25	
4	4.54	100.46	
5	4.64	100.36	
5.5	5.15	99.85	
6	6.35	98.65	
6.5	6.88	98.12	
7	7.82	97.18	
8	9.82	95.18	
9	11.44	93.56	BKF
11	11.90	93.10	
13	12.15	92.85	
15	12.31	92.69	
17	12.43	92.57	
19	12.45	92.55	
21	12.42	92.58	
23	12.45	92.55	
25	12.45	92.55	
27	12.58	92.42	
29	12.59	92.41	
31	12.74	92.26	
33	12.57	92.43	
35	12.23	92.77	
36	11.61	93.39	REW
36.5	10.15	94.85	
37	9.75	95.25	
38	7.65	97.35	
39	6.31	98.69	

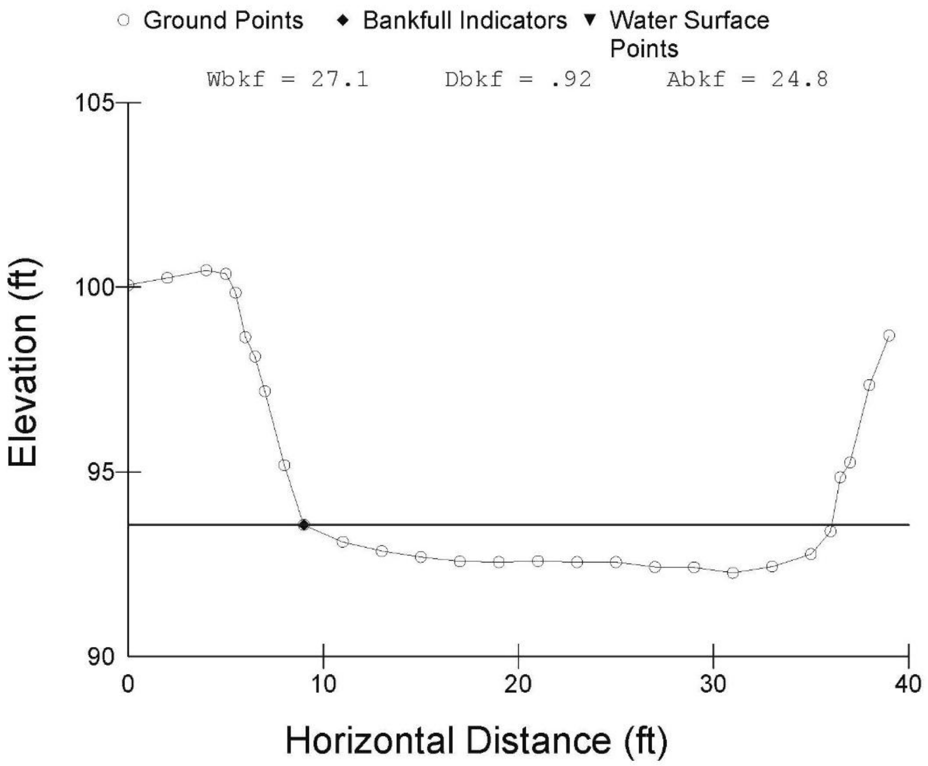


Figure A.12: Site ID 5, Storey Branch, XSEC 2 (HLR 9).

Figure A.13: (a) Upstream and (b) downstream views of Site ID 6: USGS gage 03237900 Cabin Creek (HLR 9).

Table A.9: Cross-sectional survey data for Site ID 6: USGS gage 03237900 Cabin Creek near Tollesboro, KY, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	2.53	102.47	
2	3.12	101.88	
3	3.95	101.05	
4	4.89	100.11	
6	5.30	99.70	
8	5.11	99.89	
10	5.31	99.69	
12	6.09	98.91	
13	6.70	98.30	
14	7.15	97.85	
15	7.72	97.28	
17	7.96	97.04	
19	8.20	96.80	LEW
21	8.43	96.57	
23	8.51	96.49	
25	8.30	96.70	
26	8.15	96.85	
28	8.49	96.51	
29	8.75	96.25	
30	8.88	96.12	
31	8.95	96.05	
32	9.95	95.05	
33	9.97	95.03	
34	9.90	95.10	
36	9.88	95.12	
37	9.81	95.19	
38	9.06	95.94	
39	9.15	95.85	
40	9.32	95.68	
41	9.39	95.61	
42	9.60	95.40	
43	9.75	95.25	
44	9.80	95.20	
45	10.09	94.91	
46	10.15	94.85	
47	10.15	94.85	
48	10.11	94.89	

Table A.9 cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
49	10.03	94.97	
50	9.85	95.15	
51	9.79	95.21	
52	9.74	95.26	
53	9.62	95.38	
54	9.34	95.66	
55	9.03	95.97	
56	9.01	95.99	
57	9.00	96.00	
58	8.95	96.05	
59	8.12	96.88	
59.5	7.65	97.35	
60	6.24	98.76	
61	5.69	99.31	BKF
62	6.51	99.48	
64	5.28	99.72	
66	4.95	100.05	
68	4.19	100.81	
69	3.68	101.32	
70	3.07	101.93	
71.5	2.17	102.83	

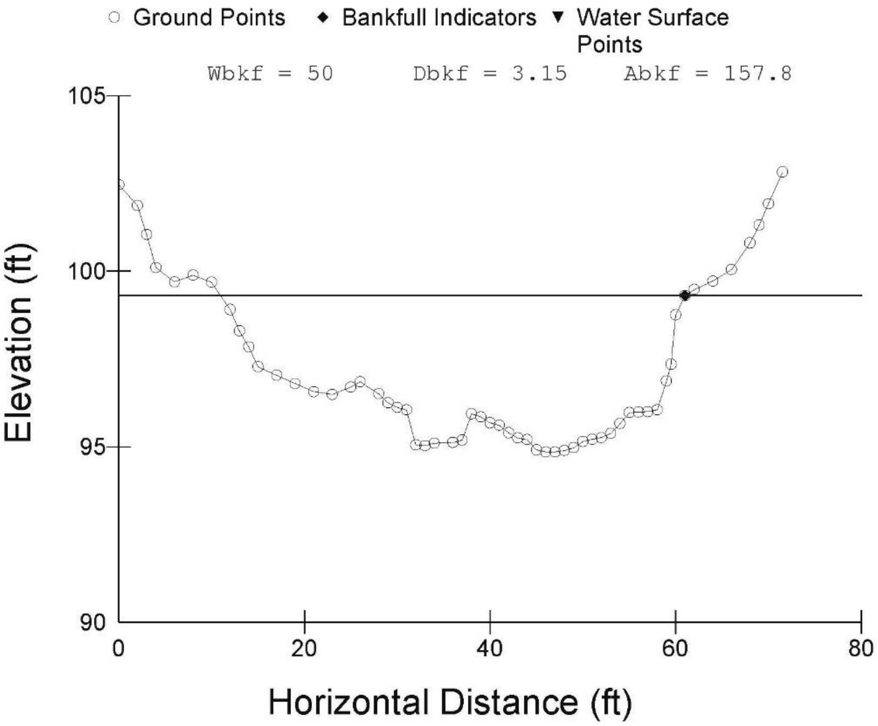


Figure A.14: Site ID 6, USGS gage 03237900 Cabin Creek, XSEC 1 (HLR 9).

Table A.10: Cross-sectional survey data for Site ID 6: USGS gage 03237900 Cabin Creek near Tollesboro, KY, XSEC 2 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
2	2.11	102.89	
4	2.29	102.71	
6	2.97	102.03	BKF
7	4.00	101.00	
8	4.45	100.55	
9	5.00	100.00	
10	5.36	99.64	
12	5.59	99.41	
14	5.87	99.13	
15	6.26	98.74	
16	6.46	98.54	
18	6.64	98.36	
20	6.76	98.24	
21	6.77	98.23	
23	7.07	97.93	
24	7.01	97.99	
25	7.27	97.73	
26	7.54	97.46	
27	7.83	97.17	
28	7.78	97.22	
29	7.72	97.28	
30	7.51	97.49	
31	7.19	97.81	
32	7.09	97.91	
33	7.18	97.82	
34	7.19	97.81	
35	7.01	97.99	
36	7.00	98.00	
37	6.93	98.07	
38	6.90	98.10	
39	6.87	98.13	
40	6.28	98.72	
41	6.23	98.77	
42	6.16	98.84	
43	6.09	98.91	
45	6.01	98.99	
47	5.83	99.17	

Table A.10: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
48	5.56	99.44	
49	5.29	99.71	
50	4.81	100.19	
51	4.32	100.68	
53	3.60	101.40	
55	2.54	102.46	
57	1.28	103.72	
58	0.77	104.23	

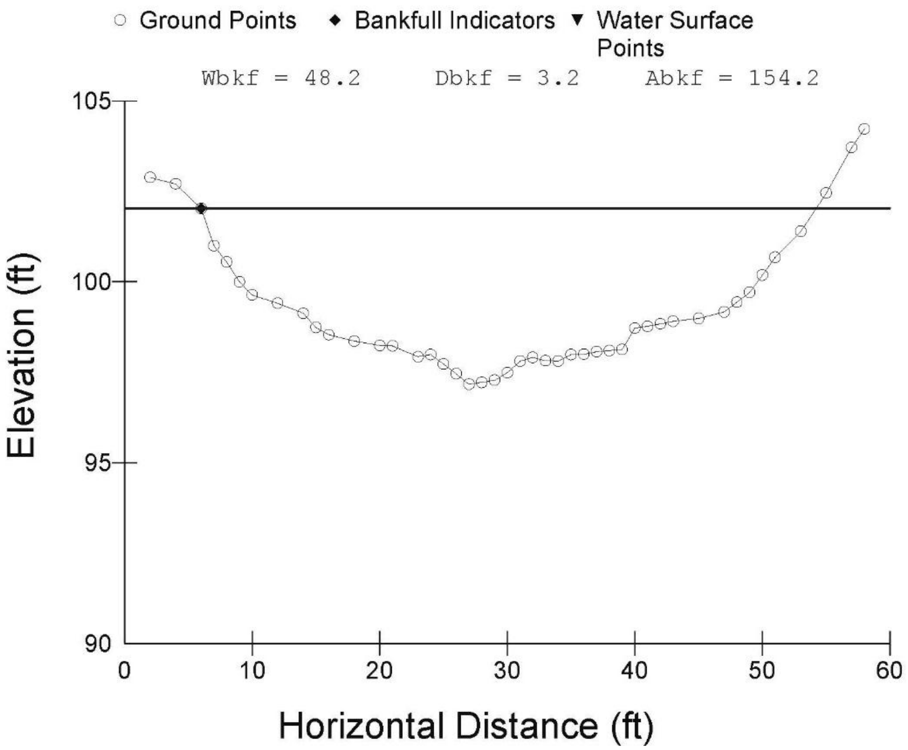


Figure A.15: Site ID 6, USGS gage 03237900 Cabin Creek, XSEC 2 (HLR 9).

(a) (b)

Figure A.16: (a) Upstream and (b) downstream views of Site ID 7: USGS gage 03250000 Triplett Creek (HLR 9).

Table A.11: Cross-sectional survey data for Site ID 7: USGS gage 03250000 Triplett Creek at Morehead, KY, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	0.50	104.50	
3	1.24	103.76	
4	1.42	103.58	
5.5	1.95	103.05	
6.5	2.42	102.58	
7	2.90	102.10	
8.5	3.73	101.27	LEW
10	4.29	100.71	
11.5	4.75	100.25	
13	5.16	99.84	
14.5	3.77	99.23	
16.5	5.82	99.18	
18.5	5.75	99.25	
20.5	5.92	99.08	
22.5	5.95	99.05	
24.5	5.87	99.13	
27	5.84	99.16	
29	5.90	99.10	
31	5.89	99.11	
33	5.87	99.13	
35	5.89	99.11	
37	5.92	99.08	
39	5.91	99.09	
41	5.90	99.10	
43	5.89	99.11	
44.5	5.62	99.38	
45.5	5.22	99.78	
47	5.00	100.00	
49	4.73	100.27	
51	4.61	100.39	
54	4.56	100.44	
57	4.56	100.44	
60	4.84	100.16	
62	5.18	99.82	
64	5.51	99.49	
66	5.54	99.46	
68	5.33	99.67	

Table A.11: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
70	5.08	99.92	
72	4.69	100.31	
74	3.81	101.19	REW
76	3.29	101.71	
78	2.06	102.94	BKF
80	1.35	103.65	
81	0.91	104.09	
82	0.63	104.37	

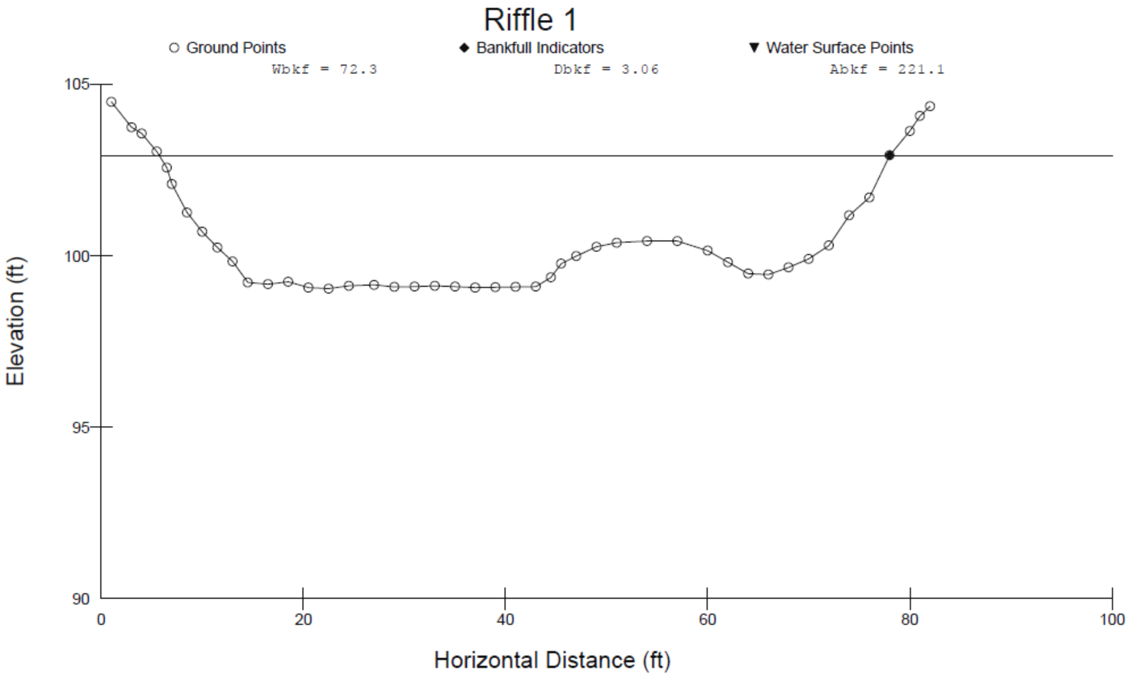


Figure A.17: Site ID 7, USGS gage 03250000 Triplett Creek, XSEC 1 (HLR 9).

Table A.12: Cross-sectional survey data for Site ID 7: USGS gage 03250000 Triplett Creek at Morehead, KY, XSEC 2 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	1.14	103.86	
2	1.63	103.37	
3	2.27	102.73	
4	3.32	101.68	
5	3.87	101.13	LEW
6.5	4.55	100.45	
8	4.79	100.21	
10	4.82	100.18	
12	4.83	100.17	
14	4.85	100.15	
15	5.40	99.60	
17	5.41	99.59	
19	5.42	99.58	
21	5.43	99.57	
24	5.44	99.56	
26	5.46	99.54	
29	5.49	99.51	
31	5.52	99.48	
33	5.54	99.46	
36	5.60	99.40	
39	5.65	99.35	
41	5.66	99.34	
43	5.62	99.38	
45	5.24	99.76	
47	5.03	99.97	
49	5.07	99.93	
52	5.42	99.58	
54	5.70	99.30	
56	5.80	99.20	
59	5.82	99.18	
51	5.75	99.24	
54	5.79	99.54	
57	5.78	99.91	
60	5.76	100.03	
63	5.46	100.15	
74	5.09	99.85	
76	4.97	100.33	

Table A.12: cont'd.

Station (ft)	**FS (ft)**	**Elevation (ft)**	**Notes**
78	4.85	100.15	
80	5.15	99.85	
82	4.67	100.33	
84	4.85	100.15	
86	4.39	100.61	
87	4.11	100.89	REW
88	3.38	101.62	
89.5	2.85	102.15	
90.5	2.60	102.4	
92	2.31	102.69	
93	2.00	103	BKF
94	1.23	103.77	
95	0.89	104.11	
96	0.25	104.75	

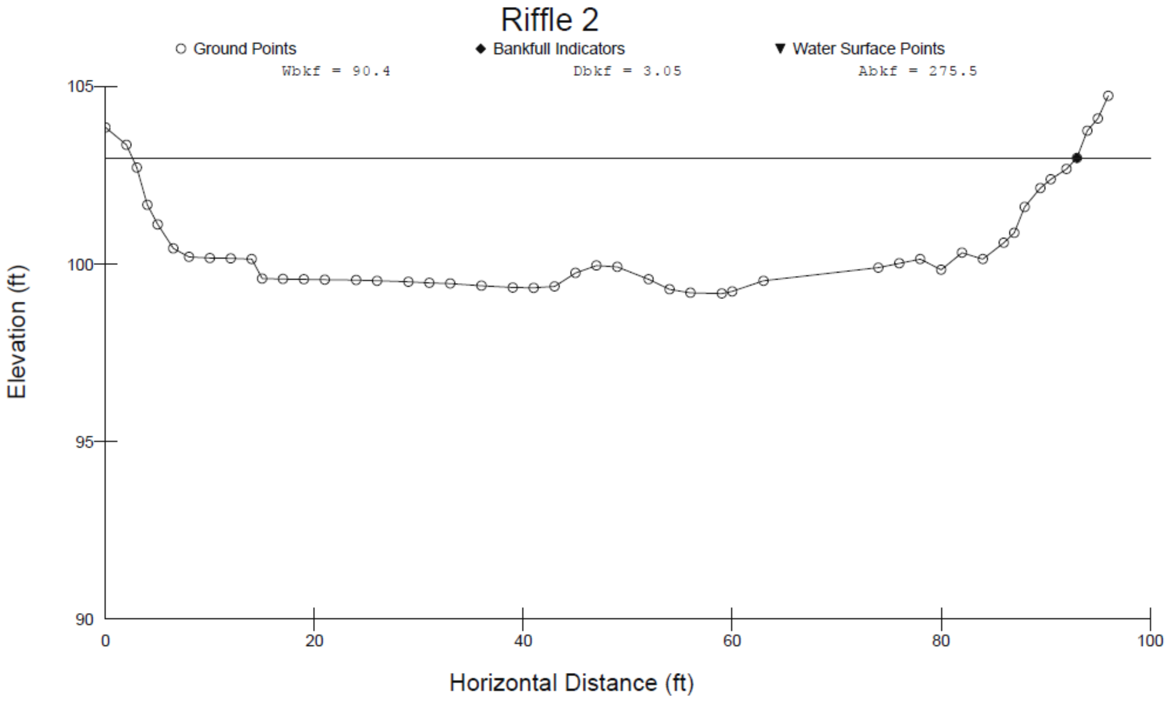


Figure A.18: Site ID 7, USGS gage 03250000 Triplett Creek, XSEC 2 (HLR 9).

Figure A.19: Upstream view of Site ID 9: USGS gage 03250100 North Fork Triplett (HLR 9).

Table A.13: Cross-sectional survey data for Site ID 9: USGS gage 03250100 North Fork Triplett near Morehead, KY, XSEC 1 (HLR 9).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	0.30	104.70	
2	0.80	104.20	
4	1.20	103.80	
6	1.48	103.52	
8	1.72	103.28	
10	2.30	102.70	
12	2.40	102.60	
14	2.22	102.78	
16	2.64	102.36	
18	2.83	102.17	
20	2.51	102.49	
21	2.75	102.25	
22	2.99	102.01	
23	3.09	101.91	
24	3.24	101.76	
25	3.63	101.37	
26	4.09	100.91	
26.8	5.08	99.92	
27.5	5.40	99.60	
28	5.70	99.30	
30	6.50	98.50	
32	6.88	98.12	
34	7.19	97.81	
36	7.45	97.55	
28	7.74	97.26	
40	7.80	97.20	
42	7.83	97.17	
44	8.04	96.96	
46	8.49	96.51	
48	8.52	96.48	
50	8.90	96.10	
52	9.31	95.69	
54	9.54	95.46	
56	9.62	95.38	
58	9.43	95.57	
60	9.42	95.58	
62	9.25	95.75	

Table A.13: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
64	9.30	95.70	
66	9.26	95.74	
68	8.73	96.27	
70	8.78	96.22	
72	8.60	96.40	
74	8.26	96.74	
76	8.60	96.40	
78	8.35	96.65	
80	8.09	96.91	
82	7.86	97.14	
84	7.63	97.37	
86	7.52	97.48	
88	7.50	97.50	
90	7.46	97.54	
92	7.46	97.54	
94	7.39	97.61	
96	7.32	97.68	
98	7.35	97.65	
100	7.33	97.67	
102	7.18	97.82	
104	6.98	98.02	
106	6.78	98.22	
108	6.60	98.40	
110	6.54	98.46	
112	6.42	98.58	
114	6.45	98.55	
116	6.37	98.63	
118	6.25	98.75	BKF
120	6.30	98.70	
121	6.24	98.76	
122	5.62	99.38	
123	3.34	101.66	
124	2.09	102.91	

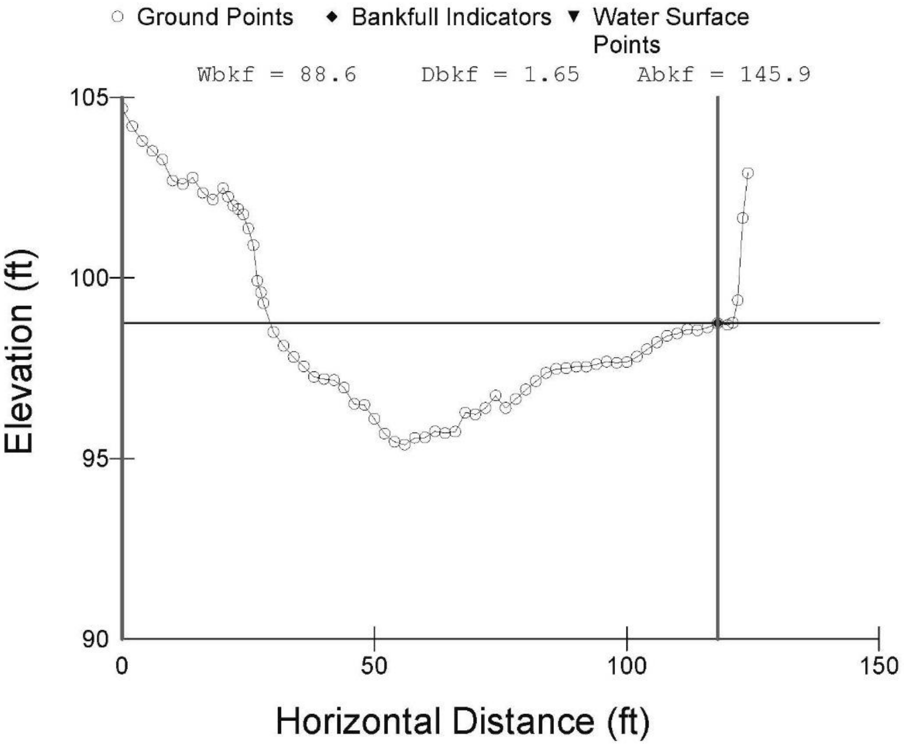


Figure A.20: Site ID 9, USGS gage 03250100 North Fork Triplett, XSEC 1 (HLR 9).

Figure A.21: (a) Upstream and (b) downstream views of Site ID 12: UT KY-191 Mile 5 (HLR 11).

Table A.14: Cross-sectional survey data for Site ID 12: UT KY-191 Mile 5, XSEC 1 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	5.29	99.71	
1	5.95	99.05	
2	6.64	98.36	
3	6.92	98.08	
4	7.43	97.57	
5	7.98	97.02	
6	7.98	97.02	
7	8.79	96.21	
8	9.45	95.55	
9	10.11	94.89	
10	10.64	94.36	
10.5	10.80	94.20	BKF
11	11.59	93.41	LEW
13	11.70	93.30	
15	11.51	93.49	
17	11.47	93.53	
19	11.40	93.60	
21	11.35	93.65	REW
22	10.76	94.24	
23	10.59	94.41	
24	9.88	95.12	
25	8.98	96.02	
26	8.25	96.75	
27	7.40	97.60	
28	6.34	98.66	
29	5.65	99.35	
30	4.67	100.33	
31	4.26	100.74	
32	3.85	101.15	
33	3.65	101.35	
34	3.53	101.47	

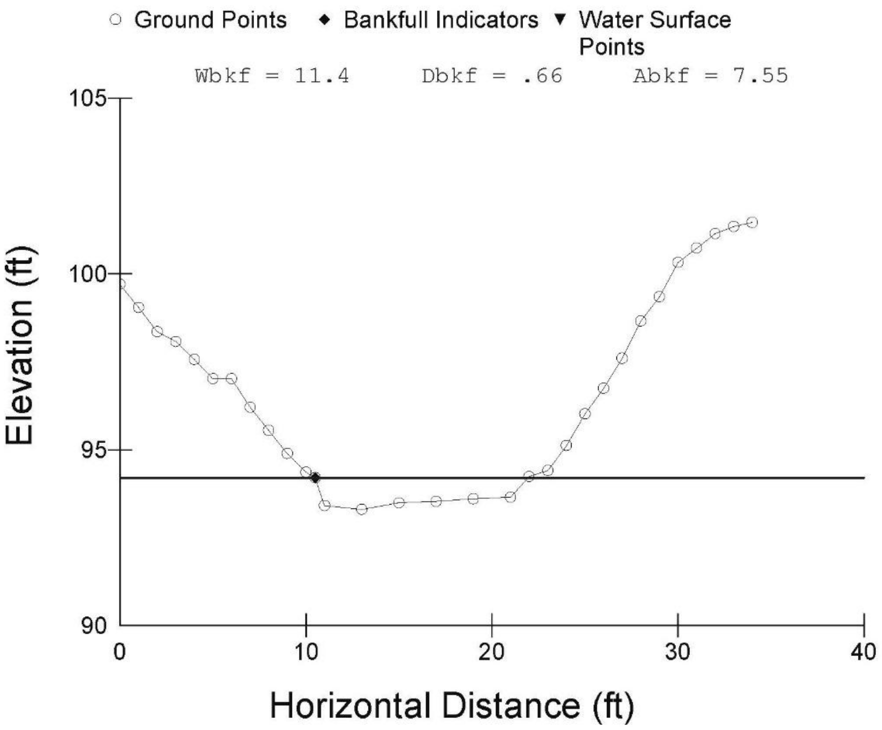


Figure A.22: Site ID 12, UT KY-191 Mile 5, XSEC 1 (HLR 11).

(a)

(b)

Figure A.23: (a) Upstream and (b) downstream views of Site ID 17: USGS gage 03216370 Big Sinking Creek (HLR 11).

Table A.15: Cross-sectional survey data for Site ID 17: USGS gage 03216370 Big Sinking Creek near Aden, KY, XSEC 1 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	1.09	103.91	
1	1.34	103.66	
2	2.10	102.90	
3	2.96	102.04	LEW
4	3.31	101.69	
5	4.52	100.48	
6	4.82	100.18	
7	5.00	100.00	
9	5.22	99.78	
11	5.78	99.22	
13	5.79	99.21	
15	5.96	99.04	
17	6.21	98.79	
18	6.32	98.68	
19	6.27	98.73	
20	6.42	98.58	BKF
22	6.38	98.62	
24	6.21	98.79	
25	6.77	98.23	
27	5.60	99.40	
29	5.51	99.49	
31	5.41	99.59	
33	5.23	99.77	
35	5.04	99.96	
37	5.15	99.85	
39	4.95	100.05	
41	4.79	100.21	REW
43	4.73	100.27	
45	4.56	100.44	
46	4.22	100.78	
47	3.88	101.12	
48	3.50	101.50	
49	3.25	101.75	
50	3.17	101.83	
51	3.00	102.00	
52	2.10	102.90	

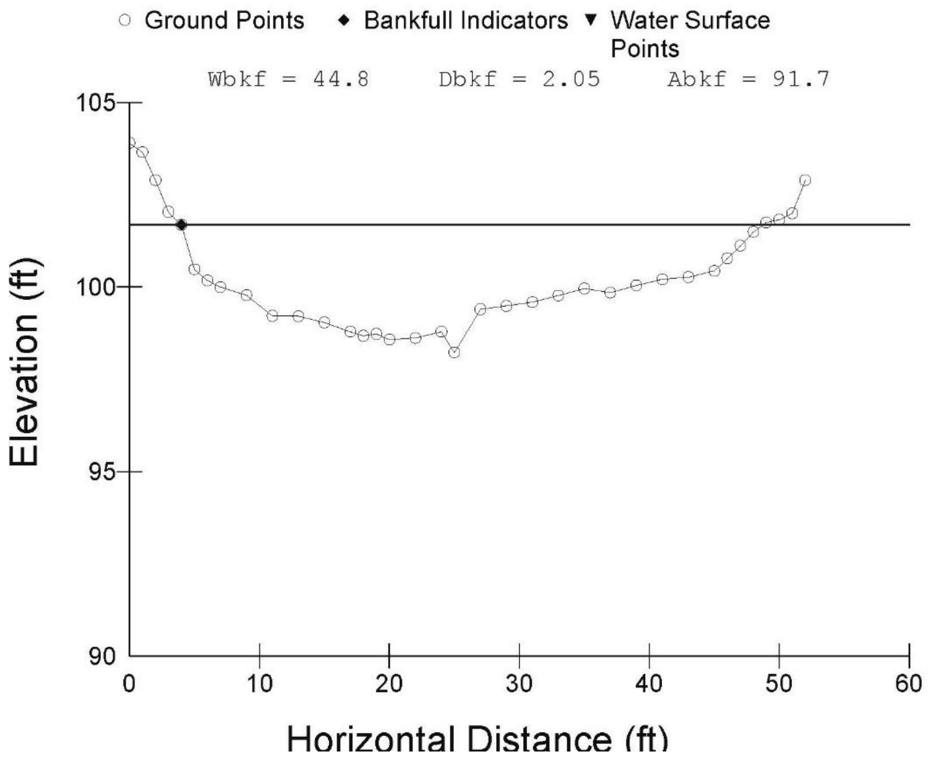


Figure A.24: Site ID 17, USGS gage 03216370 Big Sinking Creek, XSEC 1 (HLR 11).

Figure A.25: (a) Upstream and (b) downstream views of Site ID 19: USGS gage 03404900 Lynn Camp (HLR 11).

Table A.16: Cross-sectional survey data for Site ID 19: USGS gage 03404900 Lynn Camp at Corbin, KY, XSEC 1 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	1.33	103.67	
2	2.45	102.55	
4	3.49	101.51	
6	4.41	100.59	
8	5.41	99.59	
10	6.25	98.75	
11	6.90	98.10	
11.8	7.44	97.56	
12.2	9.20	95.80	
12.8	9.60	95.40	LEW
14	9.68	95.32	
16	9.69	95.31	
18	9.78	95.22	
20	9.76	95.24	
22	9.75	95.25	
24	9.76	95.24	
26	9.89	95.11	
27	9.98	95.02	
29	9.87	95.13	
30	9.50	95.50	
32	9.62	95.38	
34	9.64	95.36	
36	9.67	95.33	
38	9.70	95.30	
40	9.72	95.28	
42	9.80	95.20	
44	9.83	95.17	
46	9.75	95.25	
48	9.83	95.17	
50	9.85	95.15	
52	9.99	95.01	
54	10.03	94.97	
56	10.12	94.88	
58	10.16	94.84	
60	10.25	94.75	
62	10.19	94.81	
64	10.29	94.71	

Table A.16: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
65	10.14	94.86	
66	10.13	94.87	
68	9.95	95.05	
70	9.99	95.01	
72	9.96	95.04	
74	9.93	95.07	
75	9.81	95.19	
76	9.67	95.33	
77	9.40	95.60	REW
78	8.24	96.76	
79	7.40	97.60	
80	7.20	97.80	BKF
82	7.23	97.77	
84	7.18	97.82	
86	7.21	97.79	
88	7.08	97.92	
90	6.61	98.39	
92	5.89	99.11	
94	4.95	100.05	
96	4.18	100.82	
98	3.50	101.50	
100	2.59	102.41	

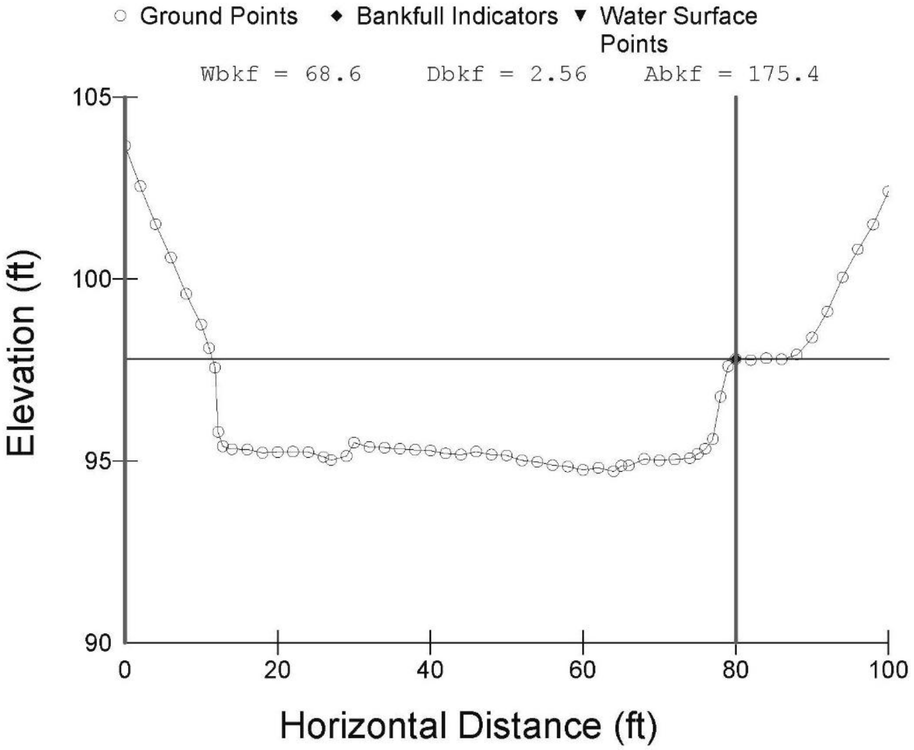


Figure A.26: Site ID 1, USGS gage 03404900 Lynn Camp, XSEC 1 (HLR 11).

Table A.17: Cross-sectional survey data for Site ID 19: USGS gage 03404900 Lynn Camp at Corbin, KY, XSEC 2 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	0.51	104.49	
3	1.60	103.40	
5	2.73	102.27	
7	4.29	100.71	
9	5.39	99.61	
11	5.75	99.25	
13	6.68	98.32	
14	7.29	97.71	BKF
14.5	8.09	96.91	
15	9.17	95.83	LEW
17	9.53	95.47	
19	9.44	95.56	
21	9.56	95.44	
23	9.59	95.41	
25	9.69	95.31	
27	9.65	95.35	
29	9.56	95.44	
31	9.48	95.52	
33	9.42	95.58	
35	9.38	95.62	
37	9.36	95.64	
39	9.41	95.59	
41	9.49	95.51	
43	9.50	95.50	
45	9.62	95.38	
47	9.57	95.43	
49	9.58	95.42	
51	9.55	95.45	
53	9.42	95.58	
55	9.36	95.64	
57	9.35	95.65	
59	9.36	95.64	
61	9.46	95.54	
63	9.49	95.51	
65	9.60	95.40	
67	9.56	95.44	
69	9.48	95.52	

Table A.17: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
71	9.52	95.48	
73	9.74	95.26	
75	9.71	95.29	
77	9.61	95.39	
79	9.22	95.78	
81	9.02	95.98	
83	9.18	95.82	
85	8.97	96.03	REW
85.5	7.38	97.62	
87	6.78	98.22	
89	5.93	99.07	
91	5.24	99.76	
93	4.64	100.36	
95	3.92	101.08	
97	2.95	102.05	
99	2.01	102.99	
101	1.03	103.97	

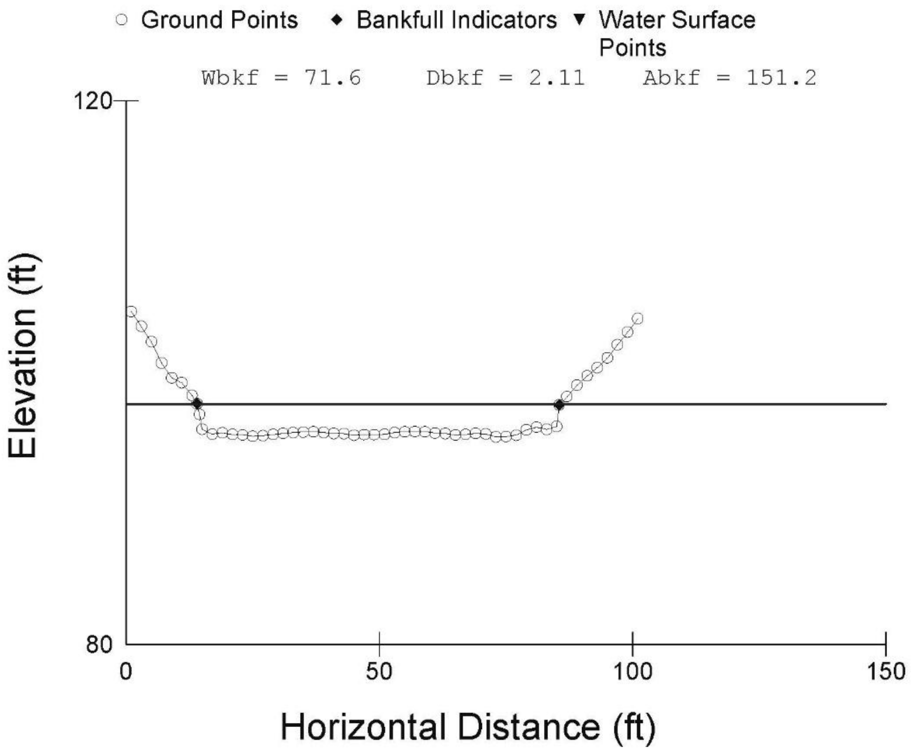


Figure A.27: Site ID 19, USGS gage 03404900 Lynn Camp, XSEC 2 (HLR 11).

Figure A.28: Upstream view of Site ID 22: USGS gage 03282040 Sturgeon Creek (HLR 11).

Table A.18: Cross-sectional survey data for Site ID 22: USGS gage 03282040 Sturgeon Creek near Cressmont, KY, XSEC 1 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	1.79	103.21	
2	2.10	102.90	
3	2.70	102.30	
4	3.11	101.89	
5	3.45	101.55	
5.5	4.43	100.57	
6	4.92	100.08	
7	5.52	99.48	
8	6.00	99.00	
9	6.35	98.65	
10	6.74	98.26	
11	6.95	98.05	
12	6.96	98.04	
14	7.15	97.85	
16	7.34	97.66	
17	7.69	97.31	
18	7.75	97.25	
20	7.85	97.15	
22	7.89	97.11	
24	8.02	96.98	
25	8.30	96.70	
27	8.46	96.54	
29	8.59	96.41	
31	8.62	96.38	
32	8.84	96.16	
33	8.90	96.10	
35	8.90	96.10	
37	8.89	96.11	
40	8.85	96.15	
42	8.74	96.26	
44	8.86	96.14	
46	8.57	96.43	
48	8.56	96.44	
50	8.22	96.78	
51	8.13	96.87	
52	7.92	97.08	
53	7.65	97.35	

Table A.18: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
54	7.77	97.23	
55	7.64	97.36	
56	7.36	97.64	
59	6.88	98.12	
61	6.49	98.51	
63	6.42	98.58	
65	6.37	98.63	
66	6.17	98.83	
67	6.25	98.75	
68	5.93	99.07	
69	5.24	99.76	BKF
70	4.73	100.27	
72	4.52	100.48	
74	3.04	101.96	
75	2.39	102.61	
76	2.09	102.91	
80	1.84	103.16	
81	1.76	103.24	
82	1.24	103.76	

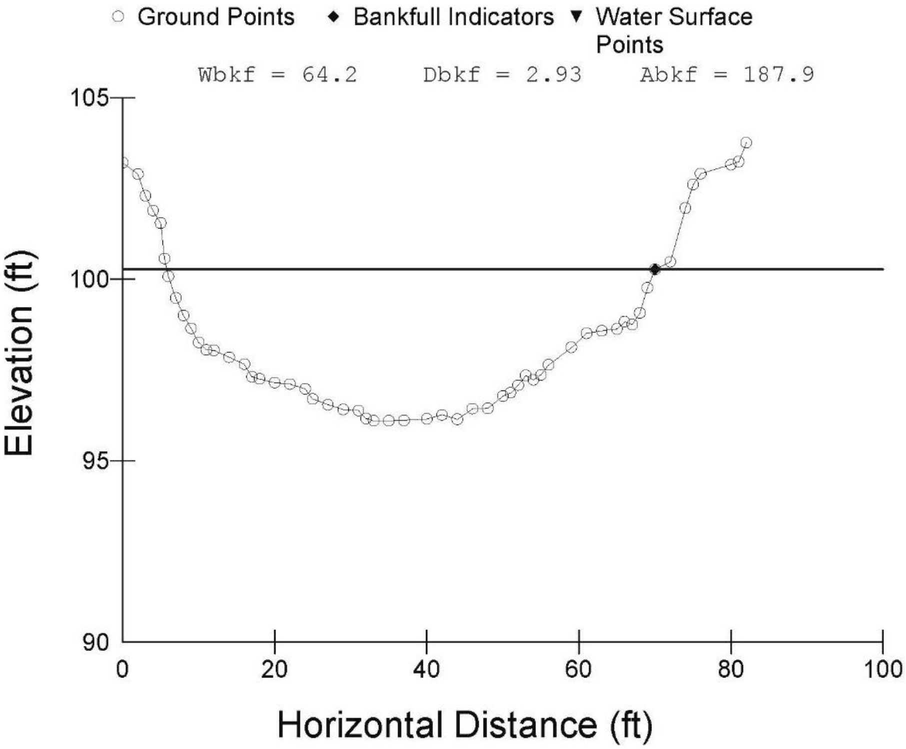


Figure A.29: Site ID 22, USGS gage 03282040 Sturgeon Creek, XSEC 1 (HLR 11).

Table A.19: Cross-sectional survey data for Site ID 22: USGS gage 03282040 Sturgeon Creek near Cressmont, KY, XSEC 2 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	1.13	103.87	
1	3.58	101.42	
1.5	4.20	100.80	
2	5.09	99.91	
3	5.49	99.51	
4	6.27	98.73	
5	6.63	98.37	
6	7.07	97.93	
7	7.44	97.56	
8	8.44	96.56	
9	9.18	95.82	
10	9.20	95.80	
11	9.61	95.39	
12	9.72	95.28	
13	10.04	94.96	
14	10.13	94.87	
15	10.51	94.49	
17	10.70	94.30	
19	10.80	94.20	
20	10.82	94.18	
22	10.98	94.02	
24	11.28	93.72	
26	11.36	93.64	
28	11.52	93.48	
30	11.54	93.46	
32	11.57	93.43	
34	11.57	93.43	
37	11.63	93.37	
39	11.63	93.37	
41	11.72	93.28	
43	11.62	93.38	
45	11.64	93.36	
47	11.62	93.38	
49	11.45	93.55	
51	11.29	93.71	
53	11.16	93.84	
55	11.18	93.82	

Table A.19: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
57	11.21	93.79	
59	11.21	93.79	
61	11.08	93.92	
63	11.08	93.92	
a65	11.01	93.99	REW
67	10.78	94.22	
68	10.65	94.35	
69	10.60	94.40	
71	10.28	94.72	
72	9.83	95.17	
74	9.45	95.55	
75	9.31	95.69	
77	9.07	95.93	
79	8.72	96.28	
81	8.63	96.37	BKF
82	8.23	96.77	
84	7.75	97.25	
86	7.63	97.37	
87	7.03	97.97	
88	6.67	98.33	
89	5.98	99.02	
90	5.42	99.58	
92	4.92	100.08	
94	4.67	100.33	
95	4.72	100.28	
96	5.19	99.81	
97	5.77	99.23	
98	5.94	99.06	
99	6.42	98.58	
100	6.70	98.30	
101	6.86	98.14	
103	6.6	98.4	
104	6.38	98.62	
105	5.65	99.35	
106	5.70	99.30	
108	5.65	99.35	
109	5.41	99.59	
110	5.11	99.89	

Table A.19: cont'd.

111	4.33	100.67	
112	4.02	100.98	

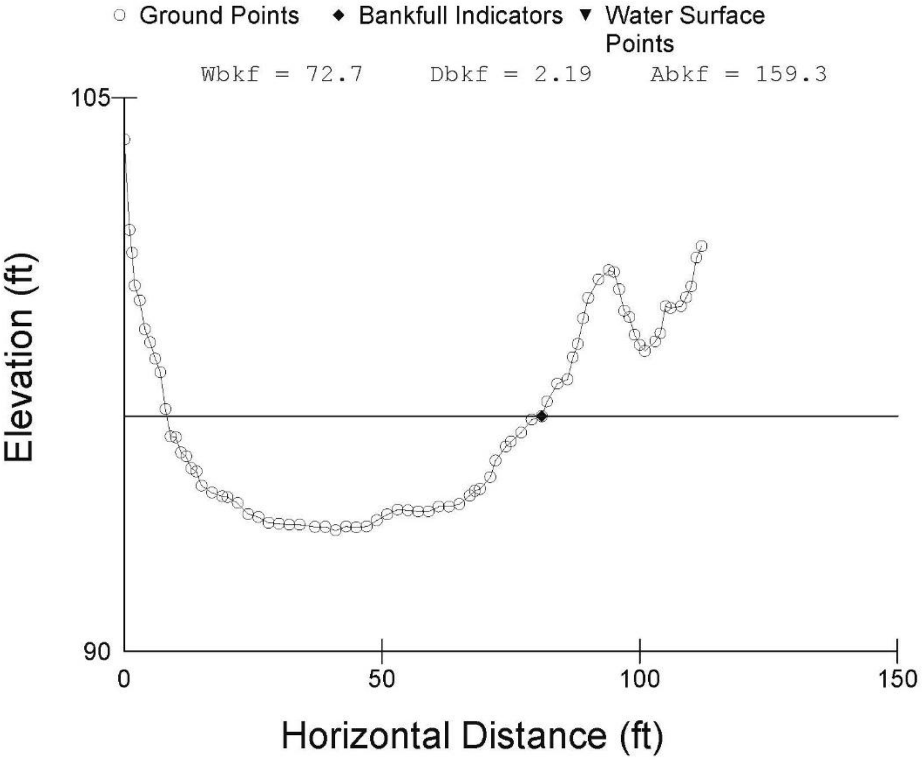


Figure A.30: Site ID 22, USGS gage 03282040 Sturgeon Creek, XSEC 2 (HLR 11).

Figure A.31: (a) Upstream and (b) downstream views of Site ID 23: USGS gage 03281100 Goose Creek (HLR 11).

Table A.20: Cross-sectional survey data for Site ID 23: USGS gage 03281100 Goose Creek at Manchester, KY, XSEC 1 (HLR 11).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	2.31	102.69	
1	3.10	101.90	
2	3.52	101.48	
3	4.05	100.95	
4	4.25	100.75	
5	4.63	100.37	
6	4.81	100.19	
7	5.25	99.75	
8	6.18	98.82	
9	6.56	98.44	
10	6.97	98.03	
11	7.22	97.78	
12	7.95	97.05	
13	8.71	96.29	
15	9.00	96.00	
17	9.12	95.88	
18	9.40	95.60	
20	9.68	95.32	
22	9.64	95.36	
24	9.65	95.35	
26	9.70	95.30	
28	9.62	95.38	
30	9.70	95.30	
32	9.74	95.26	
34	9.92	95.08	
36	9.79	95.21	
38	10.06	94.94	
40	10.15	94.85	
42	10.13	94.87	
44	10.02	94.98	
46	9.85	95.15	
48	9.67	95.33	
50	9.58	95.42	
52	9.59	95.41	
54	9.55	95.45	
56	9.33	95.67	
58	9.52	95.48	

Table A.20: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
60	9.49	95.51	
62	9.34	95.66	
64	8.97	96.03	
66	9.10	95.90	
68	8.68	96.32	
69	8.67	96.33	
71	8.39	96.61	
73	8.07	96.93	REW
75	7.82	97.18	
77	7.48	97.52	
79	6.95	98.05	
81	6.68	98.32	
83	6.67	98.33	
85	6.44	98.56	
86	6.20	98.80	
87	5.89	99.11	
89	5.35	99.65	
90	4.96	100.04	
92	4.76	100.24	BKF
94	4.75	100.25	
96	4.62	100.38	
97	4.42	100.58	
98	4.15	100.85	
100	3.68	101.32	

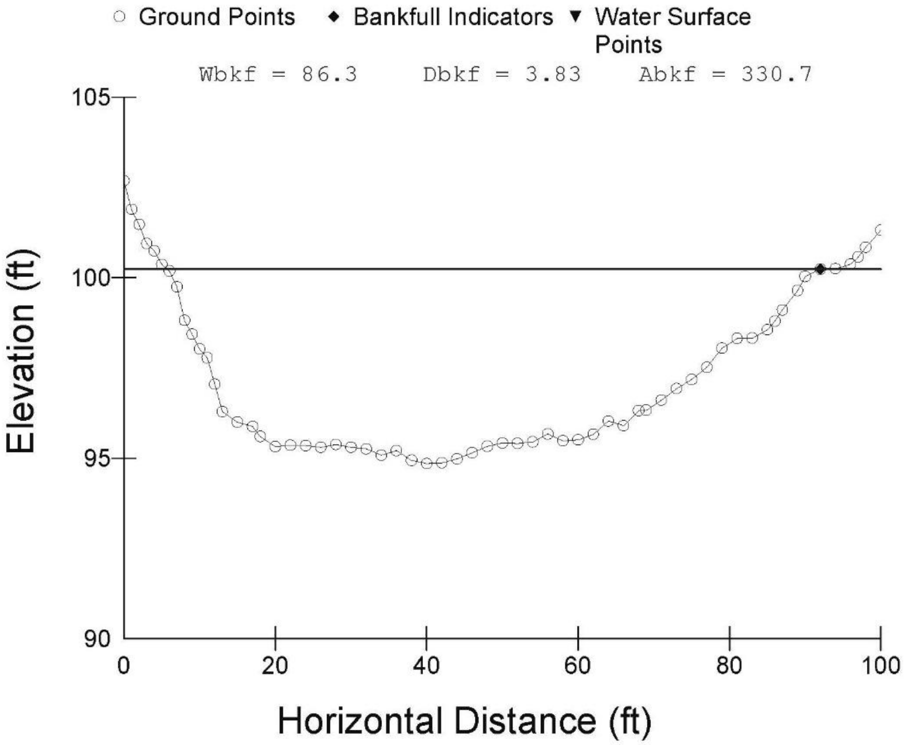


Figure A.32: Site ID 23, USGS gage 03281100 Goose Creek, XSEC 1 (HLR 11).

(a) (b)

Figure A.33: (a) Upstream and (b) downstream views of Site ID 35: Beaver Creek (HLR 16).

Table A.21: Cross-sectional survey data for Site ID 35: Beaver Creek in Frenchburg, KY, XSEC 1 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	5.58	99.42	
2	5.59	99.41	
4	5.79	99.21	
4.5	6.00	99.00	
5	6.18	98.82	
5.5	6.43	98.57	
6	6.50	98.50	
6.5	6.88	98.12	
7	7.13	97.87	
7.5	7.35	97.65	
8	7.61	97.39	
8.5	7.98	97.02	
9	8.19	96.81	
9.5	8.28	96.72	
10	8.50	96.50	
10.5	8.56	96.44	
11	8.91	96.09	
11.5	9.11	95.89	
12	9.63	95.37	
12.5	9.70	95.30	
13	9.87	95.13	
13.5	9.99	95.01	
14	10.10	94.90	
15	10.21	94.79	
16	10.34	94.66	
16.5	10.45	94.55	
17	10.58	94.42	BKF
18	10.79	94.21	
18.5	11.03	93.97	
19	11.34	93.66	REW
19.5	11.62	93.38	
20	11.83	93.17	
21	12.08	92.92	
23	12.16	92.84	
25	12.30	92.70	
27	12.54	92.46	
29	12.69	92.31	
31	12.50	92.50	
33	12.43	92.57	
35	12.39	92.61	
37	12.38	92.62	

Table A.21: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
39	12.31	92.69	
41	12.30	92.70	
43	12.28	92.72	
45	12.15	92.85	
47	11.95	93.05	
49	11.92	93.08	
51	11.85	93.15	
53	11.52	93.48	
54	11.36	93.64	LEW
54.5	11.01	93.99	
55	10.62	94.38	
55.5	10.45	94.55	
56	10.18	94.82	
56.5	9.85	95.15	
57	9.60	95.40	
58	9.19	95.81	
59	9.00	96.00	
59.5	8.89	96.11	
60	8.76	96.24	
60.5	8.60	96.40	
61	8.46	96.54	
61.5	7.79	97.21	
62	7.61	97.39	
63	7.43	97.57	
64	7.31	97.69	
65	7.20	97.80	

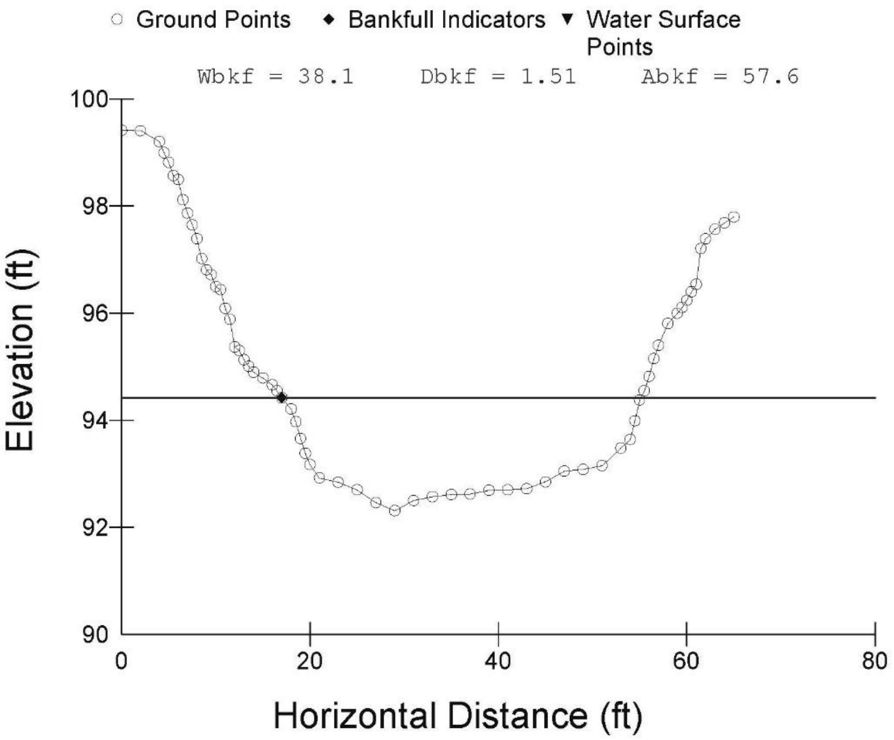


Figure A.34: Site ID 35, Beaver Creek, XSEC 1 (HLR 16).

Table A.22: Cross-sectional survey data for Site ID 35: Beaver Creek in Frenchburg, KY, XSEC 2 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	4.31	100.69	
2	4.62	100.38	
3	5.09	99.91	
3.5	5.38	99.62	
4	5.68	99.32	
4.5	5.90	99.10	
5	6.23	98.77	
5.5	6.55	98.45	
6	7.11	97.89	
6.5	7.63	97.37	
7	7.76	97.24	
7.5	8.01	96.99	
8	8.40	96.60	
8.5	8.76	96.24	
9	8.96	96.04	
10	9.20	95.80	
10.5	9.43	95.57	
11	9.77	95.23	
12	10.06	94.94	
13	10.20	94.80	BKF
13.5	10.55	94.45	
14	11.16	93.84	REW
15	11.78	93.22	
16	12.05	92.95	
18	12.40	92.60	
20	12.61	92.39	
22	12.52	92.48	
24.5	12.60	92.40	
26	12.50	92.50	
28	12.36	92.64	
30	12.49	92.51	
32	12.67	92.33	
34	12.53	92.47	
35	12.25	92.75	
36	12.12	92.88	
37	12.02	92.98	

Table A.22: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
38	11.80	93.20	LEW
39	11.65	93.35	
39.5	9.65	95.35	
40	9.15	95.85	
40.5	9.70	95.30	
41	8.56	96.44	
41.5	8.38	96.62	
42	8.20	96.80	
42.5	7.65	97.35	
43	7.40	97.60	
43.5	6.41	98.59	
45	6.09	98.91	
46	5.71	99.29	
47	5.19	99.81	

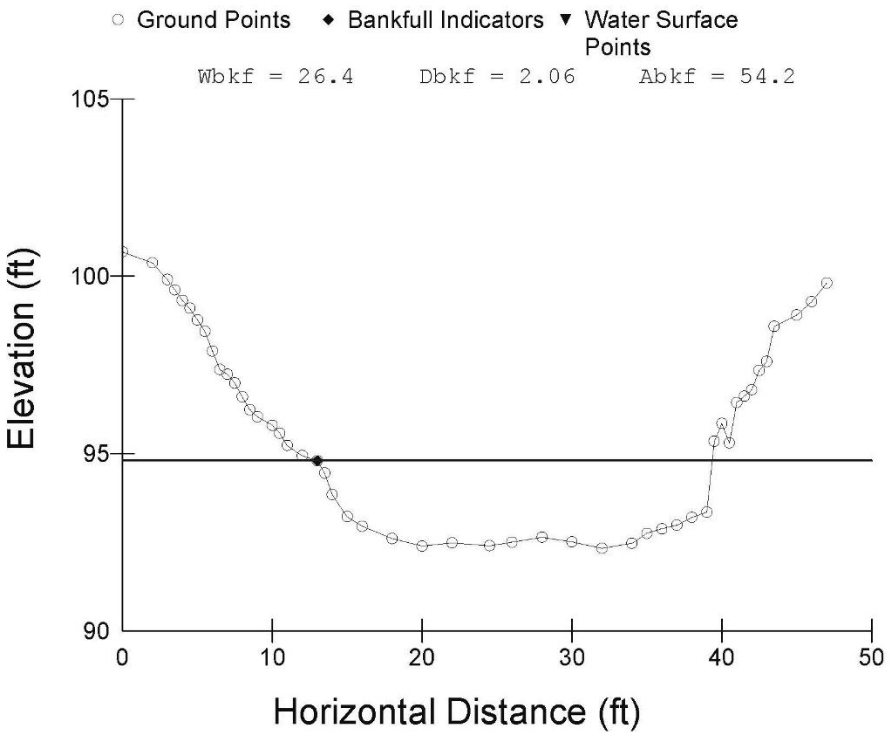


Figure A.35: Site ID 35, Beaver Creek, XSEC 2 (HLR 16).

(a)

Figure A.36: (a) ownstream views of Site ID 37: USGS gage 03283370 Cat Creek (HLR 16).

Table A.23: Cross-sectional survey data for Site ID 37: USGS gage 03283370 Cat Creek near Stanton, KY, XSEC 1 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	7.31	97.69	
2	7.45	97.55	
4	7.46	97.54	
6	7.85	97.15	
8	7.82	97.18	
10	8.15	96.85	
12	8.41	96.59	BKF
13	9.14	95.86	
14	9.89	95.11	LEW
15	10.05	94.95	
16	10.29	94.71	
17	10.24	94.76	
18	10.15	94.85	
19	10.17	94.83	
21	10.29	94.71	
23	10.31	94.69	
25	10.19	94.81	
27	10.11	94.89	
29	10.25	94.75	
31	10.39	94.61	
33	10.26	94.74	
35	10.25	94.75	
37	8.40	96.60	
38	6.41	98.59	
39	5.70	99.30	
40	5.09	99.91	
41	4.94	100.06	
42	4.75	100.25	
43	4.50	100.50	
44	4.55	100.45	

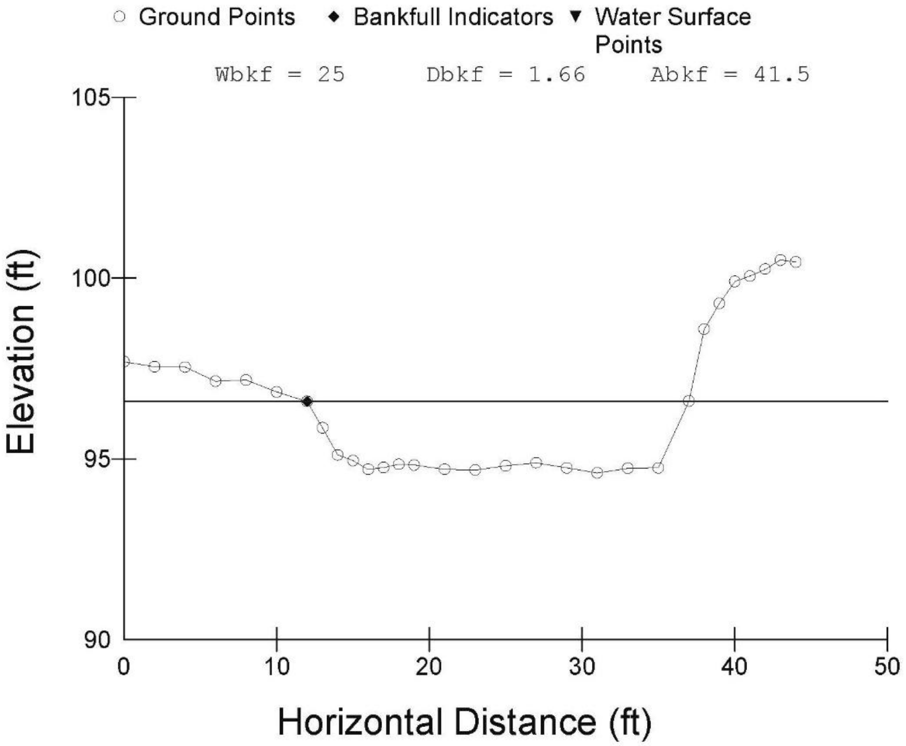


Figure A.37: Site ID 37, USGS gage 03283370 Cat Creek, XSEC 1 (HLR 16).

Table A.24: Cross-sectional survey data for Site ID 37: USGS gage 03283370 Cat Creek near Stanton, KY, XSEC 2 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	0.86	104.14	
1	1.64	103.36	
1.5	2.53	102.47	
2	3.23	101.77	
2.5	4.26	100.74	
3	5.45	99.55	
4	5.77	99.23	
5	5.53	99.47	
7	5.36	99.64	
9	5.15	99.85	
11	5.20	99.80	
13	5.20	99.80	
15	5.38	99.62	
17	5.42	99.58	
19	5.51	99.49	
21	5.40	99.60	
23	5.30	99.70	
25	5.28	99.72	
27	5.15	99.85	
28	4.91	100.09	
29	4.89	100.11	
30	3.54	101.46	BKF
31	2.99	102.01	
32	2.71	102.29	
33	2.61	102.39	
34	2.48	102.52	

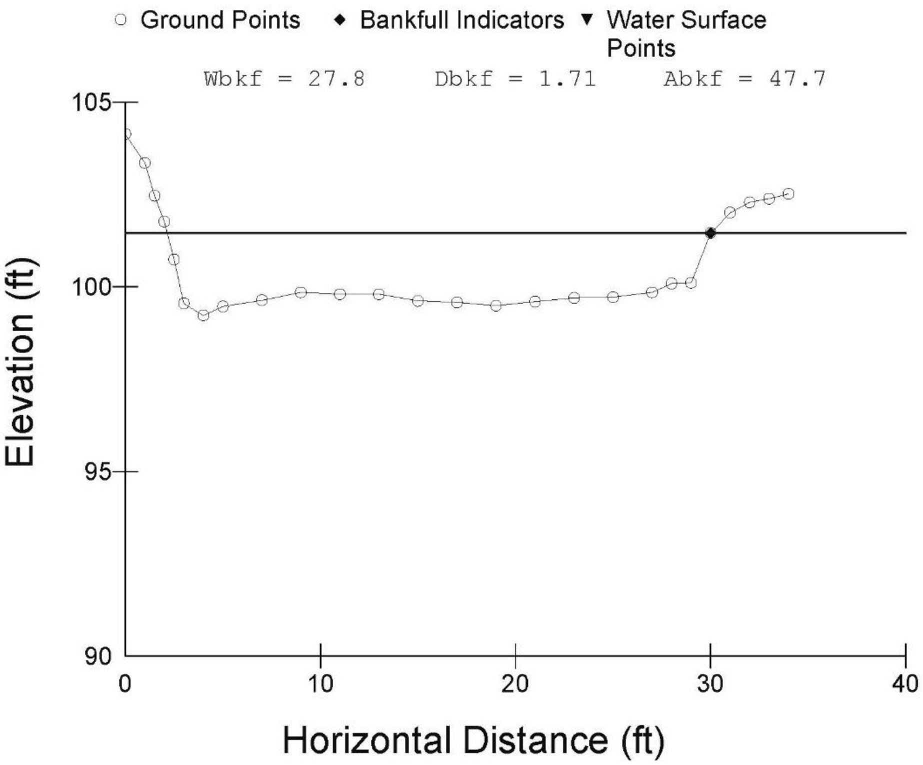


Figure A.38: Site ID 37, USGS gage 03283370 Cat Creek, XSEC 2 (HLR 16).

Figure A.39: Downstream views of Site ID 39: USGS gage 03280600 Middle Fork River (HLR 16).

Table A.25: Cross-sectional survey data for Site ID 39: USGS gage 03280600 Middle Fork River near Hyden, KY, XSEC 1 (HLR 16).

Station (ft)	FS(ft)	Elevation (ft)	Notes
0	9.01	95.99	
2	9.35	95.65	
4	9.59	95.41	
5	9.74	95.26	BFK
6	10.2	94.8	LEW
7	10.79	94.21	
8	11.00	94.00	
9	11.23	93.77	
10	11.30	93.70	
11	11.41	93.59	
12	11.51	93.49	
13	11.45	93.55	
15	11.20	93.80	
17	11.10	93.90	
19	10.94	94.06	
21	10.67	94.33	
23	10.87	94.13	
25	10.72	94.28	
27	10.71	94.29	
29	10.67	94.33	
31	10.82	94.18	
33	10.83	94.17	
34	11.01	93.99	
35	11.27	93.73	
37	11.21	93.79	
39	11.32	93.68	
41	11.22	93.78	
43	10.98	94.02	
45	10.69	94.31	
47	10.88	94.12	
49	10.81	94.19	
50	10.59	94.41	
52	10.50	94.50	
54	10.62	94.38	
56	10.55	94.45	
57	10.05	94.95	REW
60	9.52	95.48	

Table A.25: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
62	9.19	95.81	
63	8.63	96.37	
64	8.18	96.82	
65	7.79	97.21	
66	7.41	97.59	
67	6.94	98.06	
68	6.57	98.43	
69	6.24	98.76	
70	6.07	98.93	
72	5.91	99.09	
74	5.60	99.40	
76	5.31	99.69	
77	5.16	99.84	
78	5.13	99.87	

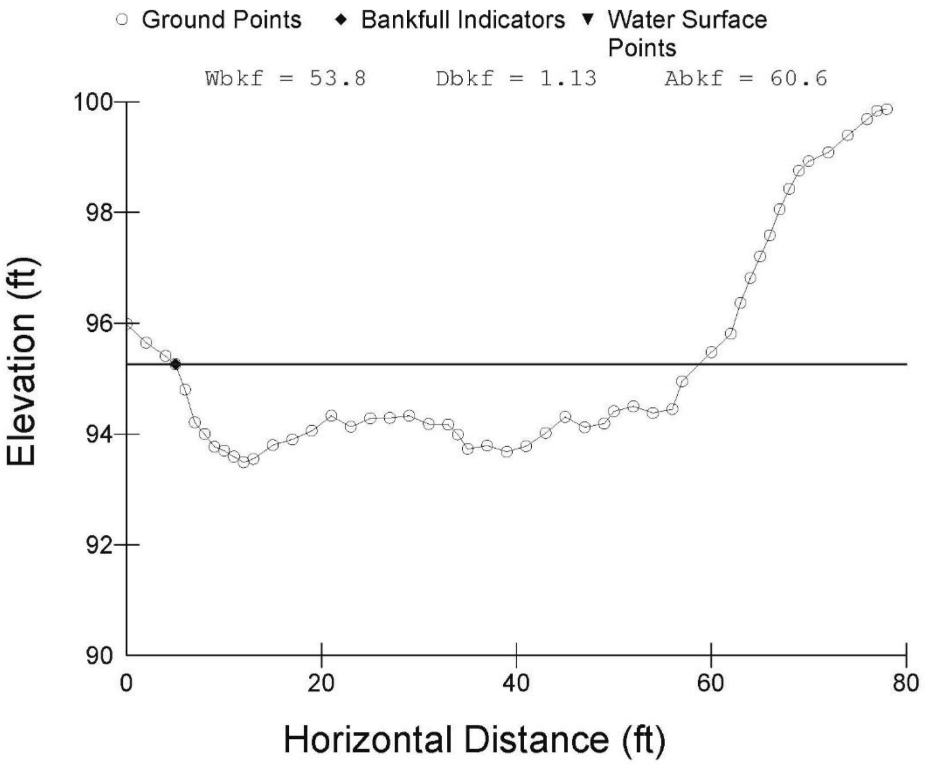


Figure A.40: Site ID 39, USGS gage 03280600 Middle Fork River, XSEC 1 (HLR 16).

Table A.26: Cross-sectional survey data for Site ID 39: USGS gage 03280600 Middle Fork River near Hyden, KY, XSEC 2 (HLR 16).

Station (ft)	**FS (ft)**	**Elevation (ft)**	**Notes**
0	3.77	101.23	
2	3.92	101.08	
4	4.37	100.63	
6	4.57	100.43	BFK
7	5.26	99.74	LEW
8	5.62	99.38	
9	6.19	98.81	
11	6.04	98.96	
13	6.95	98.05	
15	6.50	98.50	
17	6.39	98.61	
19	6.19	98.81	
21	6.25	98.75	
23	6.35	98.65	
25	6.33	98.67	
27	6.15	98.85	
29	6.22	98.78	
31	6.20	98.80	
33	6.37	98.63	
37	6.34	98.66	
39	6.30	98.70	
41	6.29	98.71	
43	6.30	98.70	
45	6.21	98.79	
47	6.24	98.76	
49	6.30	98.70	
51	6.00	99.00	
53	5.75	99.25	REW
54	5.50	99.50	
55	4.58	100.42	
56	4.39	100.61	
57	4.14	100.86	
58	3.61	101.39	
59	3.17	101.83	
60	2.65	102.35	
62	1.62	103.38	
64	1.23	103.77	

Table A.26: cont'd.

66	1.10	103.90	

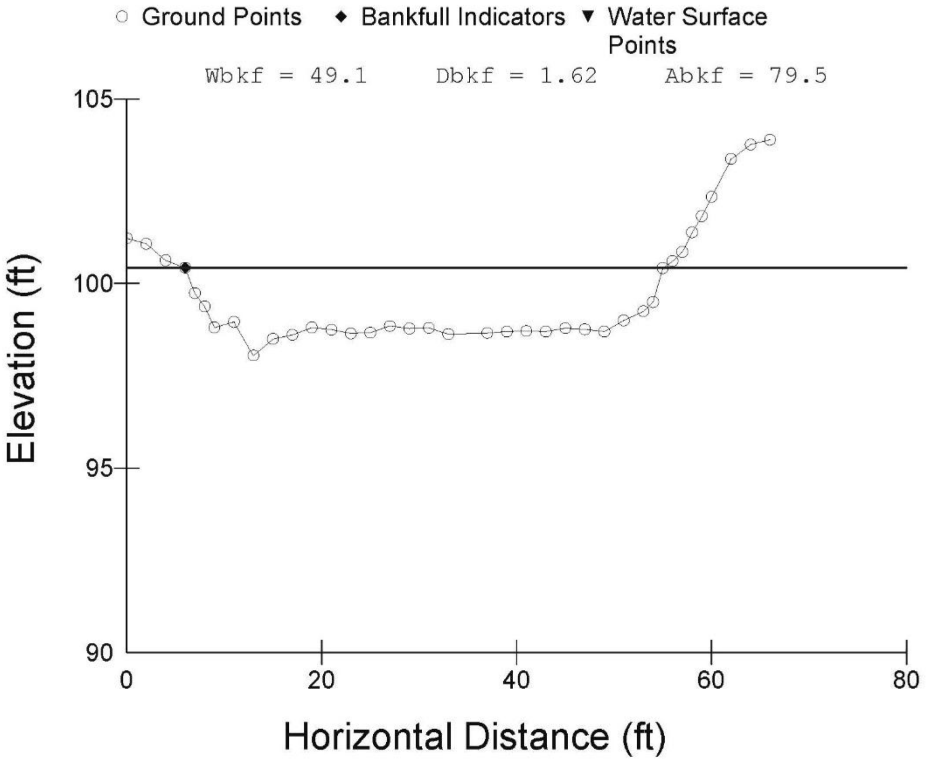


Figure A.41: Site ID 39, USGS gage 03280600 Middle Fork River, XSEC 2 (HLR 16).

Figure A.42: (a) Upstream and (b) downstream views of Site ID 42: USGS gage 03211400 Leatherwood Creek (HLR 16).

Table A.27: Cross-sectional survey data for Site ID 42: USGS gage 03211400 Leatherwood Creek at Daisy, KY, XSEC 1 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
2	0.50	104.50	
4	0.71	104.29	
6	0.96	104.04	
7	1.61	103.39	
8	2.19	102.81	
9	2.66	102.34	
10	2.90	102.10	
12	3.10	101.90	
14	4.23	100.77	
15	4.51	100.49	
17	5.24	99.76	
18	5.56	99.44	
20	5.31	99.69	
22	4.70	100.30	
23	4.94	100.06	
24	5.19	99.81	
25	5.48	99.52	
26	5.76	99.24	
27	6.22	98.78	
28	7.20	97.80	
29	7.32	97.68	
31	7.26	97.74	
33	7.48	97.52	
35	7.61	97.39	LEW
37	7.88	97.12	
39	8.05	96.95	
41	8.36	96.64	
43	8.53	96.47	
45	8.78	96.22	
47	8.65	96.35	
49	8.91	96.09	
51	9.02	95.98	
53	9.07	95.93	
55	9.05	95.95	
57	8.96	96.04	
59	9.11	95.89	
61	9.09	95.91	

Table A.27: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
63	8.95	96.05	
65	8.55	96.45	
67	8.44	96.56	
68	7.66	97.34	REW
69	6.98	98.02	
70	6.72	98.28	
71	6.45	98.55	
72	5.92	99.08	
73	5.18	99.82	
74	4.72	100.28	BKF
75	2.81	102.19	
76	1.28	103.72	
77	0.08	104.92	

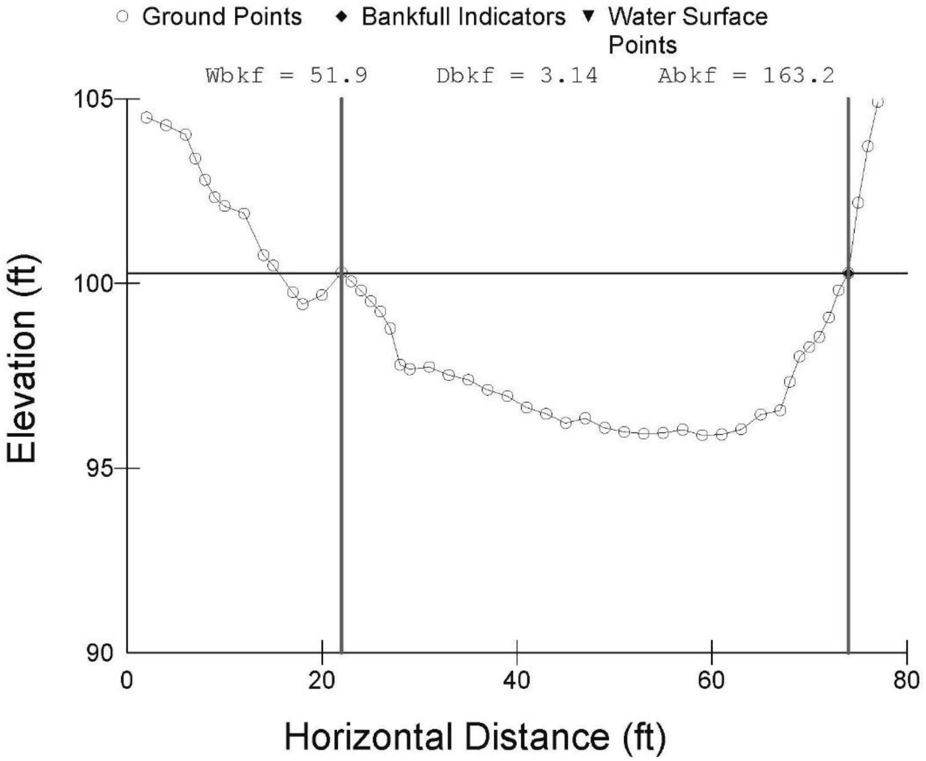


Figure A.43: Site ID 42, USGS gage 03211400 Leatherwood Creek, XSEC 1 (HLR 16).

Table A.28: Cross-sectional survey data for Site ID 42: USGS gage 03211400 Leatherwood Creek at Daisy, KY, XSEC 2 (HLR 16).

Station (ft)	**FS (ft)**	**Elevation (ft)**	**Notes**
0	1.58	103.42	
1	2.13	102.87	
2	2.58	102.42	
2.5	2.96	102.04	
3	3.40	101.60	
4	3.81	101.19	
5	4.19	100.81	
6	4.44	100.56	
7	4.58	100.42	
8	5.22	99.78	
9	5.37	99.63	
10	6.02	98.98	
11	6.29	98.71	
12	6.43	98.57	
13	6.46	98.54	
14	6.52	98.48	BKF
15	6.95	98.05	
16	7.33	97.67	
17	7.70	97.30	
17.5	7.97	97.03	
18	8.29	96.71	
19	8.70	96.30	
20	8.59	96.41	
21	8.58	96.42	
23	8.57	96.43	
25	8.78	96.22	
27	9.09	95.91	
29	9.40	95.60	
31	9.80	95.20	
33	9.87	95.13	
35	10.30	94.70	
37	10.51	94.49	
39	10.54	94.46	
41	10.54	94.46	
43	10.67	94.33	
45	10.86	94.14	
47	10.95	94.05	

Table A.28: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
49	10.98	94.02	
51	11.06	93.94	
53	11.10	93.90	
54	10.98	94.02	
55	10.85	94.15	
56	10.56	94.44	
57	10.44	94.56	
59	10.11	94.89	
61	9.60	95.40	REW
62	8.61	96.39	
63	8.03	96.97	
64	7.55	97.45	
65	7.31	97.69	
66	6.93	98.07	
67	6.76	98.24	
68	6.43	98.57	
69	6.05	98.95	
71	5.50	99.50	
72	5.19	99.81	
73	4.83	100.17	
74	4.25	100.75	
75	3.87	101.13	
76	3.23	101.77	
77	2.82	102.18	
78	2.44	102.56	

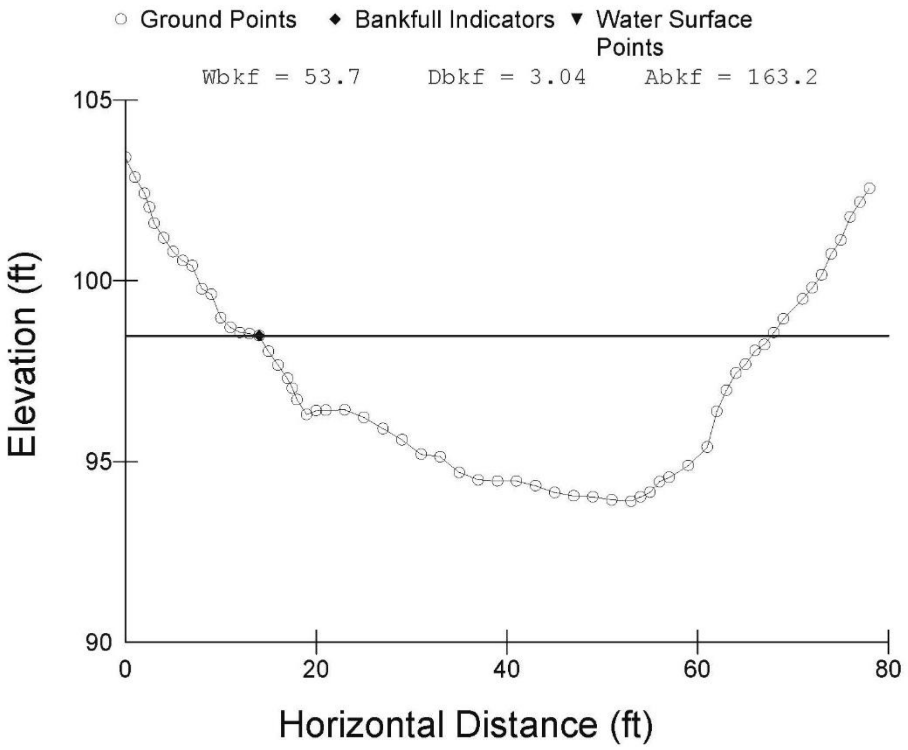


Figure A.44: Site ID 42, USGS gage 03211400 Leatherwood Creek, XSEC 2 (HLR 16).


(a)


(b)

Figure A.45: (a) Upstream and (b) downstream views of Site ID 43: USGS gage 03280700 Cutshin Creek (HLR 16).

Table A.29: Cross-sectional survey data for Site ID 43: USGS gage 03280700 Cutshin Creek at Wooton, KY, XSEC 1 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	0.88	104.12	
3	1.48	103.52	
5	1.86	103.14	
6	2.15	102.85	
8	2.74	102.26	
10	3.43	101.57	
12	3.74	101.26	
14.5	4.14	100.86	
16	3.96	101.04	
18	3.89	101.11	
20	4.32	100.68	
22	4.40	100.60	BKF
23	4.79	100.21	
24	5.64	99.36	
26	7.24	97.76	
28	7.48	97.52	
30	7.37	97.63	
32	7.31	97.69	
34	7.47	97.53	
36	7.48	97.52	
38	7.54	97.46	
40	7.57	97.43	
42	7.70	97.30	
44	7.84	97.16	
46	7.62	97.38	
48	7.71	97.29	
50	8.13	96.87	
52	8.10	96.90	
54	8.06	96.94	
56	7.88	97.12	
58	7.94	97.06	
60	8.30	96.70	
62	7.89	97.11	
64	8.20	96.80	
66	7.88	97.12	
68	7.84	97.16	
70	7.78	97.22	

Table A.29: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
72	7.65	97.35	
74	7.61	97.39	
76	7.71	97.29	
77	7.10	97.90	
78	7.21	97.79	
79	7.22	97.78	
81	7.21	97.79	
83	6.85	98.15	
85	6.39	98.61	
86	5.58	99.42	
87	4.72	100.28	
88	4.21	100.79	
89	2.00	103.00	
90	0.72	104.28	
91	0.44	104.56	

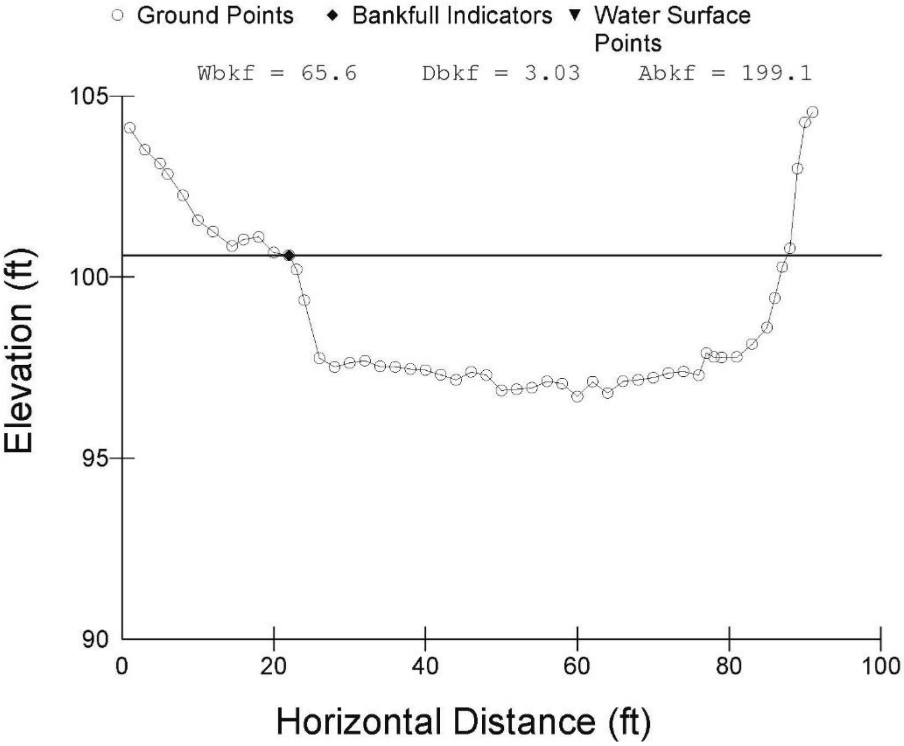


Figure A.46: Site ID 43, USGS gage 03280700 Cutshin Creek, XSEC 1 (HLR 16).

Table A.30: Cross-sectional survey data for Site ID 43: USGS gage 03280700 Cutshin Creek at Wooton, KY, XSEC 2 (HLR 16).

Station (ft)	FS(ft)	Elevation (ft)	Notes
1	1.54	103.46	
2	2.39	102.61	
3	3.35	101.65	
4	4.49	100.51	BKF
5	4.90	100.10	
6	5.38	99.62	
7	5.79	99.21	
8	6.24	98.76	
9	6.54	98.46	
10	6.90	98.10	
11	7.42	97.58	
12	7.72	97.28	
13	8.02	96.98	
14	8.26	96.74	
15	8.65	96.35	
17	8.74	96.26	
19	9.12	95.88	
21	8.86	96.14	
23	8.86	96.14	
25	8.71	96.29	
27	8.70	96.30	
29	8.39	96.61	
31	8.50	96.50	
33	8.26	96.74	
35	8.13	96.87	
37	7.91	97.09	
39	7.71	97.29	
41	7.77	97.23	
43	7.49	97.51	
45	7.70	97.30	
47	7.48	97.52	
49	7.58	97.42	
51	7.54	97.46	
53	7.38	97.62	
55	7.11	97.89	
57	7.61	97.39	
59	7.79	97.21	

Table A.30: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
61	7.35	97.65	
63	6.32	98.68	
65	5.65	99.35	
67	4.87	100.13	
68	4.59	100.41	
69	4.18	100.82	
71	3.28	101.72	
73	2.12	102.88	
75	1.33	103.67	

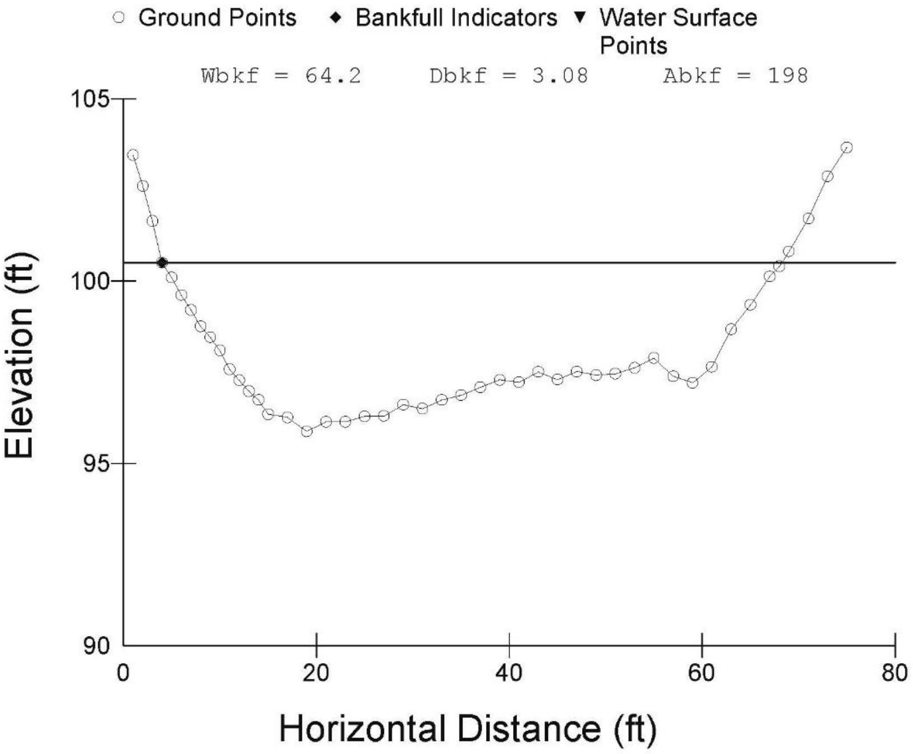


Figure A.47: Site ID 43, USGS gage 03280700 Cutshin Creek, XSEC 2 (HLR 16).

No photos available for Site ID 44: USGS gage 03212000 Paint Creek (HLR 16).

Table A.31: Cross-sectional survey data for Site ID 44: USGS gage 03212000 Paint Creek at Staffordsville, KY, XSEC 1 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	0.14	104.86	
1	1.10	103.90	
2	1.80	103.20	
3	2.59	102.41	
4	3.49	101.51	
5	4.73	100.27	
6	5.18	99.82	
8	5.52	99.48	
10	5.75	99.25	
12	6.23	98.77	
13	6.40	98.60	
14	6.94	98.06	
15	7.21	97.79	LEW
17	7.49	97.51	
19	7.58	97.42	
21	7.70	97.30	
23	7.85	97.15	
25	7.99	97.01	
27	8.10	96.90	
29	8.29	96.71	
31	8.47	96.53	
33	8.52	96.48	
35	8.69	96.31	
37	8.65	96.35	
39	8.16	96.84	
41	8.00	97.00	
43	7.72	97.28	
44.5	7.29	97.71	REW
46	7.40	97.60	
48	6.73	98.27	
50	6.78	98.22	
52	6.25	98.75	
54	5.79	99.21	
55	5.46	99.54	
56	5.08	99.92	
57	4.28	100.72	
58	3.69	101.31	

Table A.31: cont'd:

Station (ft)	FS (ft)	Elevation (ft)	Notes
60	2.80	102.20	BKF
61	2.02	102.98	
62	1.30	103.70	
63	0.01	104.99	

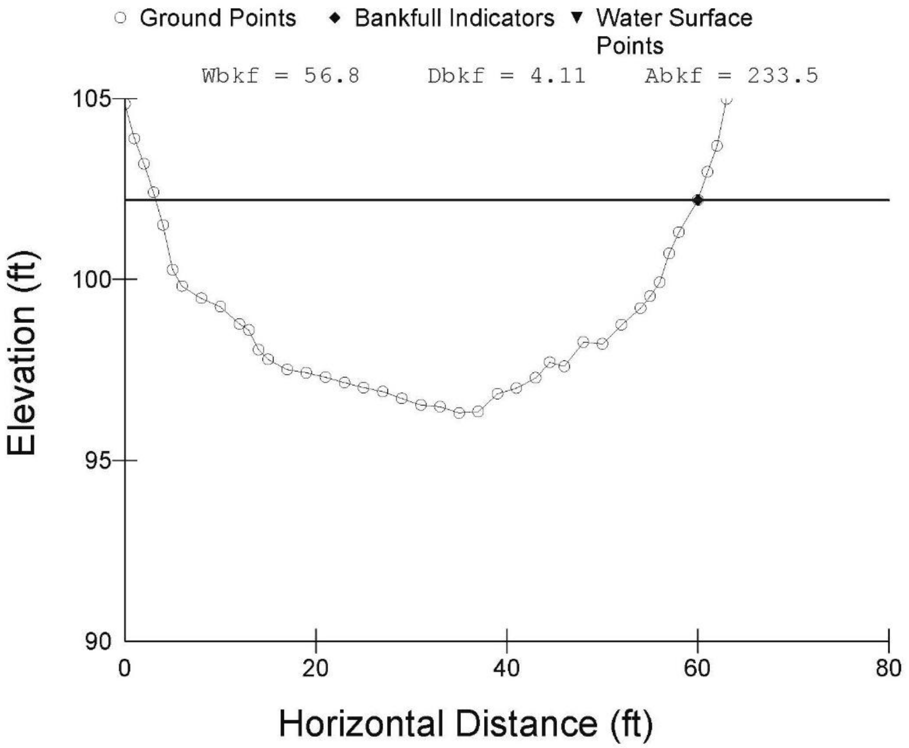


Figure A.48: Site ID 44, USGS gage 03212000 Paint Creek, XSEC 1 (HLR 16).

Table A.32: Cross-sectional survey data for Site ID 44: USGS gage 03212000 Paint Creek at Staffordsville, KY, XSEC 2 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
1	0.20	104.80	
2	0.99	104.01	
3	1.63	103.37	BKF
5	2.38	102.62	
7	3.17	101.83	
9	3.48	101.52	
11	3.95	101.05	
13	4.20	100.80	
15	3.91	101.09	
17	3.63	101.37	
19	4.42	100.58	
21	4.79	100.21	
23	4.27	100.73	
24	4.65	100.35	
25	5.69	99.31	
27	5.83	99.17	
29	6.11	98.89	LEW
30	6.56	98.44	
32	6.90	98.10	
34	6.97	98.03	
36	7.06	97.94	
38	7.21	97.79	
40	7.43	97.57	
42	7.65	97.35	
44	7.87	97.13	
46	8.05	96.95	
48	7.72	97.28	
50	7.68	97.32	
52	7.44	97.56	
54	7.06	97.94	
56	6.59	98.41	
57	6.15	98.85	REW
58	5.71	99.29	
59	5.10	99.90	
60	4.65	100.35	
61	3.99	101.01	
62	3.25	101.75	

Table A.32: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
64	2.10	102.90	
66	1.36	103.64	
68	0.51	104.49	
70	0.00	105.00	

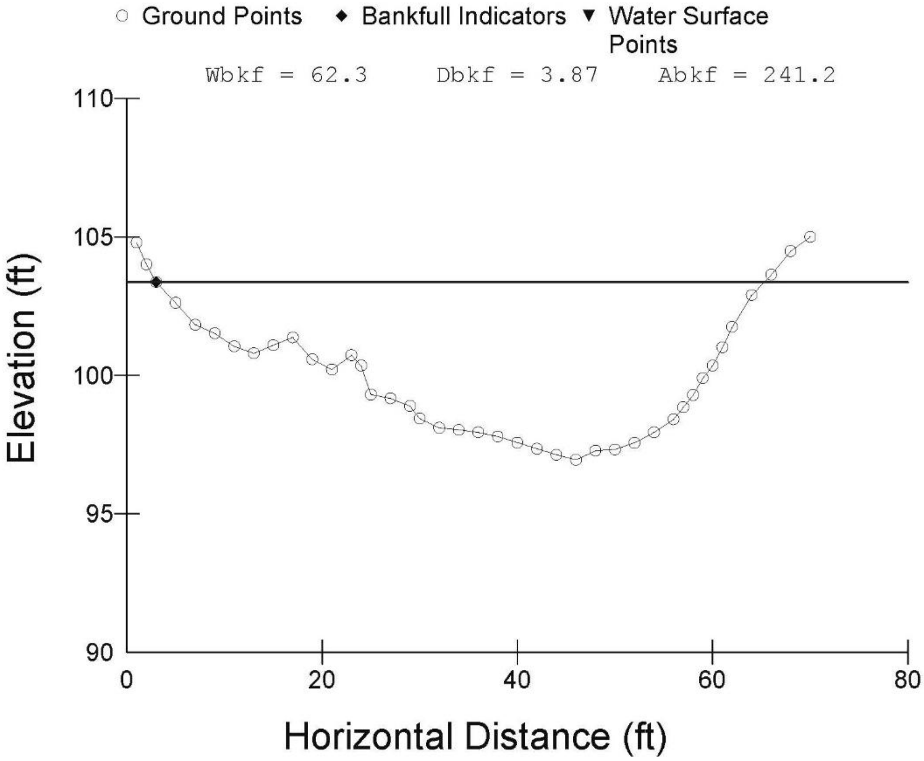


Figure A.49: Site ID 44, USGS gage 03212000 Paint Creek, XSEC 2 (HLR 16).

Figure A.50: (a) Upstream and (b) downstream views of Site ID 45: USGS gage 03248500 Licking River (HLR 16).

Table A.33: Cross-sectional survey data for Site ID 45: USGS gage 03248500 Licking River near Salyersville, KY, XSEC 1 (HLR 16).

Station (ft)	FS (ft)	Elevation (ft)	Notes
0	3.61	101.39	
1	4.10	100.90	
2	4.65	100.35	
2.5	5.57	99.43	
3	6.00	99.00	
4	7.29	97.71	
5	7.89	97.11	BKF
6	8.36	96.64	
7	8.80	96.20	
8	9.05	95.95	
9	9.65	95.35	
10	10.13	94.87	LEW
11	11.45	93.55	
12	12.60	92.40	
13	12.13	92.87	
14	12.91	92.09	
15	13.28	91.72	
17	13.76	91.24	
19	13.86	91.14	
21	13.64	91.36	
23	13.22	91.78	
25	12.85	92.15	
27	13.00	92.00	
29	13.52	91.48	
31	13.81	91.19	
33	13.81	91.19	
35	13.60	91.40	
37	13.50	91.50	
39	13.78	91.22	
41	13.98	91.02	
43	14.05	90.95	
45	14.15	90.85	
47	14.33	90.67	
49	13.98	91.02	
51	13.49	91.51	
53	12.99	92.01	
54	12.90	92.10	

Table A.33: cont'd.

Station (ft)	FS (ft)	Elevation (ft)	Notes
55	12.00	93.00	
55.5	10.97	94.03	REW
56	9.82	95.18	
57	8.93	96.07	
58	7.19	97.81	
59	7.11	97.89	
61	7.06	97.94	
62	6.49	98.51	
63	6.49	98.51	
65	4.85	100.15	
67	3.98	101.02	

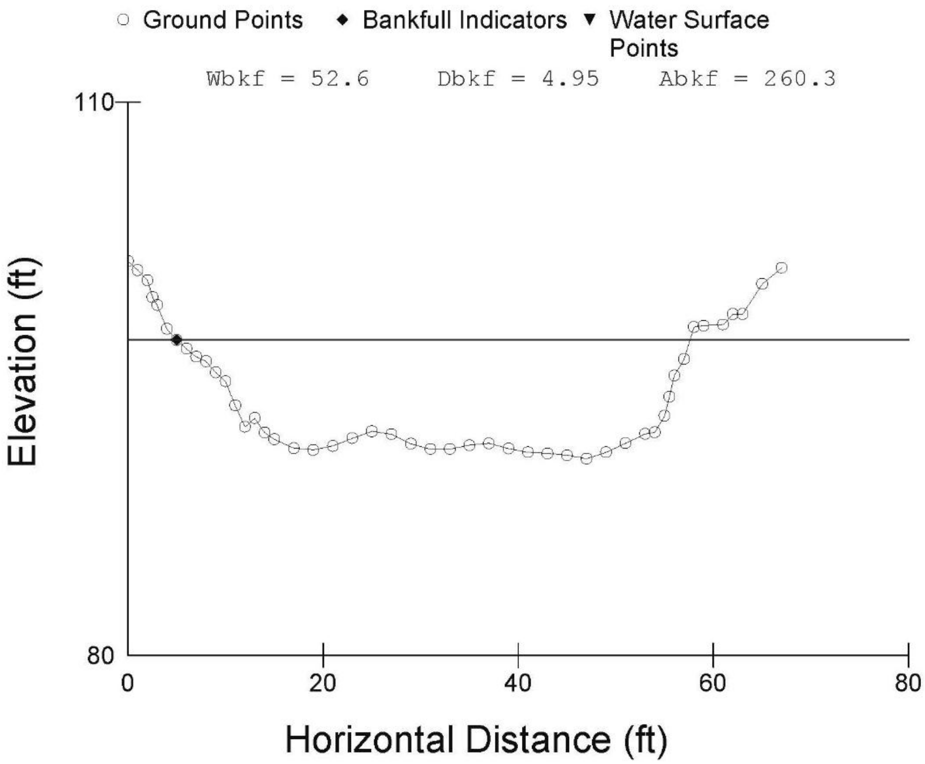


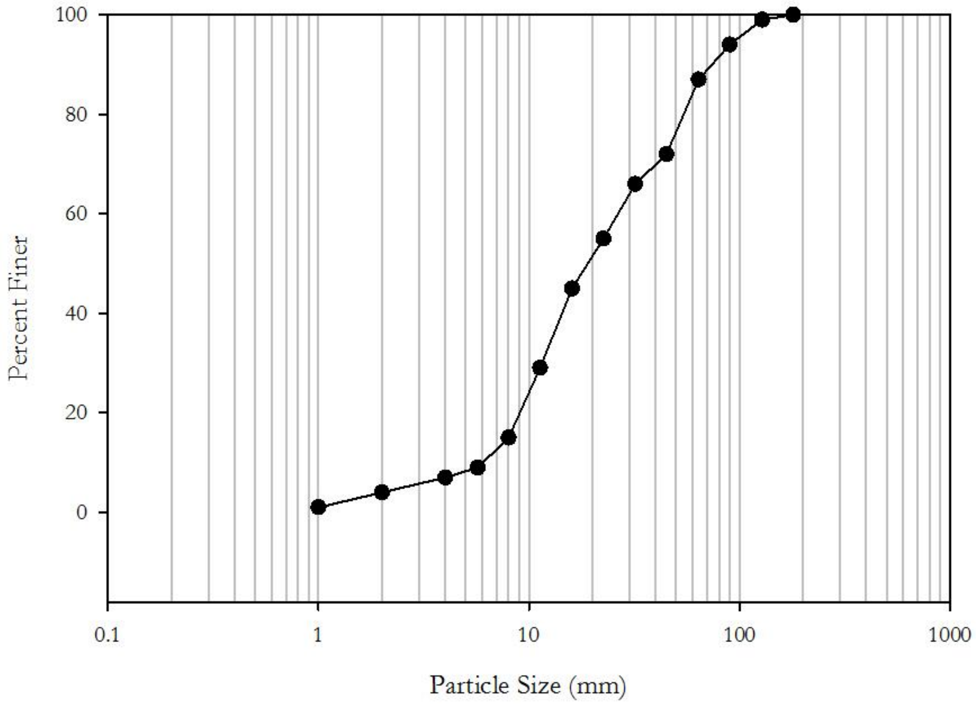
Figure A.51: Site ID 45, USGS gage 03248500 Licking River, XSEC 1 (HLR 16).

APPENDIX B: BED MATERIAL DATA

Particle Size Analysis Summary: Site ID 1, Rose Creek (HLR 9)

Size (mm)	No. Particles
0.50 - 1.0	1
1.0 - 2.0	3
2.0 - 4.0	3
4.0 - 5.7	2
5.7 - 8.0	6
8.0 - 11.3	14
11.3 - 16.0	16
16.0 - 22.6	10
22.6 - 32.0	11
32 - 45	6
45 - 64	15
64 - 90	7
90 - 128	5
128 - 180	1
180-256	0
256-362	0
362-512	0
512-1024	0
TOTAL	100

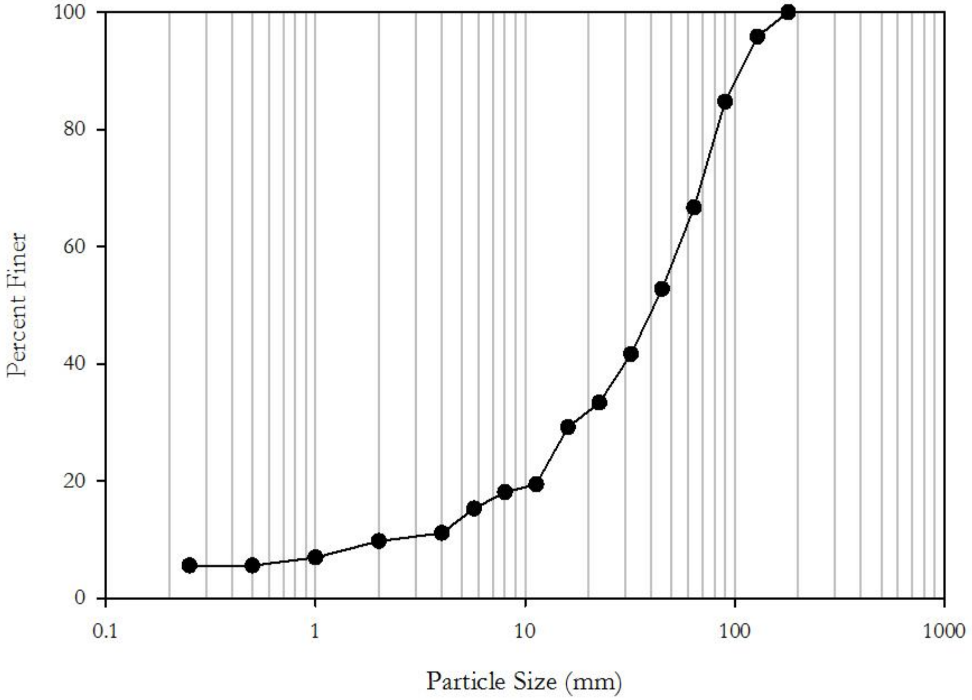
Classification	Values
D_{16} (mm)	8.24
D_{35} (mm)	13.06
D_{50} (mm)	19.3
D_{84} (mm)	60.2
D_{95} (mm)	97.6
D_{100} (mm)	179.99
Silt/Clay (%)	0
Sand (%)	4
Gravel (%)	83
Cobble (%)	13
Boulder (%)	0
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 3: USGS gage 03250150 Indian Creek (HLR 9)

Size (mm)	No. Particles
0.125-0.25	4
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	2
4.0 - 5.7	1
5.7 - 8.0	3
8.0 - 11.3	2
11.3 - 16.0	1
16.0 - 22.6	7
22.6 - 32.0	3
32 - 45	6
45 - 64	8
64 - 90	10
90 - 128	13
128 - 180	8
180-256	3
256-362	0
362-512	0
512-1024	0
TOTAL	100

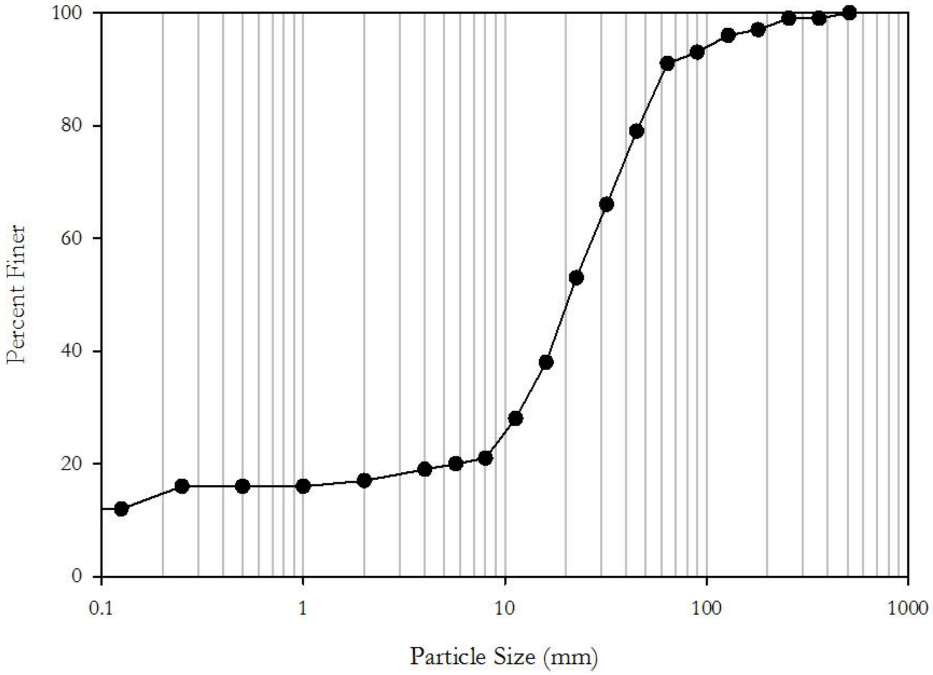
Classification	Values
D_{16} (mm)	8.85
D_{35} (mm)	34.6
D_{50} (mm)	59.25
D_{84} (mm)	126.48
D_{95} (mm)	176.12
D_{100} (mm)	256
Silt/Clay (%)	0
Sand (%)	6.94
Gravel (%)	45.84
Cobble (%)	47.22
Boulder (%)	0
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 4: USGS gage 03250322 Rock Lick Creek (HLR 9).

Size (mm)	No. Particles
0-0.062	12
0.062-0.125	0
0.125-0.25	4
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	2
4.0 - 5.7	1
5.7 - 8.0	1
8.0 - 11.3	7
11.3 - 16.0	10
16.0 - 22.6	15
22.6 - 32.0	13
32 - 45	13
45 - 64	12
64 - 90	2
90 - 128	3
128 - 180	0
180-256	1
256-362	2
362-512	0
512-1024	1
TOTAL	100

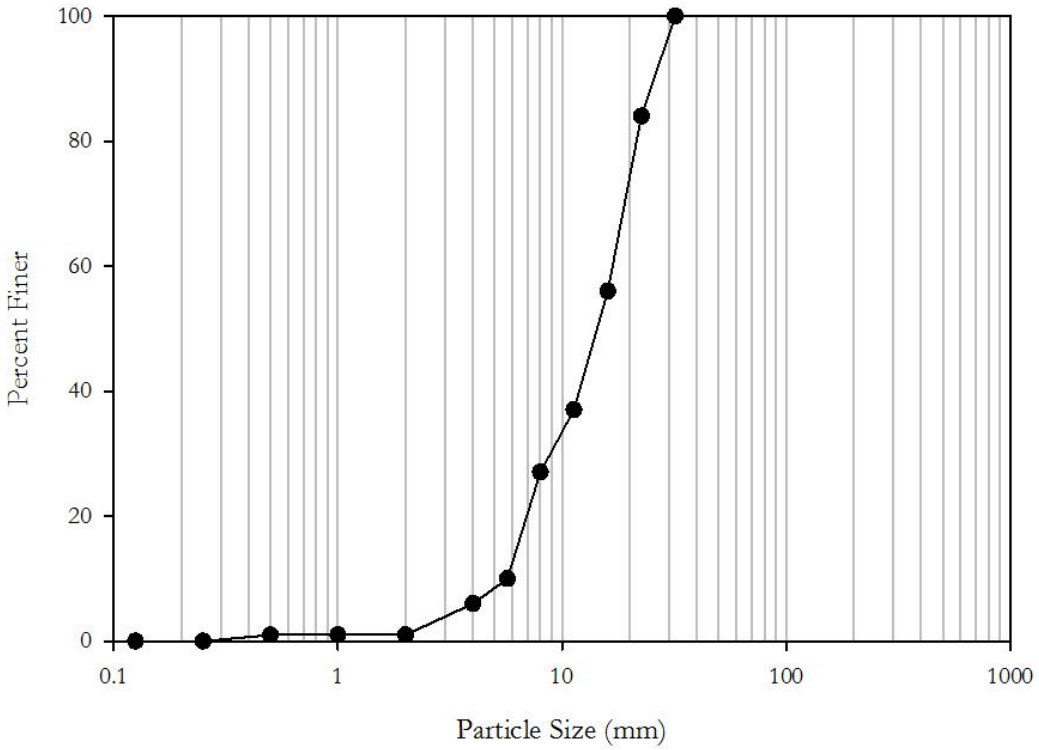
Classification	Values
D_{16} (mm)	0.25
D_{35} (mm)	14.59
D_{50} (mm)	21.28
D_{84} (mm)	52.92
D_{95} (mm)	115.33
D_{100} (mm)	1023.95
Silt/Clay (%)	12
Sand (%)	5
Gravel (%)	74
Cobble (%)	6
Boulder (%)	3
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 5: Storey Branch, (HLR 9)

Size (mm)	No. Particles
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	0
4.0 - 5.7	0
5.7 - 8.0	5
8.0 - 11.3	4
11.3 - 16.0	17
16.0 - 22.6	10
22.6 - 32.0	19
32 - 45	28
45 - 64	16
64 - 90	0
90 - 128	0
128 - 180	0
180-256	0
256-362	0
362-512	0
512-1024	0
TOTAL	100

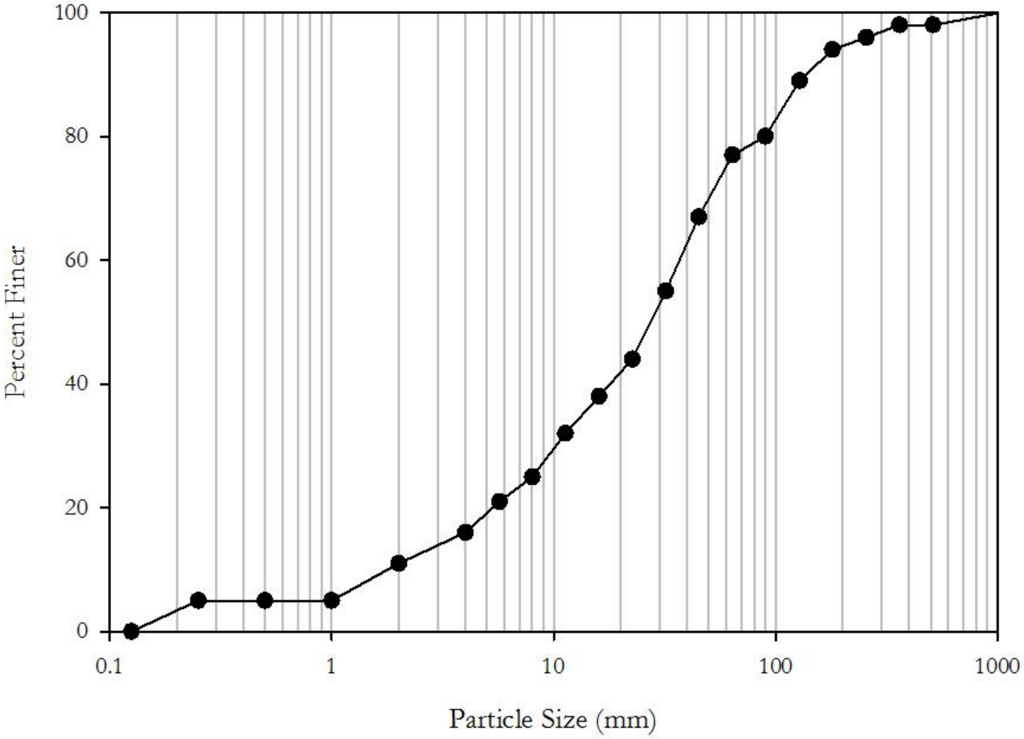
Classification	Values
D_{16} (mm)	12.96
D_{35} (mm)	21.28
D_{50} (mm)	29.03
D_{84} (mm)	45
D_{95} (mm)	58.06
D_{100} (mm)	64
Silt/Clay (%)	0
Sand (%)	1
Gravel (%)	99
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 6: USGS gage 03237900 Cabin Creek (HLR 9)

Size (mm)	**No. Particles**
0.125-0.25	5
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	6
2.0 - 4.0	5
4.0 - 5.7	5
5.7 - 8.0	4
8.0 - 11.3	7
11.3 - 16.0	6
16.0 - 22.6	6
22.6 - 32.0	11
32 - 45	12
45 - 64	10
64 - 90	3
90 - 128	9
128 - 180	5
180-256	2
256-362	2
362-512	0
512-1024	2
TOTAL	100

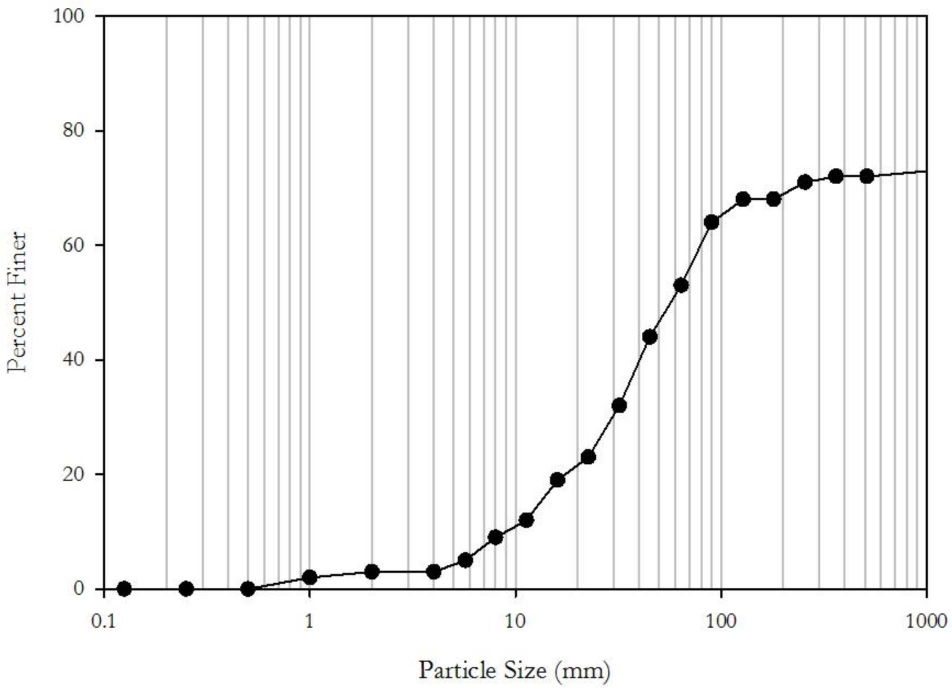
Classification	**Values**
D_{16} (mm)	4
D_{35} (mm)	13.65
D_{50} (mm)	27.73
D_{84} (mm)	106.89
D_{95} (mm)	218
D_{100} (mm)	1023.97
Silt/Clay (%)	0
Sand (%)	11
Gravel (%)	66
Cobble (%)	19
Boulder (%)	4
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 7: USGS gage 03250000 Triplett Creek (HLR 9)

Size (mm)	No. Particles
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	2
1.0 - 2.0	1
2.0 - 4.0	0
4.0 - 5.7	2
5.7 - 8.0	4
8.0 - 11.3	3
11.3 - 16.0	7
16.0 - 22.6	4
22.6 - 32.0	9
32 - 45	12
45 - 64	9
64 - 90	11
90 - 128	4
128 - 180	0
180-256	3
256-362	1
362-512	0
512-1024	1
Bedrock	27
TOTAL	100

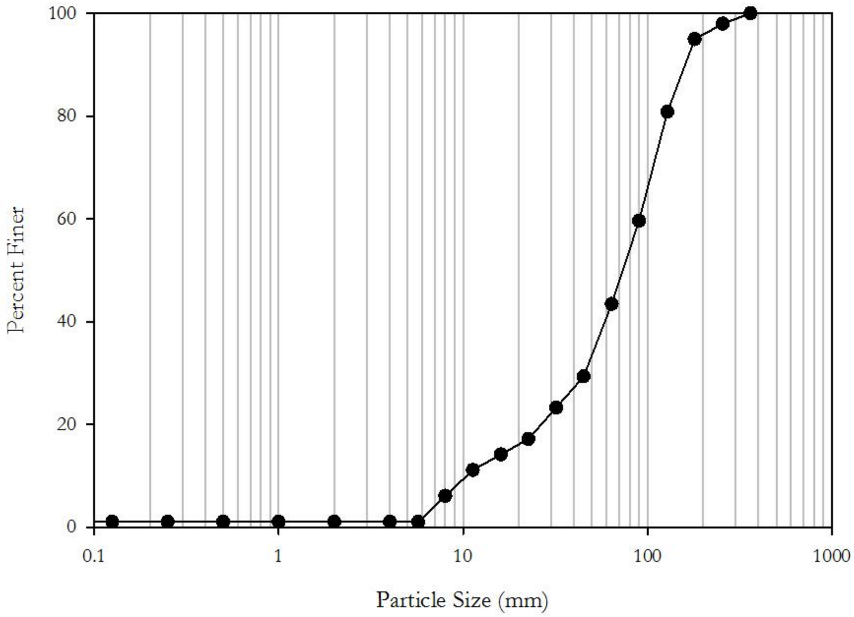
Classification	Values
D_{16} (mm)	13.99
D_{35} (mm)	35.25
D_{50} (mm)	57.67
D_{84} (mm)	BedRock
D_{95} (mm)	Bedrock
D_{100} (mm)	Bedrock
Silt/Clay (%)	0
Sand (%)	3
Gravel (%)	50
Cobble (%)	18
Boulder (%)	2
Bedrock (%)	27



Particle Size Analysis Summary: Site ID 9: USGS gage 03250100 North Fork Triplett (HLR9)

Size (mm)	No. Particles
0-0.062	1
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	0
2.0 - 4.0	0
4.0 - 5.7	0
5.7 - 8.0	5
8.0 - 11.3	5
11.3 - 16.0	3
16.0 - 22.6	3
22.6 - 32.0	6
32 - 45	6
45 - 64	14
64 - 90	16
90 - 128	21
128 - 180	14
180-256	3
256-362	2
362-512	0
512-1024	0
Bedrock	0
TOTAL	100

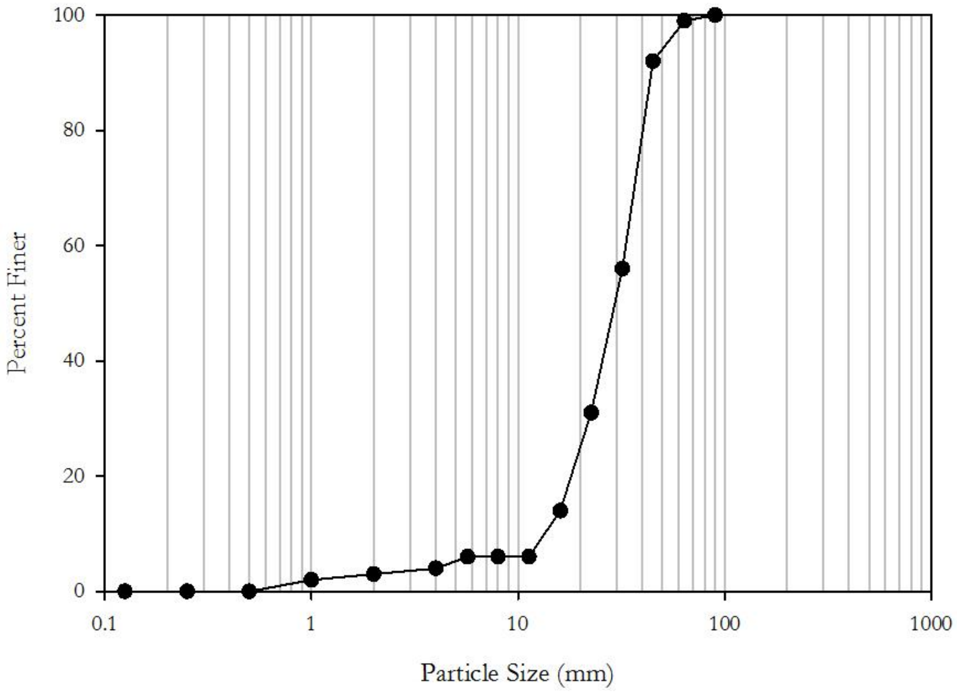
Classification	Values
D_{16} (mm)	20.05
D_{35} (mm)	52.67
D_{50} (mm)	74.56
D_{84} (mm)	139.73
D_{95} (mm)	181.25
D_{100} (mm)	361.99
Silt/Clay (%)	1.01
Sand (%)	0
Gravel (%)	42.42
Cobble (%)	54.55
Boulder (%)	2.02
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 12: UT KY-191 Mile 5, (HLR 11)

Size (mm)	No. Particles
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	2
1.0 - 2.0	1
2.0 - 4.0	1
4.0 - 5.7	2
5.7 - 8.0	0
8.0 - 11.3	0
11.3 - 16.0	8
16.0 - 22.6	17
22.6 - 32.0	25
32 - 45	36
45 - 64	7
64 - 90	1
90 - 128	0
128 - 180	0
180-256	0
256-362	0
362-512	0
512-1024	0
Bedrock	0
TOTAL	100

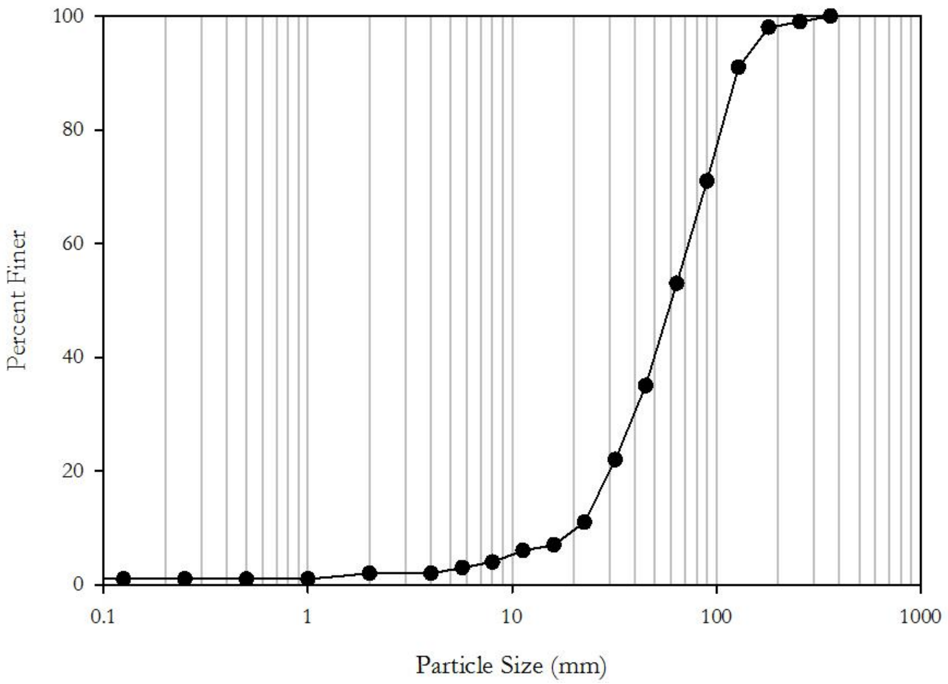
Classification	Values
D_{16} (mm)	16.78
D_{35} (mm)	24.1
D_{50} (mm)	29.74
D_{84} (mm)	42.11
D_{95} (mm)	53.14
D_{100} (mm)	90
Silt/Clay (%)	0
Sand (%)	3
Gravel (%)	96
Cobble (%)	1
Boulder (%)	0
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 17: USGS gage 03216370 Big Sinking Creek (HLR 11)

Size (mm)	No. Particles
0-0.062	1
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	0
4.0 - 5.7	1
5.7 - 8.0	1
8.0 - 11.3	2
11.3 - 16.0	1
16.0 - 22.6	4
22.6 - 32.0	11
32 - 45	13
45 - 64	18
64 - 90	18
90 - 128	20
128 - 180	7
180-256	1
256-362	1
362-512	0
512-1024	0
TOTAL	100

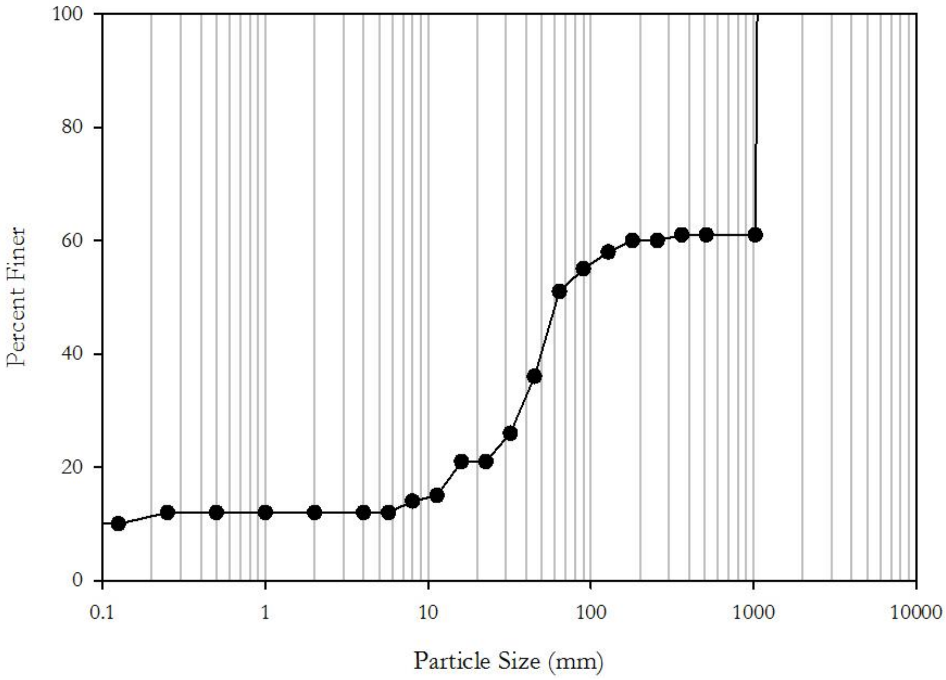
Classification	Values
D_{16} (mm)	26.87
D_{35} (mm)	45
D_{50} (mm)	60.83
D_{84} (mm)	114.7
D_{95} (mm)	157.71
D_{100} (mm)	361.99
Silt/Clay (%)	1
Sand (%)	1
Gravel (%)	51
Cobble (%)	46
Boulder (%)	1
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 19: USGS gage 03404900 Lynn Camp (HLR 11)

Size (mm)	No. Particles
0-0.062	10
0.062-0.125	0
0.125-0.25	2
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	0
2.0 - 4.0	0
4.0 - 5.7	0
5.7 - 8.0	2
8.0 - 11.3	1
11.3 - 16.0	6
16.0 - 22.6	0
22.6 - 32.0	5
32 - 45	10
45 - 64	15
64 - 90	4
90 - 128	3
128 - 180	2
180-256	0
256-362	1
362-512	0
512-1024	0
TOTAL	39

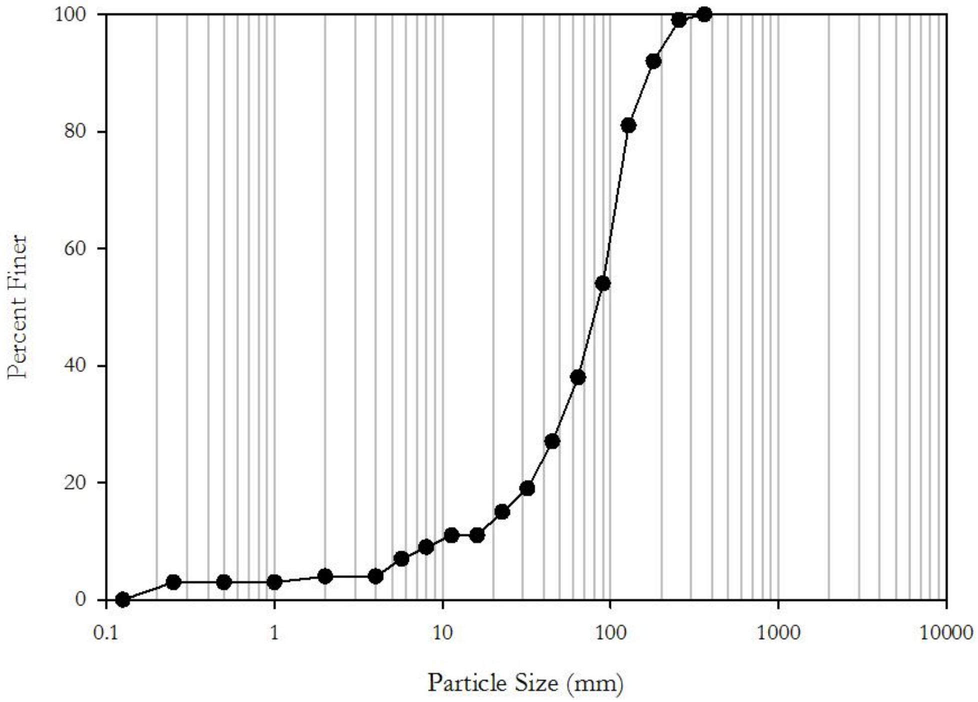
Classification	Values
D_{16} (mm)	12.08
D_{35} (mm)	43.7
D_{50} (mm)	62.73
D_{84} (mm)	Bedrock
D_{95} (mm)	Bedrock
D_{100} (mm)	Bedrock
Silt/Clay (%)	10
Sand (%)	2
Gravel (%)	39
Cobble (%)	9
Boulder (%)	1
Bedrock (%)	39



Particle Size Analysis Summary: Site ID 22: USGS gage 03282040 Sturgeon Creek (HLR 11)

Size (mm)	No. Particles
0-0.062	0
0.062-0.125	0
0.125-0.25	3
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	0
4.0 - 5.7	3
5.7 - 8.0	2
8.0 - 11.3	2
11.3 - 16.0	4
16.0 - 22.6	4
22.6 - 32.0	8
32 - 45	11
45 - 64	16
64 - 90	27
90 - 128	11
128 - 180	7
180-256	1
256-362	0
362-512	0
512-1024	0
TOTAL	100

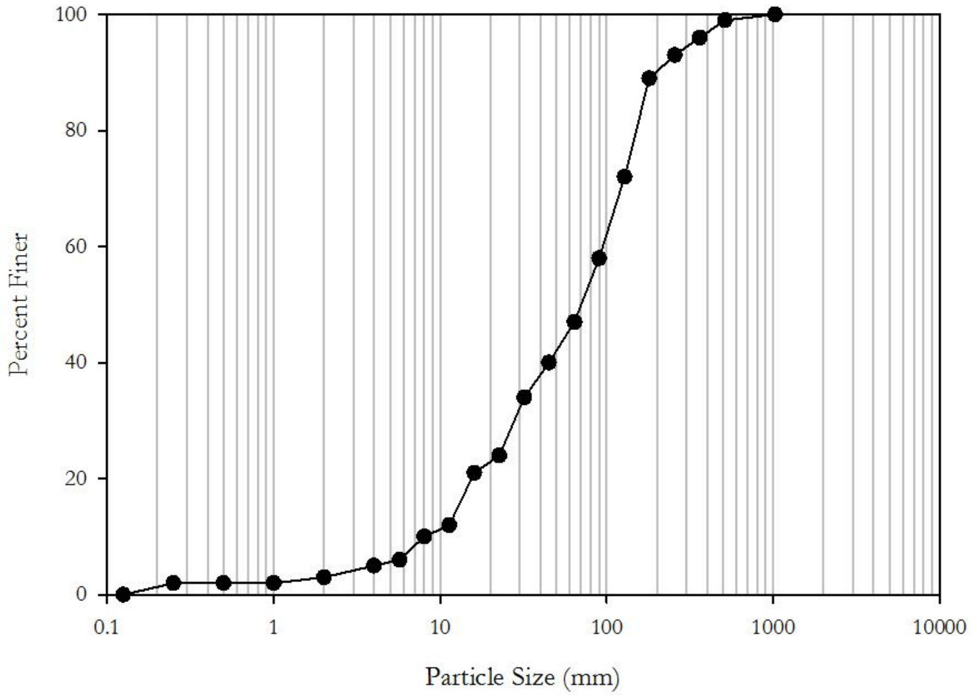
Classification	Values
D_{16} (mm)	24.95
D_{35} (mm)	58.82
D_{50} (mm)	83.5
D_{84} (mm)	142.18
D_{95} (mm)	212.57
D_{100} (mm)	361.99
Silt/Clay (%)	0
Sand (%)	4
Gravel (%)	34
Cobble (%)	61
Boulder (%)	1
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 23: USGS gage 03281100 Goose Creek (HLR 11)

Size (mm)	No. Particles
0-0.062	0
0.062-0.125	0
0.125-0.25	2
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	2
4.0 - 5.7	1
5.7 - 8.0	4
8.0 - 11.3	2
11.3 - 16.0	9
16.0 - 22.6	3
22.6 - 32.0	10
32 - 45	6
45 - 64	7
64 - 90	11
90 - 128	14
128 - 180	17
180-256	4
256-362	3
362-512	3
512-1024	1
TOTAL	100

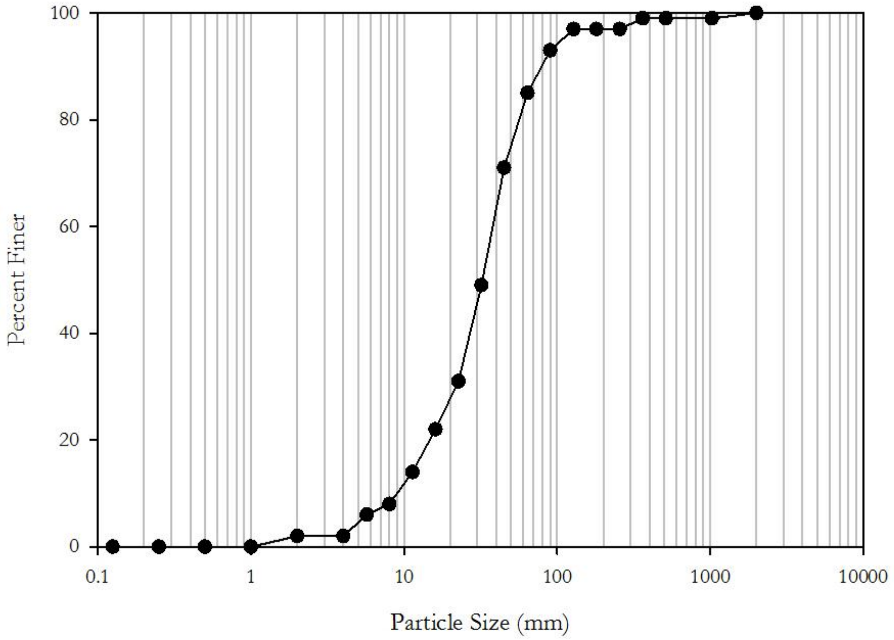
Classification	Values
D_{16} (mm)	13.39
D_{35} (mm)	34.17
D_{50} (mm)	71.09
D_{84} (mm)	164.71
D_{95} (mm)	326.67
D_{100} (mm)	1023.95
Silt/Clay (%)	0
Sand (%)	3
Gravel (%)	44
Cobble (%)	46
Boulder (%)	7
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 35, Beaver Creek (HLR 16)

Size (mm)	No. Particles
0-0.062	0
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	2
2.0 - 4.0	0
4.0 - 5.7	4
5.7 - 8.0	2
8.0 - 11.3	6
11.3 - 16.0	8
16.0 - 22.6	9
22.6 - 32.0	18
32 - 45	22
45 - 64	14
64 - 90	8
90 - 128	4
128 - 180	0
180-256	0
256-362	2
362-512	0
512-1024	0
Bedrock	1
TOTAL	100

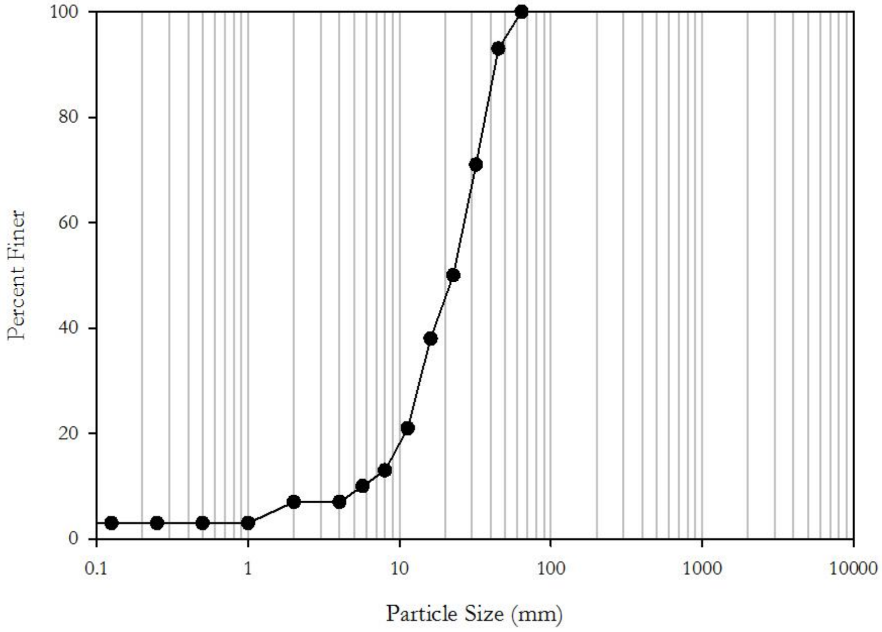
Classification	Values
D_{16} (mm)	12.48
D_{35} (mm)	24.69
D_{50} (mm)	32.59
D_{84} (mm)	62.84
D_{95} (mm)	109
D_{100} (mm)	Bedrock
Silt/Clay (%)	0
Sand (%)	2
Gravel (%)	83
Cobble (%)	12
Boulder (%)	2
Bedrock (%)	1



Particle Size Analysis Summary: Site ID 37: USGS gage 03283370 Cat Creek (HLR 16)

Size (mm)	No. Particles
0-0.062	3
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	4
2.0 - 4.0	0
4.0 - 5.7	3
5.7 - 8.0	3
8.0 - 11.3	8
11.3 - 16.0	17
16.0 - 22.6	12
22.6 - 32.0	21
32 - 45	22
45 - 64	147
64 - 90	0
90 - 128	0
128 - 180	0
180-256	0
256-362	0
362-512	0
512-1024	0
Bedrock	0
TOTAL	100

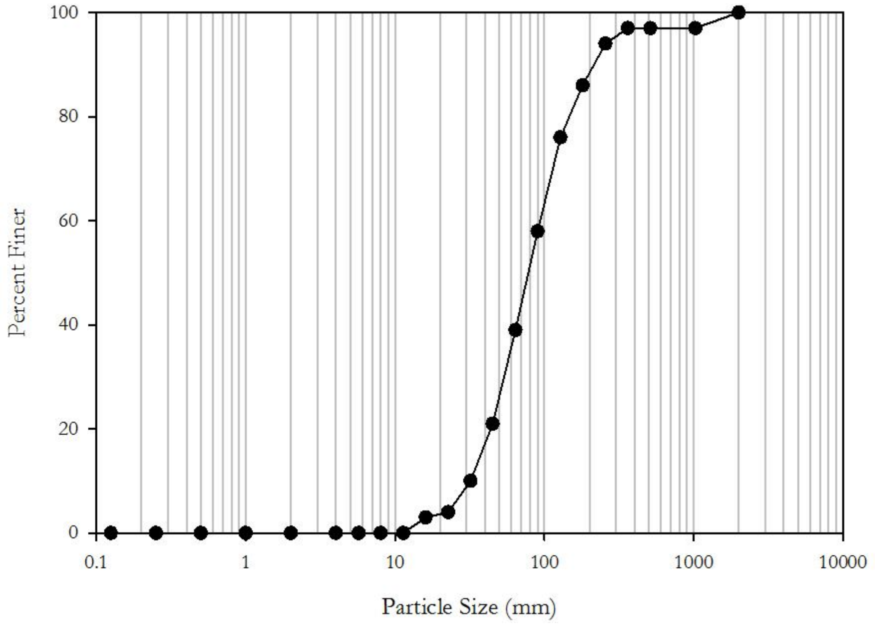
Classification	Values
D_{16} (mm)	9.24
D_{35} (mm)	15.17
D_{50} (mm)	22.6
D_{84} (mm)	39.68
D_{95} (mm)	50.43
D_{100} (mm)	64
Silt/Clay (%)	3
Sand (%)	4
Gravel (%)	93
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 39: USGS gage 03280600 Middle Fork River (HLR 16)

Size (mm)	No. Particles
0-0.062	0
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	0
2.0 - 4.0	0
4.0 - 5.7	0
5.7 - 8.0	0
8.0 - 11.3	0
11.3 - 16.0	3
16.0 - 22.6	1
22.6 - 32.0	6
32 - 45	11
45 - 64	18
64 - 90	19
90 - 128	18
128 - 180	10
180-256	8
256-362	3
362-512	0
512-1024	0
Bedrock	3
TOTAL	100

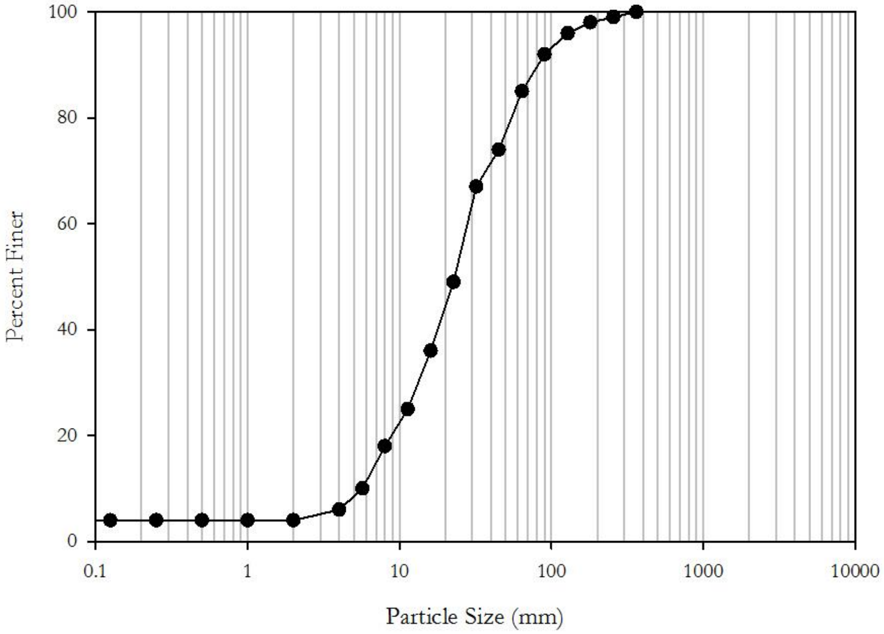
Classification	Values
D_{16} (mm)	39.09
D_{35} (mm)	59.78
D_{50} (mm)	79.05
D_{84} (mm)	169.6
D_{95} (mm)	291.33
D_{100} (mm)	Bedrock
Silt/Clay (%)	0
Sand (%)	0
Gravel (%)	39
Cobble (%)	55
Boulder (%)	3
Bedrock (%)	3



Particle Size Analysis Summary: Site ID 42, USGS gage 03211400 Leatherwood Creek (HLR 16)

Size (mm)	No. Particles
0-0.062	4
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	0
2.0 - 4.0	2
4.0 - 5.7	4
5.7 - 8.0	8
8.0 - 11.3	7
11.3 - 16.0	11
16.0 - 22.6	13
22.6 - 32.0	18
32 - 45	7
45 - 64	11
64 - 90	7
90 - 128	4
128 - 180	2
180-256	1
256-362	1
362-512	0
512-1024	0
Bedrock	0
TOTAL	100

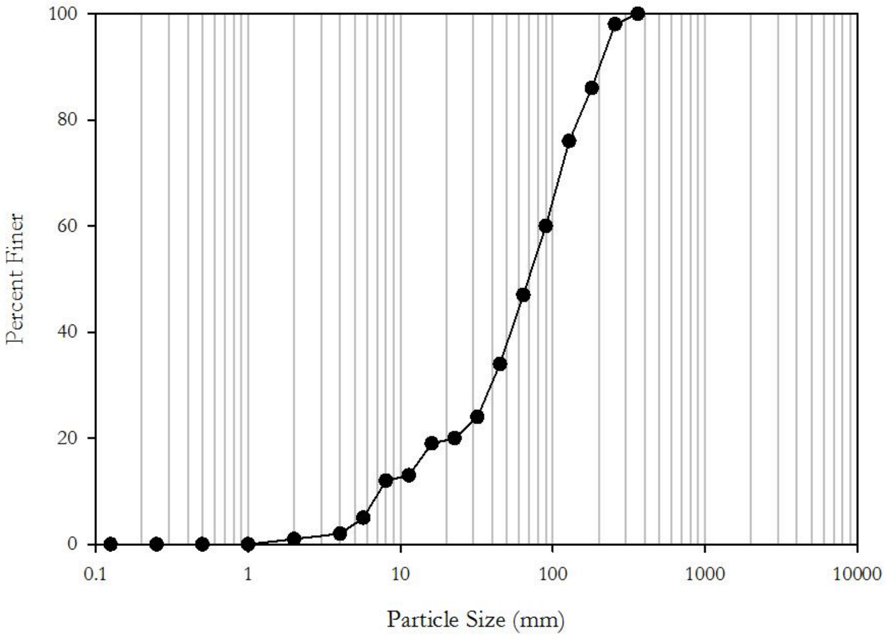
Classification	Values
D_{16} (mm)	7.42
D_{35} (mm)	15.57
D_{50} (mm)	23.12
D_{84} (mm)	62.27
D_{95} (mm)	118.5
D_{100} (mm)	361.99
Silt/Clay (%)	4
Sand (%)	0
Gravel (%)	81
Cobble (%)	14
Boulder (%)	1
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 43, USGS gage 03280700 Cutshin Creek (HLR 16)

Size (mm)	No. Particles
0-0.062	0
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	1
2.0 - 4.0	1
4.0 - 5.7	3
5.7 - 8.0	7
8.0 - 11.3	1
11.3 - 16.0	6
16.0 - 22.6	1
22.6 - 32.0	4
32 - 45	13
45 - 64	13
64 - 90	16
90 - 128	10
128 - 180	12
180-256	2
256-362	0
362-512	0
512-1024	0
Bedrock	0
TOTAL	100

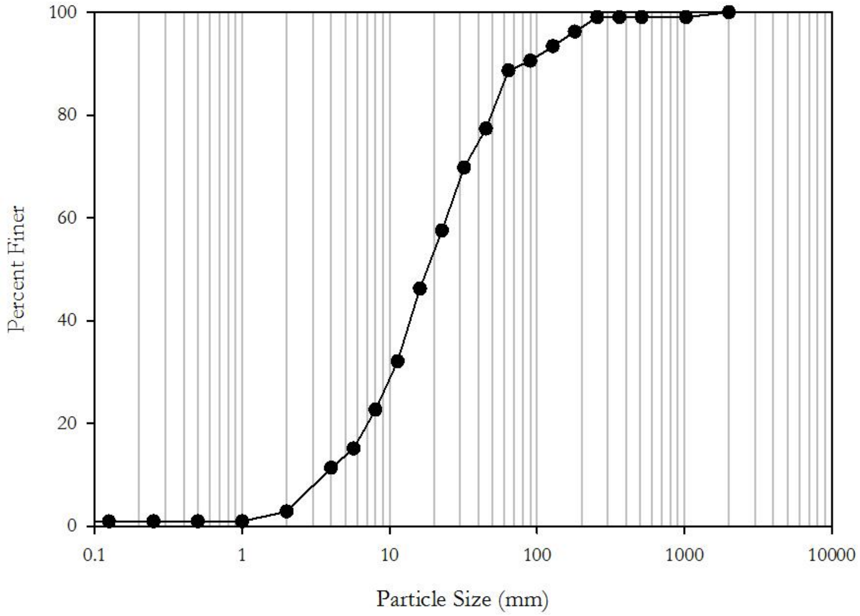
Classification	Values
D_{16} (mm)	13.65
D_{35} (mm)	46.46
D_{50} (mm)	70
D_{84} (mm)	169.6
D_{95} (mm)	237
D_{100} (mm)	361.99
Silt/Clay (%)	0
Sand (%)	1
Gravel (%)	46
Cobble (%)	51
Boulder (%)	2
Bedrock (%)	0



Particle Size Analysis Summary: Site ID 44: USGS gage 03212000 Paint Creek (HLR 16)

Size (mm)	No. Particles
0-0.062	1
0.062-0.125	0
0.125-0.25	0
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	2
2.0 - 4.0	9
4.0 - 5.7	4
5.7 - 8.0	8
8.0 - 11.3	10
11.3 - 16.0	15
16.0 - 22.6	12
22.6 - 32.0	13
32 - 45	8
45 - 64	12
64 - 90	2
90 - 128	3
128 - 180	3
180-256	3
256-362	0
362-512	0
512-1024	0
Bedrock	1
TOTAL	100

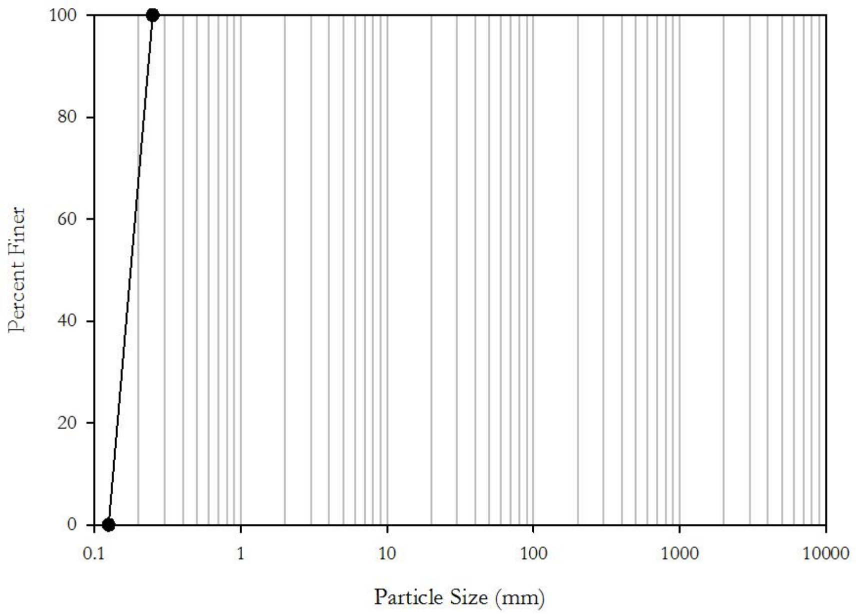
Classification	Values
D_{16} (mm)	5.98
D_{35} (mm)	12.27
D_{50} (mm)	18.2
D_{84} (mm)	56.14
D_{95} (mm)	157.4
D_{100} (mm)	Bedrock
Silt/Clay (%)	0.94
Sand (%)	1.89
Gravel (%)	85.85
Cobble (%)	10.38
Boulder (%)	0
Bedrock (%)	0.94



Particle Size Analysis Summary: Site ID 45, USGS gage 03248500 Licking River (HLR 16)

Size (mm)	No. Particles
0-0.062	0
0.062-0.125	0
0.125-0.25	100
0.25-0.5	0
0.50 - 1.0	0
1.0 - 2.0	0
2.0 - 4.0	0
4.0 - 5.7	0
5.7 - 8.0	0
8.0 - 11.3	0
11.3 - 16.0	0
16.0 - 22.6	0
22.6 - 32.0	0
32 - 45	0
45 - 64	0
64 - 90	0
90 - 128	0
128 - 180	0
180-256	0
256-362	0
362-512	0
512-1024	0
Bedrock	0
TOTAL	100

Classification	Values
D_{16} (mm)	0.14
D_{35} (mm)	0.17
D_{50} (mm)	0.19
D_{84} (mm)	0.23
D_{95} (mm)	0.24
D_{100} (mm)	0.25
Silt/Clay (%)	0
Sand (%)	100
Gravel (%)	0
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0



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VITA

Ashlan Nicole Berry

PLACE OF BIRTH

Jefferson County, Kentucky

EDUCATION

B.S. Meteorology, Western Kentucky University, Bowling Green, Kentucky, May 2014

PROFESSIONAL EXPERIENCE

Graduate Research Assistant, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, Kentucky. August 2014– Present. Advisor: Dr. C. T. Agouridis.

PROFESSIONAL SOCIETIES

American Societry of Agricultural and Biological Engineers

HONORARY SOCIETIES

Alpha Epsilon Engineering Honor Society