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HYDRAULIC GEOMETRY RELATIONSHIPS AND REGIONAL CURVES FOR THE INNER AND OUTER BLUEGRASS REGIONS OF KENTUCKY

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ABSTRACT OF THESIS

HYDRAULIC GEOMETRY RELATIONSHIPS AND REGIONAL CURVES FOR THE INNER AND OUTER BLUEGRASS REGIONS OF KENTUCKY

Hydraulic geometry relationships and regional curves are used in natural channel design to assist engineers, biologists, and fluvial geomorphologists in the efforts undertaken to ameliorate previous activities that have diminished, impaired or destroyed the structure and function of stream systems. Bankfull channel characteristics were assessed for 14 United States Geological Survey (USGS) gaged sites in the Inner Bluegrass and 15 USGS gaged sites in the Outer Bluegrass Regions of Kentucky. Hydraulic geometry relationships and regional curves were developed for the aforementioned regions.

Analysis of the regression relationships showed that bankfull discharge is a good explanatory variable for bankfull parameters such as area, width and depth. The hydraulic geometry relationships developed produced high R^2 values up to 0.95. The relationships were also compared to other studies and show strong relationships to both theoretical and empirical data. Regional curves, relating drainage area to bankfull parameters, were developed and show that drainage area is a good explanatory variable for bankfull parameters. R^2 values for the regional curves were as high as 0.98.

Keywords: Bankfull, Fluvial Geomorphology, Channel Form, Flood Frequency Analysis, Stream Restoration

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August 11, 2010
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THESIS

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The Graduate School

University of Kentucky

2010

HYDRAULIC GEOMETRY RELATIONSHIPS AND REGIONAL CURVES FOR THE INNER AND OUTER BLUEGRASS REGIONS OF KENTUCKY

THESIS

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

By

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Lexington, Kentucky

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Lexington, Kentucky

2010

for my family

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Chapter 1: Introduction

1.1 Introduction

Stream restoration refers to efforts undertaken to ameliorate previous activities that have diminished, impaired or destroyed the structure and function of stream systems. Restoration generally involves the conversion of an unstable, altered or degraded channel to its natural or pre-disturbance state while considering present and future watershed conditions (NRC, 1992). This process consists of restoring the stream's geomorphic dimension, pattern, and profile to achieve dynamic equilibrium, and hence biological and chemical integrity. Enhancement refers to activities designed to improve an aspect of an impaired stream system, but where recovery to that of the natural or pre-disturbance condition is not feasible or practical.

In highly degraded, incised stream systems, restoration programs and projects within the U.S. are primarily focused on reconstructing bankfull cross-sectional shape (e.g. area, width, depth), hydraulic gradients, in-stream habitat features (e.g. pools, riffles), and vegetation (Rosgen, 1996; McCandless and Everett, 2002; Doll *et al.*, 2003). The primary goal is to restore flow and sediment transport regimes (Hey, 2006) with the assumption that the biological components of these systems will recover soon after (Lakly and McArthur, 2000). A similar strategic emphasis is placed on restoring and protecting riparian areas (Wenger, 1999). Recognizing the need to work in conjunction with nature, designers are turning towards the use of classification systems and geomorphologic indices (i.e. dimensionless ratios) developed from natural stable streams (reference analogues) to assist in departure analyses and design of restoration plans (Harrelson *et al.*, 1994; Rosgen, 1994; Hey, 2006).

However, successful classification and indices development hinges on correctly identifying bankfull elevation; a task that can be rather challenging, especially when evaluating incised channels where bankfull indicators are infrequent to non-existent. Misidentification of bankfull can result in a designed channel with improper dimensions for maintaining dynamic equilibrium, resulting in an instable channel.

Bankfull regional curves which relate bankfull channel dimensions (e.g. area, width, depth, discharge) to drainage area as well as hydraulic geometry curves that use bankfull discharge as the independent variable are useful tools for assisting in the correct identification of bankfull. Regional curves are particularly helpful when assessing incised systems where lack of good bankfull indicators is a common and problematic occurrence. To obtain the necessary information to develop regional and hydraulic geometry curves, data must be acquired from several reference regional streams representing a wide range of drainage areas, a task that is often viewed as cost prohibitive for most project budgets. Designers not equipped with regional curves face increased risks in misidentifying bankfull, or using an incorrect return interval (e.g. 1.5-year event may be too large or too small for a specific region), and hence designing a channel with inappropriate dimensions. With increased interest in stream and riparian restoration within the Inner and Outer Bluegrass Regions of Kentucky, such as in the Cane Run watershed, the demand for regional and hydraulic geometry curves applicable to karst, hydro-physiographic regions is high.

Recent work by Parola *et al.* (2007) offers regional curves (area, width, depth and discharge) for the Bluegrass Region of Kentucky, which the authors define to include the Inner Bluegrass, Eden Shale Belt, Outer Bluegrass, and Knobs. These regions in Kentucky possess different geologic characteristics. The Inner Bluegrass and Outer Bluegrass have gently sloping topography and contain large amounts of limestone, a very erodible soil (Perfect *et al.*, 1998). The Inner Bluegrass Region is underlain by carbonate bedrock that creates a karst prone environment; the Outer Bluegrass also contains karst topography, although not as much (McDowell, 1986). The Knobs consist of non-erodible rock types over the more erodible shale that creates steep sloping hills shaped as cones (McDowell, 1986). The Eden Shale Belt is contained within the Inner and Outer Bluegrass and has similar topography to the Bluegrass Region (McDowell, 1986).

The regression equation developed by Parola *et al.* (2007) for bankfull area is particularly interesting for this study; it found the exponent of the power function to be 0.99. Bidelspach (2008) found this value to be 0.711 for an average curve using 22 other curves in the Southeastern U.S. Values for the exponent range from 0.57 to 0.82 for various curves developed across the eastern U.S., excluding only the value found in coastal Alabama which was 0.99 (Smith and Turrini-Smith, 1999; Westergard *et al.*, 2004; Metcalf and Shaneyfelt, 2005). The value found by Parola *et al.* (2007) is the same as the value found by Metcalf and Shaneyflet (2005) for coastal curves developed in Alabama, and is not similar to any other curves developed for the southeastern U.S. including other coastal streams. A value lower than the 0.99 found may be more appropriate based on prior curves developed in other parts of the U.S. Johnson and Fecko (2008) tested for similarities between physiographic regions and found that the physical and statistical similarities between the Valley and Ridge, the Appalachian Plateau and New England could produce one equation for bankfull width. This indicates that there should be similarity in regression equations between regions. While Johnson and Fecko (2008) found statistical differences in the regional curve for width developed by Cinotto (2003), the only regional curves developed in the Piedmont region to include karst watersheds, their values still fall within the range found throughout the eastern U.S. Their exponent value for bankfull area is 0.81.

Another exponent from Parola *et al.* (2007) is high; the exponent of the power function relating drainage area to bankfull depth is 0.51. Other values range from 0.21 to 0.36 for curves developed across the eastern U.S. (Harman *et al.*, 1999; McCandless, 2003a; Arcadis and SCDOT, 2004; Chaplin, 2005). Parola *et al.* (2007) is again closer to the regional curves developed for the coastal plain in Alabama; they found a value of 0.47 (Metcalf and Shaneyfelt, 2005).

Keaton *et al.* (2005) compared their regional curves with bankfull characteristics from other hydro-physiographic provinces to evaluate consistency and repeatability of methodology as well as similarity of bankfull hydraulic geometry relationships between regions. The researchers noted a large degree of similarity between the compared curves and concluded that a single set of regional curves may be appropriate for the studied areas. Such may be the case with streams located in central Kentucky in that a single regional curve is applicable for the entire area (i.e. Inner Bluegrass, Eden Shale Belt, Outer Bluegrass, and Knobs); however, until separate curves are developed for these regions, this remains unknown.

1.2 Cane Run Watershed Project Background

The Cane Run watershed serves as the major recharge for the city of Georgetown (pop.: 25,000), as it feeds the Royal Spring Aquifer, which is the major source of water for the city. Segments of the watershed have been identified as having high levels of sedimentation/siltation, pathogens, and nutrient/organic enrichment, which has resulted in the stream being placed on the state 303(d) list. While not confirmed, it is anticipated that a major source of sediment is from the banks Cane Run. For streams with accelerated bank erosion, as seen with portions of Cane Run, sediment contributions from banks can be significant. Van Eps *et al.* (2004) estimated that over 21,000 metric tons of sediment was supplied to a northwestern Arkansas stream from 64 km of reach length within a one-year period. DeWolfe *et al.* (2004) also noted the importance of streambanks in nutrient contribution. In some instances, streambank erosion was determined to be the largest phosphorus contributor to the watershed. Streambank erosion can also affect pathogen levels in the water. Research into the role of stream sedimentation and fecal coliforms indicates that bottom sediments act as reservoirs for the organisms. Stephenson and Rychert (1982) indicated a definite relationship between the concentrations of *E. coli* in bottom sediments as compared to the overlying waters. Greater concentrations were found in the bottom sediments as compared to the overlying waters. Van Donsel and Gelreich (1971) noted similar results, with concentrations of sediment fecal coli forms 100 to 1,000 times greater than that of overlying waters.

Disturbance of bottom sediments causes resuspension of the organisms, thereby raising concentration levels in overlying waters (Stephenson and Rychert, 1982). To ameliorate in-stream contributions of sediment, and hence bacteria and nutrients, it will be necessary to enhance or restore a number of segments along Cane Run. Improvements in the quality of water within the watershed will benefit not only the effected stream miles, but the downstream water users as well. While regional curves are often used in the assessment phase to assist in the identification of bankfull elevation, these curves along with hydraulic geometry curves can be used in the design process, particularly in the efforts to restore stream segments along Cane Run, its tributaries, and other streams located in the Inner and Outer Bluegrass regions. Regression equations can provide a starting point for design dimensions of the new channel; bankfull area, width and depth can be calculated from regional curves for reaches. Regional curves and hydraulic geometry relationships can also be helpful in estimating a bankfull discharge and checking velocities along the channel.

1.3 Objectives

The goal of this project is to provide design tools for use in developing stream restoration plans for the Cane Run watershed as well as other watersheds within the Inner and Outer Bluegrass regions of Kentucky. The specific objectives of the project are to:

- Determine bankfull recurrence intervals and develop bankfull regional curves and hydraulic geometry relationships for the Inner and Outer Bluegrass regions of Kentucky.
- Examine the Inner and Outer Bluegrass curves for regional differences.
- Compare the Inner and Outer Bluegrass curves to theoretical values and results from other regional curves developed in the eastern U.S.

1.4 Organization of Thesis

Chapter One is the introduction to the thesis. It details background information of the research and outlines the objectives of the project. Chapter Two provides an overview of relevant literature including topics such as hydraulic geometry relationships, regional curves, and urban, vegetative and karst influences on channel geomorphology. Chapter Three depicts the methods used to complete the research. Chapter Four presents the results and a discussion of the research. Chapter Five states conclusions drawn from the project and identifies areas of future research. Appendix A presents the dimension, pattern and profile related data for all streams surveyed in this project. Appendix B summarizes the bed material for each of the surveyed streams.

Chapter 2: Literature Review

2.1 Introduction

Understanding how a stream functions is an important part of stream restoration. One principle fluvial geomorphologists and engineers use is hydraulic geometry theory. Hydraulic geometry theory, both theoretical and empirical, allows scientists to better understand morphologic linkages in the stream networks where they are working. Leopold and Maddock (1953) were one of the first to develop hydraulic geometry theory. Their empirically developed equations have since been scrutinized theoretically; others have also contributed to the idea of hydraulic geometry. These equations are used to describe characteristics of streams, such as the bankfull area, bankfull width, and bankfull depth, throughout the U.S. and the world. Bankfull is an important parameter in hydraulic geometry because the stream parameters are developed at the bankfull stage of flow in a stream. Bankfull is described, for non-incised streams, as the stage of the stream where the water flow just begins to overflow its banks (Leopold *et al.*, 1964). Bankfull hydraulic geometry, also known as regional curves, is a type of empirical hydraulic geometry theory that relates bankfull parameters, such as area and discharge, to the corresponding drainage area of a stream. They are used by engineers to assist in the identification of bankfull in the field for complex situations, such as those found in an incised stream, and they are used often in the stream restoration design process.

2.2 Hydraulic Geometry Curves

Hydraulic geometry theory is a quantitative way to understand characteristics of a stream such as the relationship between depth and velocity (Leopold *et al.*, 1964). Understanding how a stream works is important in the field of stream restoration because this influences the decisions of channel dimensions in the redesign of a stream. Hydraulic geometry is a method of describing what happens to river's characteristics such as width and velocity, in quantitative terms, both at-a-station (e.g. changes in cross sectional area with changes in discharge) and downstream (e.g. with increasing drainage area) along a stream network (Leopold and Maddock, 1953; Singh, 2003). Hydraulic geometry includes parameters from the stream's form such as width, depth, cross sectional area, and meander length, and other hydraulic variables such as mean slope, friction, and mean velocity (Singh, 2003). There are many studies pertaining to hydraulic geometry; some use empirical data to develop hydraulic relationships (Leopold and Maddock, 1953; Emmett, 1975; Dunne and Leopold, 1978; Doll *et al.*, 2003; Keaton *et al.*, 2005) while others attempt to define these empirical studies with theoretical explanations (Leopold *et al.*, 1964).

2.2.1 Channel Forming Discharge

The U.S. Army Corps of Engineers (USACE) defines channel forming discharge as "a theoretical discharge that if maintained indefinitely would produce the same channel geometry as the natural long-term hydrograph" (Copeland *et al.*, 2000). Channel forming discharge is presented in three forms: discharge at a specific recurrence interval, effective discharge, and bankfull discharge (Copeland *et al.*, 2000; Crowder and Knapp, 2005). A recurrence interval, also referred to as a return period, is the frequency of time between past events (Baer, 2008). Discharge at a specific recurrence interval refers to the discharge that occurs at the same recurrence interval; for channel forming discharge, this value is considered to be the discharge with a recurrence interval that falls between the mean annual and five-year peak value (Copeland *et al.*, 2000). Effective discharge refers to the discharge that transports the maximum annual bed load (Wolman and Miller, 1960; Wolman, 1967;

Copeland *et al.*, 2000; Emmett and Wolman, 2001). Bankfull discharge for a non-incised channel is commonly known as the discharge at which a channel flows at the top of its banks just before it spills onto its floodplain (Williams, 1978; Andrews, 1980; Copeland *et al.*, 2000; Radecki-Pawlik, 2002). Channels that are incised may contain other bankfull characteristics, but they are not able to flow out of their banks at the bankfull discharge; rather a larger event is required. Each of these methods of determining channel forming discharge has its own limitations Copeland *et al.* (2000) suggest using more than one method to accurately determine the channel forming discharge. A general review of the literature concludes that effective and bankfull discharges do not necessarily occur at specific recurrence intervals, but can occur at a range of intervals. Thus, the best way to describe channel forming discharge is viewed to be through effective discharge and/or bankfull discharge (Andrews, 1980; Emmett and Wolman, 2001).

Each of the methods of determining channel forming discharge (e.g. discharge at a specific recurrence interval, effective discharge, or bankfull discharge) are interconnected. Each has a different way to determine its value from stream data, and all three ideally yield similar results; many studies use values from all three methods to accurately determine the channel forming discharge. The USACE suggests checking the calculations of effective discharge by means of determining the effective discharge's return interval (Biedenharn and Copeland, 2000). Biedenharm and Copeland (2000) suggest the return interval for an accurately calculated effective discharge is typically between 1.01 and 3 years with most values between the 1.01 and 2 year interval. This is closely related to the suggested return periods of bankfull discharge (Leopold *et al.*, 1964; Harman *et al.*, 1999). Andrews (1980) conducted a study that involved several gaging stations in the Yampa River Basin in Colorado and

Wyoming, and found that effective and bankfull discharges were nearly equal. This demonstrates the strong similarities between these forms of channel forming discharges. Andrews and Nankervis (1995) also found in the Rocky Mountains effective and bankfull discharges were closely related.

While many studies have found these methods of estimating channel forming discharge to be related, other have noted large differences (Crowder and Knapp, 2005). Benson and Thomas (1966) found that the dominant or effective discharge was significantly lower than the bankfull stage discharge for nine rivers across the U.S. This study used histograms to relate maximum sediment loads to discharge. These researchers were skeptical that a dominant discharge was even a meaningful way to describe channel morphology because they noted that the same amount of sediment was transported over a range of discharges. Pickup and Warner (1976) also found that bankfull discharge was significantly higher than effective discharge for streams in the Cumberland River Basin in New South Wales, Australia. The authors examined bankfull discharge calculated with the Strickler equation and determined the discharge at the 1.58 year return interval (as guided by previous research in their geographic location); this was not a field verification of bankfull. While the authors admit that the bankfull discharges could be incorrectly calculated using the Strickler equation, they still conclude that the most effective discharge in moving sediment is different than the bankfull discharge, whether it is calculated morphologically or statistically.

2.2.1.1 Recurrence Interval

To determine the return period of a specific event for a stream, peak flow data are typically used. Peak flow data are also used to determine the amount of flow at a given frequency, for instance the $Q_{1.5}$ or Q_2. The 1.5-year return interval is of interest in many studies because it has been found to be the average return period for bankfull discharge (Dunne and Leopold, 1978; Williams, 1978; Harman *et al.*, 1999; Harman *et al.*, 2000). However, this return interval does not always predict channel forming discharge. Some researchers conclude that using the 1.5- year return period will not yield acceptable results (Andrews, 1980; Copeland *et al.*, 2000; Emmett and Wolman, 2001). Factors such as morphology, watershed area, and hydrologic regime may cause differences in the return period calculated for a stream, and researchers argue that a single recurrence interval is not representative (Castro and Jackson, 2001; Crowder and Knapp, 2005). For instance, Adams and Spotila (2005) found that the stream banks potential to be eroded influenced channel forming discharge in the Blue Ridge Basin in the southern Appalachian Mountains. The Blue Ridge basin's watershed is characterized by deep soils that are able to store moisture which can later be contributed to a stream as base flow (Adams and Spotila, 2005). The author noted that the two-year discharge was less than bankfull for this site (Andrews, 1980; Copeland *et al.*, 2000). Variance in bankfull discharge return interval calculations from other studies ranges from sub-annual to 4.4 years (Harman *et al.*, 1999; Harman *et al.*, 2000; Doll *et al.*, 2002; Lawlor, 2004; Keaton *et al.*, 2005; Metcalf *et al.*, 2009). These studies exemplify the need to verify geomorphic indicators in the field rather than solely relying on an average return period (e.g. 1.5 years) for a large geographic area (Copeland *et al.*, 2000).

2.2.1.2 Effective Discharge

Effective discharge was introduced by Wolman and Miller (1960); they were trying to find a balance between the magnitude and frequency of geomorphic events and channel forming flow (Doyle and Shields, 2008). Since their study, many studies have scrutinized better methods of determination, such as using sediment load hydrographs, and its applicability in the field (Benson and Thomas, 1966; Andrews, 1980; Emmett and Wolman, 2001). A multi-step process is required to calculate the effective discharge as both suspended sediment measurements and discharge measurements are required for the site of interest. Data must also be available from multiple years (Benson and Thomas, 1966; Andrews, 1980; Copeland *et al.*, 2000; Emmett and Wolman, 2001; Crowder and Knapp, 2005). This information is often difficult to attain because suspended sediment and discharge measurements are not always collected together. For example, the United States Geological Survey (USGS) has 346 stream sites measuring peak flow and 919 sites measuring water quality properties such as sediment in Kentucky. Only 206 of these sites measure both suspended sediment and discharge, and the data are not always measured for the same amount of time, or on the same dates. Other factors make calculating effective discharge difficult; climatic, geologic, and physiographic characteristics are different from stream to stream making it difficult to compare effective discharge results among streams of the same size (Andrews, 1980). Studies have shown that it is "rarely possible to compute the effective discharge of a given reach of stream channel accurately" (Emmett and Wolman, 2001).

2.2.1.3 Bankfull Discharge

The level of difficulty in identifying bankfull elevation varies among streams. Those streams which are non-incised and have expansive floodplains such as the Rosgen stream types C and E generally have multiple bankfull indicators. Plus, the indicators that are present such as bankfull coinciding with the tops of banks or point bars are readily identifiable. However, the number and presence of such indicators decreases as streams become more entrenched as with B stream types or even degraded as is typical of F and G stream types. In such systems only small interspersed depositional flats may be evident. Because of the potential scarcity of bankfull indicators and the potential to misidentify inner berm features as bankfull features, which if present are often at half the bankfull elevation, field identification of bankfull is best performed by a trained practitioner (Williams, 1978). It has also become one of the most scrutinized forms because of its role in hydraulic geometry development, as seen in Leopold and Maddock (1953), as well as playing an integral role in the Rosgen classification system and natural channel design (Rosgen, 1996; Simon *et al.*, 2004). Bankfull discharge is determined from cross-sectional data used with gaged data from the bankfull stage identified in field surveys (Williams, 1978; Copeland *et al.*, 2000). Dunne and Leopold (1978) define the bankfull stage as the stage that: "corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphologic characteristics of channels." This definition incorporates many of the components of channel forming discharge because bankfull identification is a practical method of determining it. Bankfull is generally determined by analyzing features in field surveys, as opposed to calculations used to determine effective discharge. While many field identification techniques have been proposed, some considered better than others, identifying a number of these techniques together is generally considered the best way to identify bankfull (Williams, 1978).

One of the earliest definitions of bankfull comes from Wolman (1955). In this study, the identification of bankfull is where the W/D (width-to-depth ratio) is at a minimum. Pickup and Warner (1976) also use this definition. This application of bankfull relies on accurate field surveys (Copeland *et al.*, 2000; Simon *et al.*, 2004). Williams (1978) used a change in the relationship between the cross-sectional area and the top width of the channel to define the bankfull stage (Radecki-Pawlik, 2002); this method also relies on accurate field surveys.

Channel characteristics, such as the height of flat depositional surfaces (especially the tops of point bars), breaks in slope along the banks, a change in particle size in bed material, and undercuts in banks are used in some studies' identification of bankfull; the highest elevation of channel bars was used as a bankfull indicator by Wolman (1957). The middle bench of a channel with three or more overflow surfaces is used as a bankfull indicator (1968). The low bench is also used as an indicator in Schumm (1960), but care needs to be used when using the low bench as an indicator of bankfull because it can be an inner berm.

Various characteristics of channel vegetation have also been used as bankfull indicators, but this indicator is mostly used in the western U.S. as opposed to the eastern U.S. because vegetation often grows below the bankfull stage in the eastern U.S. (Wolman, 1955; Schumm, 1960; Williams, 1978; Leopold, 1994). These vegetative characteristics include the height of the lower limit of perennial vegetation (Schumm, 1960), and a change in vegetation such as from grasses and shrubs (Leopold, 1994). Wolman (1955) used a combination of changes in vegetation (or sedimentation on banks) with the minimum W/D ratio to determine the bankfull stage. Leopold and Skibitzke (1967) also used sedimentation techniques to identify bankfull; they used the location of the upper limit of sand sized particles in the boundary sediment (Leopold and Skibitzke, 1967).

The most widely accepted definition of bankfull is from Leopold *et al.* (1964) and describes bankfull as the highest flow a channel can handle before it starts to spill onto its banks; this definition is accepted for non-incised streams. The location Leopold *et al.* (1964) describe has many descriptions in literature: elevation of the active floodplain (Wolman, 1957; Nixon, 1959), the tops of banks (Williams, 1978), and the height of the valley floor (Nixon, 1959; Woodyer, 1968; Williams, 1978; Radecki-Pawlik, 2002). This description of bankfull is often used in combination with other bankfull indicators, such as the highest elevation of point bars, and a prominent break in slope (Harman *et al.*, 1999; Harman *et al.*, 2000; Doll *et al.*, 2003). It is common to use a variety of indicators in the field because the correct identification of bankfull is so critical in channel classification (Rosgen technique) and natural channel design. By using a combination of bankfull indicators many stream types in many varying environments can be analyzed.

While it may seem easy to some to correctly identify bankfull, it can be considerably difficult particularly for entrenched (e.g. Rosgen stream type B) or degraded (e.g. Rosgen stream type F or G) stream systems. In such instances, experience is often necessary to correctly determine bankfull (Copeland *et al.*, 2000). Given the vast differences and the level of professional judgment required in the correct identification of bankfull, it becomes easier to understand why high variability in the identification of bankfull exists (Copeland *et al.*, 2000).

2.2.2 Hydraulic Geometry Curve Summary

Leopold and Maddock (1953) applied a quantitative approach to geomorphology, a branch of geology that was classically described as qualitative (Singh, 2003). They noted that the physical characteristics of natural streams are all interconnected (Stall and Yang, 1970). Their quantitative equations were developed using empirical data which were collected over a period of 70 years (Leopold and Maddock, 1953). The hydraulic geometry equations developed by Leopold and Maddock (1953), which are centered on the concept of discharge or Q are as follows:

$$w = aQ^b \qquad \text{(Equation 1)}$$

$$d = cQ^f \qquad \text{(Equation 2)}$$

$$v = kQ^m \qquad \text{(Equation 3)}$$

The variables w, d, and v are the bankfull parameters width, depth, and velocity, respectively. The coefficients or intercepts are a, c, and k; the exponents or slopes are b, f, and m. Based on the continuity equation (Q=wdv), the product of the respective coefficients (a x c x k) equals one; the summation of the exponents (b + f + m) also equals one (Leopold et al 1964).

The equations developed by Leopold and Maddock (1953) assume steady, uniform flow in streams. Steady flow implies no change in velocity with time. Uniform flow implies no change in velocity with distance along the channel. Hence, the water surface slope follows the energy grade line (Leopold *et al.*, 1964). Because of this phenomenon, the mean values of the variables used in the general hydraulic geometry relationships must correspond to the equilibrium state of the channel (Singh 2003). Equilibrium in a stream channel involves the interaction of sediment discharge, sediment particle size, stream flow, and stream slope, and is achieved when all four independent variables are in balance (Lane, 1955). Lane (1955) showed the relationship between these independent variables:

$$Q_s \cdot D_{50} \propto Q_w \cdot S \qquad \text{(Equation 4)}$$

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. "The graded stream is a system in equilibrium"; a graded stream is one in which the slope adjusts to provide the velocity required to transport the sediment load provided by the watershed, using available discharge and channel characteristics (Leopold *et al.*, 1964). If one variable changes, the other variables will either increase or decrease to maintain equilibrium. For example, if flow increases, either the sediment load or particle size (or both) must also increase to maintain equilibrium in the channel. Leopold and Maddock (1953), and Wolman (1955) found that a stream adjusts its hydraulic geometry to carry sediment, or reach quasi-equilibrium. Since each stream has different boundary conditions, for example the soil that makes up the stream bed and the vegetation surrounding the stream, the equilibrium state for each stream differs (Knighton, 1998; Singh, 2003). Knighton (1977) found that channels can have changes in their form over a short period of time, in the absence of high flows, and suggested that the approach to equilibrium is relatively rapid.

Equations developed to describe hydraulic geometry of channels use data collected from streams in a state of equilibrium. Many areas become urbanized, deforested, or have increases in agriculture; these are all things that can alter the equilibrium state. While a stream may be in equilibrium at the time of a study, many changes can happen to the environment that contributes to the stream. The effects of urbanization and vegetation are discussed in Section 2.4.

Since the study by Leopold and Maddock (1953), the power function has been used in developing and evaluating hydraulic geometry relationships (Emmett, 1975; Dunne and Leopold, 1978; Singh, 2003; Lee and Julien, 2006). Dury (1976) combined an abundance of data, from more than 105 points, to validate the use of the power function in streams. Dury (1976) used the 1.58 year flood to represent the channel forming discharge, or bankfull discharge; this combined with data from other studies was used to validate how well power functions were able to predict actual channel properties.

The many equations developed empirically have been scrutinized theoretically. Empirical studies of at-a-station relationships, where channel characteristics are taken at a given cross section and plotted against discharge (Leopold *et al.*, 1964), and the theoretical attempts to explain them were reviewed by Ferguson (1986). He rejected the theoretical approaches taken to explain the channel shape, frictional characteristics, and law relating velocity to friction and depth because none could fully explain the interactions among all variables (Lawrence, 1987). Singh (2003) identifies a large number of hypotheses used in the development of theoretical hydraulic geometry relationships such as regime theory, similarity theory, and minimum stream power theory, but there is no study that uses one set of data to evaluate all theories. Through all of the studies using these theories, none were able to fully explain the hydraulic geometry relationships found empirically. This was found to be the case because of the assumptions made in the individual theories, such as a constant longitudinal profile (Leopold *et al.*, 1964). Leopold *et al.* (1964) noted that theory would be the behavior expected of rivers if they displayed all "tendencies postulated". The solution would be the most probable distribution, or what would be the most likely to be observed in a river that satisfies the hydraulic conditions (Leopold *et al.*, 1964).

Since the evaluation of Singh (2003), other studies continued to develop hydraulic geometry. Lee and Julien (2006) developed regression equations using data from a wide range of conditions from sand-bed, gravel-bed, and cobble-bed streams with meandering and braided forms, all from previous works. The curves compared their equations to the semitheoretical equations developed by Julien and Wargadalam (1995) hoping to improve the relationships by using a larger data set. The data set used by Lee and Julien (2006) included a total of 1,485 data points of which 1,125 were field measurements of bankfull (for calibration) and 360 were from field and laboratory measurements for validation (Lee and Julien, 2006). Julien and Wargadalam (1995) were able to combine four fundamental relationships: flow rate, resistance to flow, particle mobility and secondary flow to define the hydraulic geometry of alluvial channels. Their relationships using discharge and particle size as independent variables were able to predict channel dimensions, such as width and velocity, with R^2 values ranging from 0.77 to 0.93. The exponents of Q from the hydraulic geometry relationships developed by Leopold and Maddock (1953) can be explained and predicted by these relationships (Julien and Wargadalam, 1995). Lee and Julien (2006) were able to improve these equations; the proposed equations better predicted field and laboratory measurements.

Table 2.1 depicts some of the theoretically developed values for hydraulic geometry theory. These values show the variations in the expected exponents for different river types.

Table 2.1 Theoretical Values for Hydraulic Geometry Exponents Developed by Langbein in 1963. Table derived from Leopold (1964).

Type of Environment	Width b	Velocity m	Depth f	Roughness y	Slope z
River, down-stream direction	0.53	0.10	0.37	-0.22	-0.73
Tidal esturary, downstream	0.72	0.05	0.23	0.01	-0.11
Meltwater stream on clacier	0.50	0.22	0.28	-0.04	-
River, at a station cohesive	0.25	0.32	0.43	-0.035	0
River, at a station non-cohesive	0.50	0.23	0.27	-0.04	-
Canal system	0.47	0.17	0.36	0.01	-0.12

Although many studies have tried to use mathematical theory to describe environmental phenomena, no theory has been found that can completely explain the empirically developed equations. The interactions among the many variables of a channels form, discharge, and atmospheric conditions cannot be defined consistently for each stream as independent or dependent.

2.3 Regional Curves

To accommodate the possible physiographic differences in hydraulic geometry relationships, Dunne and Leopold (1978) were the first to develop them on a regional level. Although original works in hydraulic geometry developed primarily using data from the western U.S. were considered to be universal in nature (Leopold and Maddock, 1953), studies since have shown that they are only useful when they are used on streams that share physiographic characteristics such as hydrology, soils and extent of development (Rosgen, 1996; Keaton *et al.*, 2005). Stall and Fok (1968) and Stall and Yang (1970) found that physiographic characteristics of a watershed influenced the coefficients of the power functions (Singh, 2003). This can be seen when comparing urban and rural curves; higher coefficients are seen in urban curves (Harman *et al.*, 1999; Doll *et al.*, 2003). Lane and Foster (1980) studied the effects of changing land use on stream morphology. They found that channel width increased as discharge increased, and a larger critical stress caused a narrower stream. They concluded that changes in land use were the cause of the stream channel characteristics (Lane and Foster, 1980; Singh, 2003). The influence of land use is discussed in a Section 2.4.

The curves developed on the regional level are known as regional curves or bankfull hydraulic geometry relationships and use drainage area as the independent variable to predict channel dimensions such as bankfull width, depth and area. Original works in hydraulic geometry theory used discharge as the independent variable (Leopold and Maddock, 1953). Using drainage area is a more practical way to utilize the regional curves in the field to help identify bankfull because drainage area is an easier variable to obtain than a stream's discharge (Johnson and Fecko, 2008). These equations follow the general form:

$$P_{bkf} = gDA^h \qquad \text{(Equation 5)}$$

Where P_{bkf} is the bankfull parameter (area, width, depth or discharge), DA is the watershed drainage area, and g and h are the fitting parameters of an exponential equation (Johnson and Fecko, 2008).

2.3.1 Regional Curve Summary

Regional curves have been developed across the United States in many physiographic regions; of particular interest to this study are the curves developed in the humid region in the eastern portion of the U.S. The states of Alabama, North Carolina, South Carolina, Georgia, Virginia, West Virginia, Kentucky and Florida are of particular interest, and the southern parts of Ohio, Maryland, Delaware, Pennsylvania and New Jersey also fall into this category. The regional curves developed in these areas can be found in Table 2.2.

Table 2.2 Regional Curves Developed Across the Humid Eastern U.S.

Location	DA (mi^2)	Regional Curves[2]		Return Interval (yrs)	Source
		Appalachian Plateau			
PA, MD	< 220	$A_{bkf}=12.04DA^{0.797}$ $R^2=0.92$ $Q_{bkf}=43.21DA0.867$ $R^2=0.92$	$W_{bkf}=14.65DA0.449$ $R^2=0.81$ $D_{bkf}=0.875DA^{0.330}$ $R^2=0.72$	1.0-1.8	Chaplin (2005)
MD	0.2-102.0	$A_{bkf}=13.17DA^{0.75}$ $R^2=0.93$ $Q_{bkf}=34.02DA^{0.94}$ $R^2=0.99$	$W_{bkf}=13.87DA^{0.44}$ $R^2=0.92$ $D_{bkf}=0.95DA^{0.31}$ $R^2=0.91$	1.05-1.8	McCandless (2003a)
NY (Catskill Mts)	3.7-332	$A_{bkf}=12.67DA^{0.81}$ $R^2=0.90$ $Q_{bkf}=62.96DA^{0.87}$ $R^2=0.81$	$W_{bkf}=12.51DA^{0.51}$ $R^2=0.88$ $D_{bkf}=1.01DA^{0.31}$ $R^2=0.85$	1.2-2.7 (avg 1.5)	Miller and Davis (2003)
NY (Region 5)	0.7 - 332	$A_{bkf}=10.8DA^{0.823}$ $R^2=0.98$ $Q_{bkf}=45.3DA^{0.856}$ $R^2=0.96$	$W_{bkf}=13.5DA^{0.449}$ $R^2=0.92$ $D_{bkf}=0.801DA^{0.373}$ $R^2=0.91$	1.11-3.40	Westergard *et al.* (2004)
		Valley and Ridge and Blue Ridge			
PA, MD	< 220	$A_{bkf}=12.04DA^{0.797}$ $R^2=0.92$ $Q_{bkf}=43.21DA^{0.867}$ $R^2=0.92$	$W_{bkf}=14.65DA^{0.449}$ $R^2=0.81$ $D_{bkf}=0.875DA^{0.330}$ $R^2=0.72$	1.0-1.8	Chaplin (2005)
MD	0.1 - 24	$A_{bkf}=12.595DA^{0.7221}$ $R^2=0.9449$ $Q_{bkf}=43.249DA^{0.7938}$ $R^2=0.9066$	$W_{bkf}=12.445DA^{0.4362}$ $R^2=0.8939$ $D_{bkf}=1.001DA^{0.2881}$ $R^2=0.8705$	<1.1-1.9	Keaton *et al.* (2005)
MD	0.2-102.0	$A_{bkf}=13.17DA^{0.75}$ $R^2=0.93$ $Q_{bkf}=34.02DA^{0.94}$ $R^2=0.99$	$W_{bkf}=13.87DA^{0.44}$ $R^2=0.92$ $D_{bkf}=0.95DA^{0.31}$ $R^2=0.91$	1.05-1.8	McCandless (2003a)

Table 2.2 (continued)

Location	DA (mi^2)	Regional Curves[2]		Return Interval (yrs)	Source
Piedmont					
NC (Rural)	0.2 - 128	$A_{bkf}=21.43DA^{0.68}$ $R^2=0.95$ $Q_{bkf}=66.57DA^{0.89}$ $R^2=0.97$	$W_{bkf}=11.89DA^{0.43}$ $R^2=0.81$ $D_{bkf}=1.50DA^{0.32}$ $R^2=0.88$	1.1-1.8 avg (1.4)	Harman *et al.* (1999)
NC (Urban)	<200	$A_{bkf}=60.34DA^{0.65}$ $R^2=0.95$ $Q_{bkf}=306.80DA^{0.63}$ $R^2=0.94$	$W_{bkf}=24.39DA^{0.33}$ $R^2=0.88$ $D_{bkf}=2.43DA^{0.33}$ $R^2=0.87$	-	Doll *et al.* (2002)
MD	1.47-102	$A_{bkf}=17.42DA^{0.73}$ $R^2=0.95$ $Q_{bkf}=84.56DA^{0.76}$ $R^2=0.93$	$W_{bkf}=14.78DA^{0.39}$ $R^2=0.83$ $D_{bkf}=1.18DA^{0.34}$ $R^2=0.86$	1.26-1.75 (avg 1.5)	McCandless and Everett (2002)
MD, PA	2.57 - 102	$A_{bkf}=12.4DA^{0.810}$ $R^2=0.94$ $Q_{bkf}=53.1DA^{0.842}$ $R^2=0.93$	$W_{bkf}=13.6DA^{0.469}$ $R^2=0.80$ $D_{bkf}=0.912DA^{0.339}$ $R^2=0.72$	1.0-1.5	Cinotto (2003)
SC[1]	< 250	$A_{bkf}=14.434DA^{0.6946}$ $R^2=0.9375$ $Q_{bkf}=47.031DA^{0.7115}$ $R^2=0.8852$	$W_{bkf}=13.191DA^{0.369}$ $R^2=0.8736$ $D_{bkf}=1.0664DA^{0.3114}$ $R^2=0.7877$	-	Arcadis and SCDOT (2004)

Table 2.2 (continued)

Location	DA (mi^2)	Regional Curves[2]		Return Interval (yrs)	Source
Coastal Plain					
NC (Rural)	0.2 - 161	$A_{bkf}=14.52DA^{0.66}$ $R^2=0.88$ $Q_{bkf}=16.56DA^{0.72}$ $R^2=0.90$	$W_{bkf}=10.97DA^{0.36}$ $R^2=0.87$ $D_{bkf}=1.29DA^{0.30}$ $R^2=0.74$	1.0-1.25	Doll *et al.* (2003)
MD	0.3-113	$A_{bkf}=10.34DA^{0.70}$ $R^2=0.96$ *East* $Q_{bkf}=14.65DA^{0.76}$ $R^2=0.97$ *West* $Q_{bkf}=31.35DA^{0.73}$ $R^2=0.98$	$W_{bkf}=10.3DA^{0.38}$ $R^2=0.88$ $D_{bkf}=1.01DA^{0.32}$ $R^2=0.87$	1.04-1.37 (avg 1.16)	McCandless (2003b)
FL (North)	1-474	$A_{bkf}=6.1DA^{0.71}$ $R^2=0.98$ $Q_{bkf}=7.54DA^{0.77}$ $R^2=0.92$	$W_{bkf}=9.2DA^{0.28}$ $R^2=0.85$ $D_{bkf}=0.67DA^{0.43}$ $R^2=0.84$	avg 1.1	Metcalf *et al.* (2009)
FL (nw)	1-474	$A_{bkf}=17.1DA^{0.64}$ $R^2=0.99$ $Q_{bkf}=27.7DA^{0.71}$ $R^2=0.95$	$W_{bkf}=10.4DA^{0.39}$ $R^2=0.96$ $D_{bkf}=1.64DA^{0.25}$ $R^2=0.86$	avg 1.1	Metcalf *et al.* (2009)
NC	0.6-182	$A_{bkf}=9.43DA^{0.74}$ $R^2=0.96$ $Q_{bkf}=8.79DA^{0.76}$ $R^2=0.92$	$W_{bkf}=9.64DA^{0.38}$ $R^2=0.95$ $D_{bkf}=0.98DA^{0.36}$ $R^2=0.92$	<1.0	Sweet and Geratz (2003)
AL[1]	1 - 200	$A_{bkf}=4.35DA^{0.99}$ $R^2=0.98$ $Q_{bkf}=10.94DA^{0.84}$ $R^2=0.93$	$W_{bkf}=5.67DA^{0.52}$ $R^2=0.94$ $D_{bkf}=0.78DA^{0.47}$ $R^2=0.96$	avg 1.0	Metcalf and Shaneyfelt (2005)

Table 2.2 (continued)

Location	DA (mi^2)	Regional Curves[2]		Return Interval (yrs)	Source
New England and Adirondack Regions					
NY[1] (Region 6)	1.02-290	$A_{bkf}=17.6DA^{0.662}$ $R^2=0.89$ $Q_{bkf}=48.0DA^{0.842}$ $R^2=0.90$	$W_{bkf}=16.9DA^{0.419}$ $R^2=0.79$ $D_{bkf}=1.04DA^{0.244}$ $R^2=0.64$	1.01-3.35	Mulvihill *et al.* (2005)
NY[1] (Region 3)	0.42-329	$A_{bkf}=39.8DA^{0.503}$ $R^2=0.92$ $Q_{bkf}=83.8DA^{0.679}$ $R^2=0.93$	$W_{bkf}=24.0DA^{0.292}$ $R^2=0.85$ $D_{bkf}=1.66DA^{0.210}$ $R^2=0.77$	1.16-3.35	Mulvihill *et al.* (2005)
NY[1] (Region 6)	1.02-290	$A_{bkf}=17.6DA^{0.662}$ $R^2=0.89$ $Q_{bkf}=48.0DA^{0.842}$ $R^2=0.90$	$W_{bkf}=16.9DA^{0.419}$ $R^2=0.79$ $D_{bkf}=1.04DA^{0.244}$ $R^2=0.64$	1.01-3.35	Mulvihill *et al.* (2007a)
NY[1] (1 & 2)	0.52-396	$A_{bkf}=22.3DA^{0.694}$ $R^2=0.97$ $Q_{bkf}=49.6DA^{0.849}$ $R^2=0.95$	$W_{bkf}=21.5DA^{0.362}$ $R^2=0.89$ $D_{bkf}=1.06DA^{0.329}$ $R^2=0.89$	1.01-3.8	Mulvihill *et al.* (2007b)

Table 2.2 (continued)

Location	DA (mi^2)	Regional Curves[2]		Return Interval (yrs)	Source
Interior and Central Lowlands					
OH[1] (Region A)	0.29-685	$A_{bkf}=27.1DA^{0.621}$ $R^2=0.95$ $Q_{bkf}=93.3DA^{0.637}$ $R^2=0.82$	$W_{bkf}=18.0DA^{0.356}$ $R^2=0.91$ $D_{bkf}=1.52DA^{0.265}$ $R^2=0.88$	1.01-9.65	Sherwood and Huitger (2005)
OH[1] (Region B)	0.55-387	$A_{bkf}=64.5DA^{0.621}$ $R^2=0.95$ $Q_{bkf}=230DA^{0.637}$ $R^2=0.82$	$W_{bkf}=32.0DA^{0.356}$ $R^2=0.91$ $D_{bkf}=2.02DA^{0.265}$ $R^2=0.88$	1.01-9.65	Sherwood and Huitger (2005)
TN[1] (Western)	6-2309	$A_{bkf}=16.4DA^{0.57}$ $R^2=0.89$	$W_{bkf}=9.6DA^{0.36}$ $R^2=0.90$ $D_{bkf}=1.7DA^{0.22}$ $R^2=0.68$	-	Smith and Turrini-Smith (1999)
KY[1] (*Bluegrass*)	0.25-154	$A_{bkf}=7.71DA^{0.99}$ $R^2=0.99$ $Q_{bkf}=27.9DA^{0.98}$ $R^2=0.96$	$W_{bkf}=10.97DA^{0.48}$ $R^2=0.97$ $D_{bkf}=0.70DA^{0.51}$ $R^2=0.93$	1.1-1.16	Parola *et al.* (2007)

1- Studies not included in Johnson and Fecko (2008)

2 - A_{bkf} is the bankfull area measured in ft^2; W_{bkf} is the bankfull width measured in ft; D_{bkf} is the bankfull depth measured in ft; Q_{bkf} is the bankfull discharge measured in ft^3/s

Even in the humid region, there are vast differences within sub-regions. Differences in rock type range from sedimentary rock (in the Appalachian Plateau) (McCandless, 2003a; Chaplin, 2005; Johnson and Fecko, 2008) with limestone underlying (in the Allegheny Mountain and Pittsburg Low Plateau) to sandstone and conglomerate with limestone and shale that underlie the valleys (in the Valley and Ridge physiographic region) (USGS, 2003). Regions also contain igneous and metamorphic rocks, and marine sedimentary rocks are found in the coastal regions (Doll *et al.*, 2003; Hanley, 2006). Some regions have karst features, such as those found in the Valley and Ridge and throughout Kentucky (Chaplin, 2005) created by the dissolution of underlying limestone. The humid eastern U.S. also contains many different physiographic characteristics such as the high slopes and deep valleys found in the mountain areas, to more gently sloping Piedmont areas, to the more flat coastal plains (Doll *et al.*, 2003; Johnson and Fecko, 2008).

Johnson and Fecko (2008) identified six regions within the humid eastern U.S. and evaluated the statistical similarities and differences among the regional curves found for bankfull width: Appalachian Plateau, Blue Ridge, Coastal Plain, New England, Piedmont, and Valley and Ridge. Regional curves were not examined for similarities in area, depth or discharge. They found that the regional curves developed for the Appalachian Plateau region: developed in Pennsylvania, Maryland and New York (Miller and Davis, 2003; McCandless, 2003a; Westergard *et al.*, 2004; Chaplin, 2005), and those developed in the Valley Ridge region: Pennsylvania and Maryland (McCandless and Everett, 2002; McCandless, 2003a; Chaplin, 2005; Keaton *et al.*, 2005) were statistically similar. Keaton *et al.* (2005) found the equations in the Valley Ridge region to be statistically similar as well. The equation for width was found to be statistically different for the Piedmont Region (Johnson and Fecko, 2008).

The equations developed by Doll *et al.* (2002) and Cinotto (2003) were found to be statistically different. Doll *et al.* (2002) developed equations in urban watersheds, and because urbanization can contribute to channels deviating from their natural flow patterns, this may explain the differences (Johnson and Fecko, 2008). It is not known why the data from Cinotto (2003) does not fit (Johnson and Fecko, 2008), but the study area by Cinotto (2003) is the only one in the Piedmont physiographic region that included sites with karst influences. Johnson and Fecko (2008) found a statistical difference in the bankfull width for the North Florida streams in the Coastal region. Metcalf *et al.* (2009) recognized the difference and separated the equation; they attributed the difference to mean annual runoff (Metcalf *et al.*, 2009). Data from New England were determined to fit with data from the Appalachian Plateau and Valley and Ridge; the data from the Blue Ridge were determined to be statistically different than the other regions (Johnson and Fecko, 2008).

Other studies have performed statistical analyses on regional curves developed in different physiographic regions (McCandless, 2003b; Johnson and Fecko, 2008). McCandless (2003b) compared the curves relating drainage area to bankfull discharge for the Allegheny Plateau, a part of the Appalachian Plateau, Ridge and Valley (McCandless, 2003a), Piedmont (McCandless and Everett, 2002), and Coastal Plain physiographic regions. The authors found that the curves were not statistically similar.

Johnson and Fecko (2008) also tested for similarities between the physiographic regions and found that the physical and statistical similarities between the Valley and Ridge, the Appalachian Plateau, and the New England regions could produce one combined equation for bankfull width. This equation is:

$$w = 2.65A_d^{0.45} \quad \text{(Equation 6)}$$

where w is the bankfull width in m and A_d is the drainage area in km^2, but caution when using this equation was advised (Johnson and Fecko, 2008). This validates the use of sites from both regions for the aforementioned studies.

Although many similarities exist among the regional curves developed throughout the humid region of the U.S., there still exists enough statistical difference to warrant the development of regional curves for each specific region (Johnson and Fecko, 2008).

2.4 Influences on Channel Morphology

Many factors influence the morphology of a stream; two main influences are the amount of development in a watershed (urbanization) and the vegetation along a stream's banks (Hession *et al.*, 2003). Urbanization of a watershed increases the runoff into a stream, and therefore the flow within the stream (Hollis and Luckett, 1976; Schueler, 1995; Hession *et al.*, 2003; Brath *et al.*, 2006; Villarini *et al.*, 2009). The reaction a stream has to the development may depend on the amount and type of vegetation along its banks. Hession *et al.* (2003) found that the type of riparian vegetation and the land use in the watershed equally influenced the downstream hydraulic geometry of alluvial streams. While both urbanization and vegetation influence a channel's morphology, Hession *et al.* (2003) argued that vegetation exerts a stronger influence on channel shape than urbanization (Hession *et al.*, 2003). The authors found that when comparing grassy to forested sites, the changes in channel morphology, namely the width, exist despite the effects of urbanization in the watershed.

2.4.1 Urbanization

Urbanization of a watershed changes the amount of water and sediment supplied to streams (Wolman, 1967). An increased amount of paved surfaces increases the volume of runoff and the magnitude of peak discharges (Hollis and Luckett, 1976; Schueler, 1995; Hession *et al.*, 2003; Brath *et al.*, 2006; Villarini *et al.*, 2009). The increased water volume causes additional channel erosion (Hollis and Luckett, 1976; Pizzuto *et al.*, 2000; Hession *et al.*, 2003) and increases the channel size (Hollis and Luckett, 1976; Hession *et al.*, 2003). The morphology of an urban stream also tends to be different than that of a non-urban stream; the depth has been found to be more uniform and urban streams do not have as defined pool-riffle sequences (Cianfrani *et al.*, 2006). There is also evidence to support that an increase in urbanization causes a reduced return interval (Huang *et al.*, 2008; Villarini *et al.*, 2009).

The amount of urbanization in a watershed is often quantified by the amount of imperviousness (Schueler, 1995). Schueler (1995) stated that there are two components that make up imperviousness: building rooftops, including residential and business structures, and transportation systems, including roads, sidewalks, driveways and parking lots. Rooftop structures are considered to have fewer detrimental effects on natural channels because runoff from them often drains into the ground, and does not enter the storm water system. While knowing the amount of imperviousness in a watershed is important, it is equally important to the threshold at which degradation occurs (Schueler, 1995). Studies have shown this threshold to be as low as 10% impervious cover (Hollis and Luckett, 1976; Booth, 1991; Schueler, 1995); however other researchers use 20% or greater (Cinotto, 2003; Chaplin, 2005)

Studies have shown that some channels become larger in reaction to urbanization (Hollis and Luckett, 1976; Hession *et al.*, 2003). Hollis and Luckett (1976) found that channels with erodible material would enlarge with urbanization of a watershed. They found that 10% imperviousness increases downstream channels by 1.7 times, and 20% increases channels by 2.5 times. They noted that the rate and severity of a stream's instability would be a function of floods that were less than bankfull, and the frequency of those floods can increase by a factor of 10 even when the levels of imperviousness are low (Hollis, 1975; Schueler, 1995). Hammer (1972) found that it was also important to note the number of years since construction to determine the degree of channel enlargement.

Other studies show that the return period of a large flood event becomes more frequent (Brath *et al.*, 2006; Huang *et al.*, 2008; Villarini *et al.*, 2009). For instance, Villarini *et al.* (2009) found that in the 1950s (before urbanization of the watershed), a 3.2 $m^3s^{-1}km^{-2}$ event was exceeded every 1,000 years, and by the present, this same event had a return interval of approximately 10 years. Increased return intervals were more significant for lower return period events (Hollis, 1975; Brath *et al.*, 2006).

It is apparent that an increase in urbanization, even at as little as 10% of a watershed, can influence streams. Some channels respond by increasing their size (those with grassy or weak rooted vegetation), while others maintain their shape (those with strong rooted vegetation), but carry the increased flows more frequently.

2.4.2 Vegetation

Studies have shown that vegetation plays an important role in the morphology of streams (Kauffman and Krueger, 1984; Hey and Thorne, 1986; Hession *et al.*, 2003). Vegetation can protect stream banks from erosion by particle entrainment and preventing mass wasting; however the effects vegetation has on stream banks can be hard to quantify due to variability in the root networks (Simon *et al.*, 2006). Vegetation can provide the same amount of stability for channels as would be provided by reducing the slope of the stream bank (Simon *et al.*, 2006).

Seven degrees of freedom have been considered to change for gravel bed rivers: bankfull width (or wetted perimeter), mean depth (or hydraulic radius), maximum depth, slope, velocity, sinuosity and meander arch length (Hey and Thorne, 1986). Vegetation provides major control on width, wetted perimeter, and the velocity of a stream (Hey and Thorne, 1986). Maintaining streambank cover and stability has shown to reduce the erosion potential which affects the channel morphology (Kauffman and Krueger, 1984; McInnis and McIver, 2001; McIver and McInnis, 2007).

Allmendinger *et al.* (2005) found that the extent of grassy vegetation influenced the differences in width between forested and non-forested streams; the study measured erosion rates on the outside of meander bends and deposition rates on the inside. Narrow non-forested channels migrate and have high flood plain accretion rates while forested, wider channels, migrate slowly (Hession *et al.*, 2003).

The type of vegetation plays an important role in the stability provided by its cover (Simon *et al.*, 2006). Studies have found that streams running though grasslands are wider than those that run through forested areas (Murgatroyd and Ternan, 1983; Rosgen, 1996; Hession *et al.*, 2003), while others find that streams running through forested watersheds are wider (Sweeney, 1992; Hession *et al.*, 2003). These contradictory results lead researchers to still be confused on the effects of vegetation on stream stability.

While some studies split the types of vegetation simply into grassy or forested vegetation, it is also important to study the type of grassy and forested vegetation (Simon *et al.*, 2006). Simon (2006) studied two types of forested vegetation, the Lemmon's willow and lodgepole pine. The two types of trees were found to have the same tensile strength in the root system, but after studying the bank stability of stream channels, the Lemmon's willow site was found to have more stability than that of the lodgepole pine; the additional stability it provides being an order of magnitude larger than that of the lodgepole pine (Simon *et al.*, 2006). Simon (2006) attributes this to the Lemmon's willow's ability to provide a greater number and larger area of roots.

Chapter 3: Materials and Methods

3.1 Study Area

The area selected for this study is the Bluegrass Region of Kentucky, which is separated into the Inner Bluegrass and the Outer Bluegrass. These regions lie in the north and central parts of the state. The Inner Bluegrass is an almost circular region, centered on Lexington, KY (latitude 38.05°N, longitude 85.00°W). This region is approximately 1,800 square miles and includes portions or all of the following counties: Anderson, Bourbon, Boyle, Clark, Fayette, Franklin, Garrard, Harrison, Jessamine, Madison, Mercer, Nicholas, Pendleton, Scott and Woodford. The Outer Bluegrass is approximately 6,800 square miles and surrounds the entire Inner Bluegrass. The Outer Bluegrass includes portions or all of the following counties: Anderson, Bath, Boone, Boyle, Bracken, Bullitt, Campbell, Carroll, Clark, Fleming, Franklin, Gallatin, Garrard, Grant, Henry, Jefferson, Kenton, Lincoln, Madison, Marion, Mason, Mercer, Montgomery, Nelson, Nicholas, Oldham, Owen, Pendleton, Robertson, Scott, Shelby, Spencer, Trimble, and Washington.

The Inner Bluegrass's "gently sloping" topography and phosphate rich soils contribute to its well-known rich agricultural land (KGS, 2007). The geology of the area is dominated by Lexington Limestone of the Ordovician strata that is rarely exposed by soil (McDowell, 1986). Because of the weathering of the limestone underground, the area contains many "sink holes, sinking streams, springs and caves" (KGS, 2007). These are all a part of the abundant karst topography found in the Inner Bluegrass (Perfect *et al.*, 1998). The Kentucky River also traverses the region contributing to erosion; the river creates gorges and canyons along its path where it cuts through resistant massive limestones (KGS, 2007).

The Outer Bluegrass has gentle rolling hills, hill slopes ranging from 20-30% (Perfect *et al.*, 1998). The soils are nearly as rich (for agricultural uses) as those of the Inner Bluegrass (McDowell, 1986). The valleys are deeper because the rock type is "interbedded" and erodes more easily than the material in the Inner Bluegrass (KGS, 2007). The geology in the Outer Bluegrass consists of "limestones, dolomites and shales of the Late Ordovician and Silurian age" (McDowell, 1986). These geologic features are those that contribute to the karst topography in the Inner Bluegrass, and while the Outer Bluegrass does contain karst topography, it is not as abundant as it is in the Inner Bluegrass. The soils found in the Outer Bluegrass vary in depth from thick layers covering limestone, to thin layers covering shale. Unstable slopes and landslides are common from the contribution of these swelling clays (McDowell, 1986).

The entire region is located in the humid subtropical region of the United States; this region experiences hot and humid summers with mild winters (Perfect *et al.*, 1998). The average annual precipitation is 46 inches (116.6 cm) for the Commonwealth of Kentucky with the maximum rainfall occurring during the months of March and May; the minimum precipitation in October (KGS, 2007). The average temperature in Kentucky is 54.4°F (13°C) (Perfect *et al.*, 1998). The highest temperatures are experienced in July, averaging 75.5°F (24.2°C), but reaching maximum degrees in the 90s (greater than 32°C), and minimum temperatures in December, averaging 35.9°F (2.2°C) according to the Kentucky Climate Center.

3.2 USGS Gage Selection

The USGS monitors many streams throughout the U.S. They measure stream level, discharge, water quality, and precipitation. Thirty-six gaged streams in the Inner Bluegrass and 64 gaged streams in the Outer Bluegrass were considered for this study because each measured discharge and either real time data were collected at the site or a functioning staff gage was present. These sites were then reduced by field visits; 50 sites were visited to determine if they were able to be surveyed; the streams were inspected for a lack of tributaries entering near gaging stations, accessibility and location of a possible cross section. If tributaries could be identified on aerial photos, or new construction was identified at a discontinued gage, it was not visited. Of these 50 sites, 33 were surveyed; from these surveys, other determining factors were considered, such as the stability of the stream, measured by the bank height ratio, and the accuracy of the bankfull indicators noted in the field. Based on these criteria, 14 of the surveyed streams in the Inner Bluegrass fit the criteria while 15 surveyed streams met the criteria in the Outer Bluegrass. The selection criteria are discussed in greater detail in Sections 3.2.1 through 3.2.9.

3.2.1 Drainage area

The first narrowing factor for USGS gaged streams was the drainage area. The study focused on wadable streams, which were typically less than 150 square miles (388.5 km^2). The drainage areas were obtained from the gage information data presented on the USGS website. Two non-wadable streams were included to use in comparison to the study conducted by Parola *et al.* (2007). They were surveyed using a paddle boat.

3.2.2 Presence of bankfull indicators

Each selected site had the presence of one or more readily identifiable bankfull indicators such as (listed in order of consideration):

- Flat depositional surfaces, at a consistent elevation, immediately adjacent to the stream,
- Tops of point bar,
- Prominent breaks in slope, and/or
- Erosion or scour features.

Because vegetation can grow below bankfull stage in the eastern U.S., it was not used as an indicator.

3.2.3 Lack of severe bank erosion

Stream reaches with severe bank erosion were avoided. Signs of severe bank erosion include overhanging or undercut banks, presence of bank slumps, and absence or scarcity of riparian vegetation.

3.2.4 Bank height ratio (BHR)

Bank height ratio (BHR) is a method of quantifying vertical stability of the banks or the degree of channel incision. The BHR is defined as the height of the lowest bank divided by the maximum bankfull depth, both measured at the cross section of interest (Rosgen, 2001). The further the BHR deviates from 1.0, the greater the amount of incision and hence vertical confinement present. Guidance from Metcalf *et al.* (2009) suggest that for gaged streams, a BHR of 1.5 or less should be used. As such, streams with BHR greater than 1.5 were not used.

3.2.5 Rosgen Classification

Each stream reach was classified according to the Rosgen (1994; 1996) stream classification system. Only single threaded channels were surveyed. Stream types B, C and E were targeted; stream types F, G, D and D_A were avoided. Due to the topography of the Inner and Outer Bluegrass regions, A stream types were not encountered.

3.2.6 Vegetation

Riparian vegetation exerts a strong influence on channel geometry as noted by (Hey and Thorne, 1986; Hession *et al.*, 2003). As such, the type of riparian vegetation present at each site (e.g. forest, grass) was recorded and photographed; riparian vegetation density was visually estimated.

3.2.7 Lack of flow regulation

In-stream structures such as weirs or fords were avoided. Because of tributary contributions, or lack of bankfull indicators downstream, some surveys were conducted in the proximity of the bridge that housed the gaging station; care was taken to avoid any stream contributions from the bridge such as debris, and channel altering structures such as bridge piers.

3.2.8 Proper Location of Bed Features

Sites were assessed for the proper location of bed features. The riffle/pool sequence was evaluated noting that all pools were in bends, and riffles were in straight reaches between bends. No reaches were included that contained riffles in bends.

3.2.9 Accessibility

All sites selected were accessible through public property; if this was not possible, landowner permission was obtained.

3.3 Data Collection

3.3.1 Equipment

The majority of the cross sections taken were done using a CST/berger 24X SAL automatic level. Additional standard equipment such as tripod, level rod, tapes, and pins were also used. Longitudinal surveys were conducted using a Sokkia 530R Total Station (accuracy: ±1" horizontal angle, ±5" vertical angle, ±2mm + 2ppm distance) equipped with a Carlson Explorer II handheld data logger. Cross-sections at two locations were surveyed using this equipment as well; these cross-sections were at the South Fork Elkhorn and Town Branch in the Inner Bluegrass Region. For bed material analysis, standard equipment such as ruler and sand cards were used.

3.3.2 Surveying Techniques

Guidelines for field data collection as described in Harrelson *et al.* (1994) were used to complete the data collection. The surveyed cross-sections and longitudinal profiles were linked to the water surface elevations at the gaging stations during the surveys by using either the real-time data if available from the USGS, or by using a staff gage located in the field.

3.3.3 Bankfull Identification

Identification of bankfull stage was a critical component of the project. Prior to each survey, the stream reach was walked both upstream and downstream of the USGS gage for a minimum distance of 20 bankfull widths. The visual assessment was performed to ensure the reach met the stated criteria and to assist in the identification of consistent bankfull indicators. Refer to Chapter 3.2.2 for additional details on bankfull indicators.

3.3.4 Cross-sections

Cross-sections were surveyed at stable riffles. If a riffle was not present within the vicinity of the USGS gage or was not accessible due to lack of landowner permission, then a stable run was selected. In no case were pools or glides used. The elevations surveyed at each cross-section included bankfull, water surface, thalweg, slope breaks, top of banks, terraces, and flood prone width (if this feature was accessible). Visual estimates were made in instances where the extents of the flood prone widths were not accessible. Cross-sections with anomalies, such as divided flow or debris jams, were avoided. The surveyed cross-section data were used to calculate the bankfull parameters (i.e. width, depth, area, and discharge) using RIVERMorph software.

3.3.5 Main Channel Slopes

Local slopes were measured in accordance with methods outlined in Harrelson et al (Harrelson *et al.*, 1994); however, property assessment issues (e.g. landowner permission not granted) limited the lengths of some of the longitudinal surveys. As such, main channel slopes were also computed and compared to local slopes. Main channel slopes (feet per mile) were computed for each surveyed stream using ArcGIS and the 10M digital elevation model from the USGS Seamless Server (http://seamless.usgs.gov). The elevations of the channel were measured at locations 10 percent and 85 percent along the stream (main branch only), as measured from the basin divide to the basin outlet. The distance between these points was calculated and the average slope was calculated as the difference in elevation between the 10 percent and 85 percent elevation divided by the distance between those points (McCuen, 2004).

3.3.6 Bed Material

Both representative reach and representative riffle pebble counts were performed for each surveyed stream via the modified Wolman procedure (Harrelson *et al.*, 1994). A minimum of 100 samples were collected for each pebble count. Particle size graphs were developed, and the D_{50} was determined to allow for classification of the reach via the Rosgen stream classification system.

3.3.7 Sinuosity

To compute the sinuosity, a satellite image of each stream was imported into AutoCAD. The stream lengths (numerators) and respective valley lengths (denominators) were measured and sinuosities were computed.

3.3.8 Impervious Area

The percent imperviousness of the watershed draining each USGS gage was computed using ArcGIS and the 2001 impervious dataset and 2005 KY land cover dataset from the KY Geonet FTP site (ftp.kymartian.ky.gov). Drainage areas of each gage were computed using 100 grid cell threshold catchments (Terrain Preprocessing functions on ArcHydro Extension). The contributing drainage area for each gage was clipped to each gage and it was dissolved on the percent impervious attribute. The amount (in acres) of each type of impervious area was determined and the weighted attribute calculated and summed.

3.3.9 Riparian Buffer Assessment

The type of riparian vegetation at each site was noted as either forest-dominated or grass-dominated (e.g. non-forested) (Hession *et al.*, 2003). Forest-dominated riparian buffers were those whose streambanks primarily consisted of large trees. Grass-dominated or non-forested riparian buffers consisted mostly of grass or other short rooted vegetation (e.g. weeds).

3.3.10 Bankfull Discharge

A USGS gaging station was present at all of the selected sites. Most of the sites were active though a few were inactive. Each gaging station was equipped with either real-time data collection or had a staff gage present at the site. Using the method outlined in Williams (Williams, 1978), the difference between the water surface (at the time of the survey) and bankfull elevation was determined. The water surface elevation was also correlated to the USGS stage reading for using in the ratings table. This correlation was done by both noting the time of the survey and downloading the corresponding water surface stage reading from the USGS website (real time data only) or reading the water surface on the staff gage while in the field. By knowing the difference between bankfull elevation and water surface elevation along with the respective stage for water surface at the gage, then bankfull on the gage was computed. Using the most current ratings tables supplied by the USGS (active sites only) (http://ky.water.usgs.gov/hyd_data/rating_depot.htm), the bankfull discharge was determined. For discontinued sites, the USGS does not supply ratings tables. As such, stage-discharge curves were developed for these sites by using annual peak flow data (McCuen, 2004).

3.3.11 Manning's n

Manning's n values were back-calculated using Manning's equation (listed below in English units) and surveyed bankfull dimensions (e.g. cross-sectional area and hydraulic radius), main channel slope, and bankfull discharges.

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \qquad \text{(Equation 7)}$$

The variable Q is the bankfull discharge in ft^3/s, A is the bankfull area ft^2, R is the hydraulic radius in ft, S is the main channel slope in ft/ft, and n is Manning's roughness coefficient.

3.3.12 Return Period

Return periods were calculated using the Log Pierson III method with procedures outlined in the USGS Bulletin 17B *Guidelines for Determining Flood Flow Frequency* (1982). Peak flow data was downloaded for the sites into RIVERMorph. RIVERMorph was utilized to determine the bankfull discharge recurrence interval as well as the 1.5-year discharge. A generalized skew coefficient of 0.011 and a standard error of prediction of 0.520 were used (Hodgkins and Martin, 2003).

3.3.13 Photographic Documentation

Each stream reach was photographed in the upstream and downstream direction at each surveyed cross-section. These photos were used to verify cross-section characteristics such as bankfull and to document the riparian vegetation at each site.

3.4 Statistical Analysis

All cross-section surveys and pebble counts were entered into RIVERMorph. Bankfull dimensions, stream classifications, and return period calculations were performed in this program. Power functions were used for both hydraulic geometry relationships and regional curves (Leopold *et al.*, 1964). The power function regression relationships were developed in Excel.

For the comparison of the data presented in this study to the data presented by Parola *et al.* (2007), an analysis of covariance (ANCOVA) was used with guidance from Johnson and Fecko (2008). This statistical analysis was performed in SAS, statistical analysis software.

Chapter 4: Results and Discussion

4.1 Hydraulic Geometry Curves

Hydraulic geometry relationships were developed using bankfull parameters: area, width, depth, velocity, channel slope, and Manning's n. Twenty eight of the 29 sites were included in this analysis. Site number 03288000 North Elkhorn Creek near Georgetown did not have a staff gage at site and does not collect real time data as the site is inactive, so it was not considered in discharge calculations. Checking for continuity, the coefficients of width, depth and velocity multiply to equal to one, and the exponent values of width, depth and velocity sum to one.

4.1.1 Area Hydraulic Geometry Relationships

Bankfull area was plotted as a function of bankfull discharge. These hydraulic geometry relationships are presented in Table 4.1. The graphs of the data with regression equation are presented in Figure 4.1. When the equation is separated into the Inner and Outer Bluegrass, the R^2 value only changes slightly for each region. The most significant divergence in the equations for the two regions occurs at the higher bankfull discharges. The Inner Bluegrass only has one site with a higher drainage area, and this seems to be the cause of the divergence in the two curves. Additional streams with higher drainage areas could possibly increase the predictability of the equation for the Inner Bluegrass.

The hydraulic geometry equations developed for the combined regions, the Inner Bluegrass and the Outer Bluegrass show similarities to other studies. McCandless (2003a, 2003b) found exponents to be 0.79 and 0.89 in the Allegheny Plateau, Valley and Ridge, and the Coastal Plain Maryland. The values for the exponents in the combined regions are 0.8483, the Inner Bluegrass 0.8853, and the Outer Bluegrass 0.8304; these values are similar to those found by McCandless (2003a, 2003b).

Table 4.1 Hydraulic Geometry Relationships for Bankfull Area as a Function of Bankfull Discharge where Bankfull Area is measured in Square Feet and Bankfull Discharge is Measured in Cubic Feet Per Second.

Region	Regression Equation	R^2
Combined Region	$A_{bkf}=0.8226Q_{bkf}^{0.8483}$	0.94
Inner Bluegrass	$A_{bkf}=0.7080Q_{bkf}^{0.8853}$	0.92
Outer Bluegrass	$A_{bkf}=0.8891Q_{bkf}^{0.8304}$	0.95

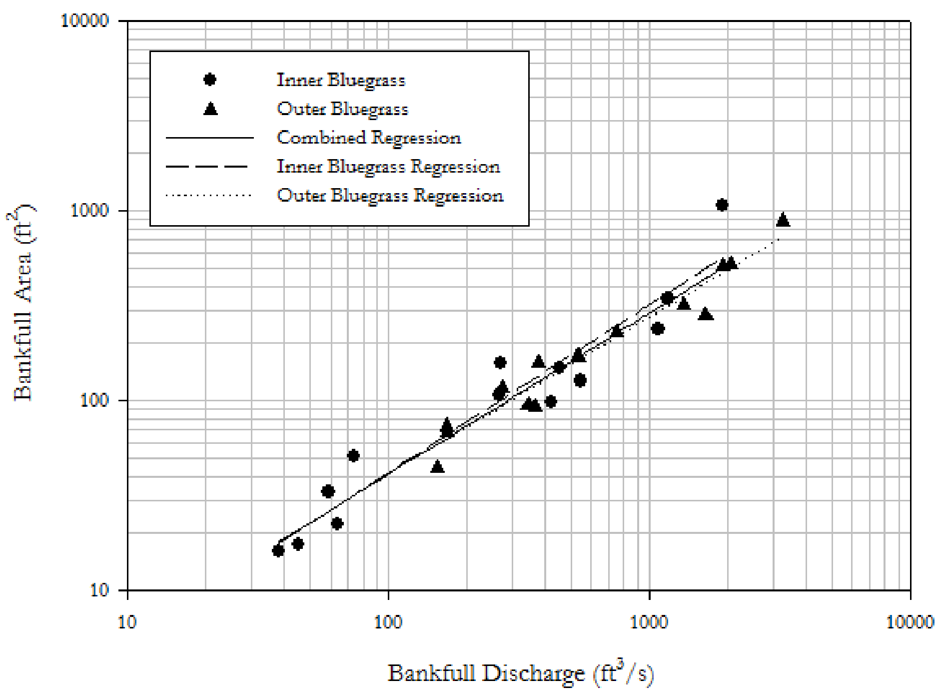

Figure 4.1 Bankfull Cross-sectional Area versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

4.1.2 Width Hydraulic Geometry Relationships

Bankfull width was plotted as a function of bankfull discharge. These hydraulic geometry relationships are presented in Table 4.2. The graphs of the data with regression equations are presented in Figure 4.2. Bankfull width plotted against bankfull discharge provides a strong relationship; the R^2 value for all regions is 0.94. While the exponent and coefficient of the relationships change when the Inner and Outer Bluegrass are separated, the predictability of the equation does not. The exponents for the hydraulic geometry relationships developed for bankfull width fall within those sited in the literature; the values for the exponent range from 0.45 – 0.55 (Miller and Davis, 2003). Hey and Thorne (1986) determined an exponent value of 0.52 for bankfull width which is slightly higher than the combined value of 0.49 found in this study. Leopold *et al.* (1964) found this exponent to be 0.50.

Table 4.2 Hydraulic Geometry Relationships for Bankfull Width as a Function of Bankfull Discharge where Bankfull Width is measured in Feet and Bankfull Discharge is Measured in Cubic Feet Per Second.

Region	Regression Equation	R^2
Combined Region	$W_{bkf}=2.6441Q_{bkf}^{0.4861}$	0.94
Inner Bluegrass	$W_{bkf}=2.2376Q_{bkf}^{0.5172}$	0.94
Outer Bluegrass	$W_{bkf}=3.522Q_{bkf}^{0.4406}$	0.94

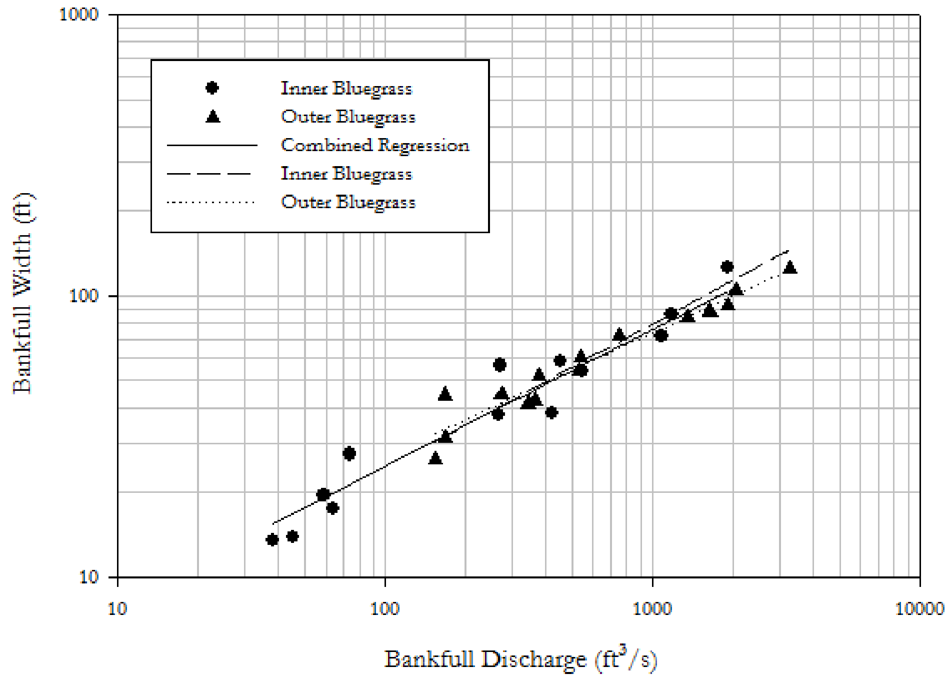

Figure 4.2 Bankfull Width versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

4.1.3 Depth Hydraulic Geometry Relationships

Bankfull depth was plotted as a function of bankfull discharge. These hydraulic geometry relationships are presented in Table 4.3. The graphs of the data with regression equations are presented in Figure 4.3.

Table 4.3 Hydraulic Geometry Relationships for Bankfull Depth as a Function of Bankfull Discharge where Bankfull Depth is measured in Feet and Bankfull Discharge is Measured in Cubic Feet Per Second.

Region	Regression Equation	R^2
Combined Region	$D_{bkf}=0.3126Q_{bkf}^{0.3623}$	0.84
Inner Bluegrass	$D_{bkf}=0.3164Q_{bkf}^{0.3681}$	0.84
Outer Bluegrass	$D_{bkf}=0.2525Q_{bkf}^{0.3898}$	0.85

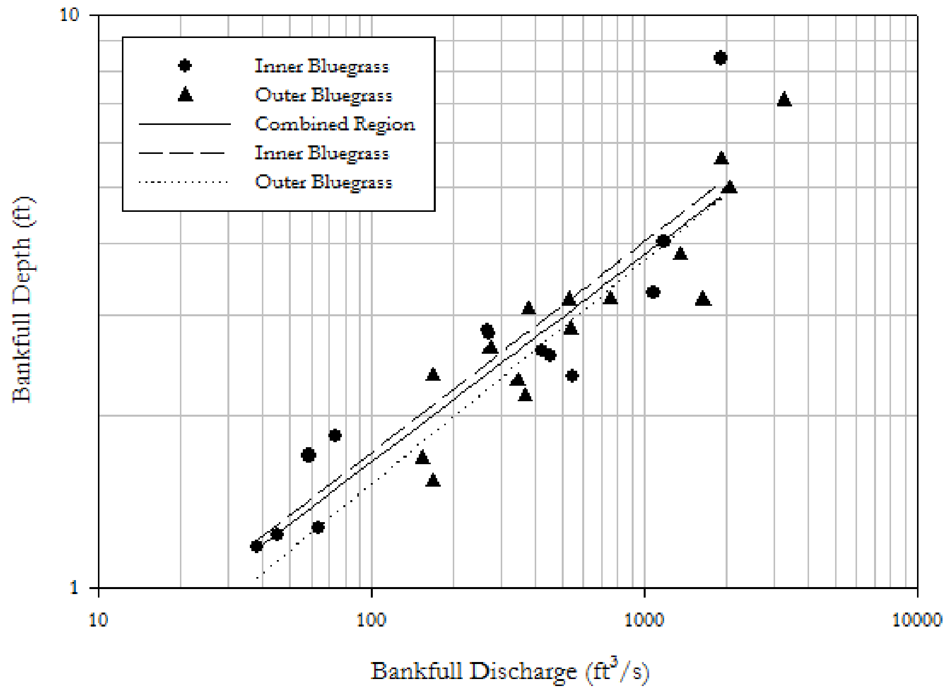

Figure 4.3 Bankfull Depth versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

The bankfull depth plotted as a function of bankfull discharge displays a strong relationship between the two variables; however the R^2 value of 0.84 is not as high as those seen in the hydraulic geometry relationships of bankfull area and bankfull width. The bankfull depth hydraulic geometry relationship is expected to have the lowest R^2 value; this is seen in other studies such as that done by McCandless (2003a) where the R^2 value for the hydraulic geometry relationship of bankfull area was 0.95, for width was 0.94 and for depth was 0.91. The values for the exponents of the equations developed for bankfull depth fall within those found in the literature, between 0.33 – 0.40 (Miller and Davis, 2003). The values in this study match well with those found by Hey and Thorne (1986); the value for the depth exponent was 0.39 when plotted versus bankfull discharge, compared to a combined value of 0.36 for the combined regions in this study.

4.1.4 Velocity Hydraulic Geometry Relationships

Bankfull velocity was plotted as a function of bankfull discharge. These hydraulic geometry relationships are presented in Table 4.4. The graphs of the data with regression equations are presented Figure 4.4. The values of the exponents compare well with those found by Hey and Thorne (1986); they found the exponent of velocity to be 0.10 when plotted versus bankfull discharge. The plot of bankfull discharge versus bankfull velocity shows a high amount of scatter between points. Because the bankfull area versus bankfull discharge plot did not show as much scatter, area may be explaining more of the bankfull discharge than velocity. Channels adapt to the discharge supplied by multiple means, one is through dimensional adjustment (e.g. width, depth, and/or slope). There are many channel characteristics that influence velocity, bed material and vegetation are two.

Table 4.4 Hydraulic Geometry Relationships for Bankfull Velocity as a Function of Bankfull Discharge where Bankfull Velocity is measured in Feet per Second and Bankfull Discharge is Measured in Cubic Feet Per Second.

Region	Regression Equation	R^2
Combined Region	$V_{bkf}=1.2098Q_{bkf}^{0.1517}$	0.32
Inner Bluegrass	$V_{bkf}=1.4123Q_{bkf}^{0.1147}$	0.17
Outer Bluegrass	$V_{bkf}=1.1247Q_{bkf}^{0.1696}$	0.43

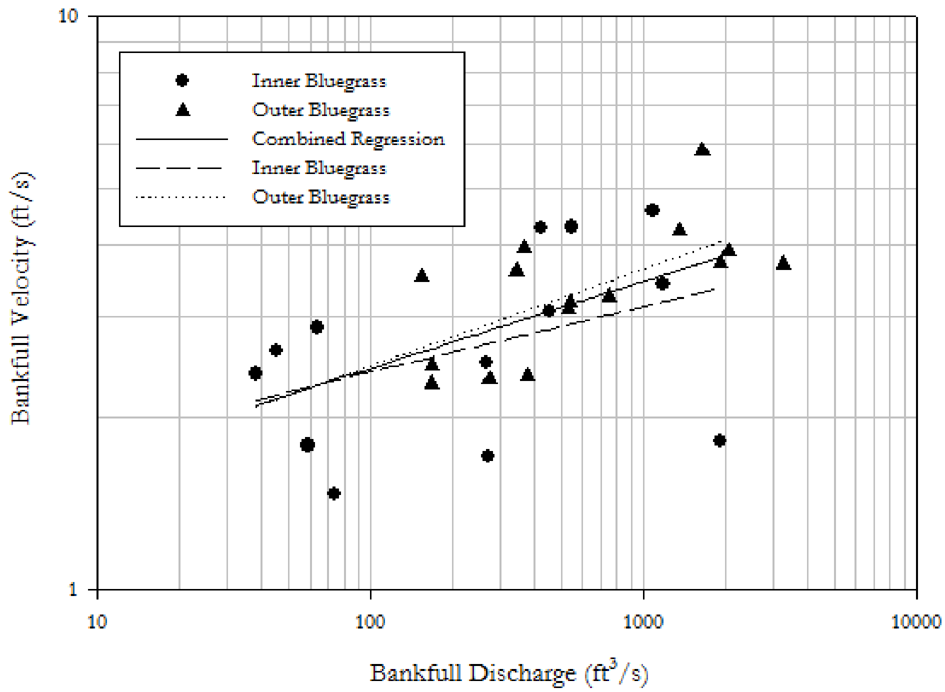

Figure 4.4 Bankfull Velocity versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

4.1.5 Slope Hydraulic Geometry Relationships

Main channel slope (GIS computed) was plotted as a function of bankfull discharge. These hydraulic geometry relationships are presented in Table 4.5. The graphs of the data with regression equations are presented in Figure 4.5. The values for the exponent match well with those found by Hey and Thorne (1986); the value they found was -0.43.

Table 4.5 Hydraulic Geometry Relationships for Channel Slope as a Function of Bankfull Discharge where Bankfull Discharge is Measured in Cubic Feet Per Second.

Region	Regression Equation	R^2
Combined Region	$S_{bkf}=0.032Q_{bkf}^{-0.350}$	0.42
Inner Bluegrass	$S_{bkf}=0.0363Q_{bkf}^{-0.429}$	0.71
Outer Bluegrass	$S_{bkf}=0.0991Q_{bkf}^{-0.484}$	0.57

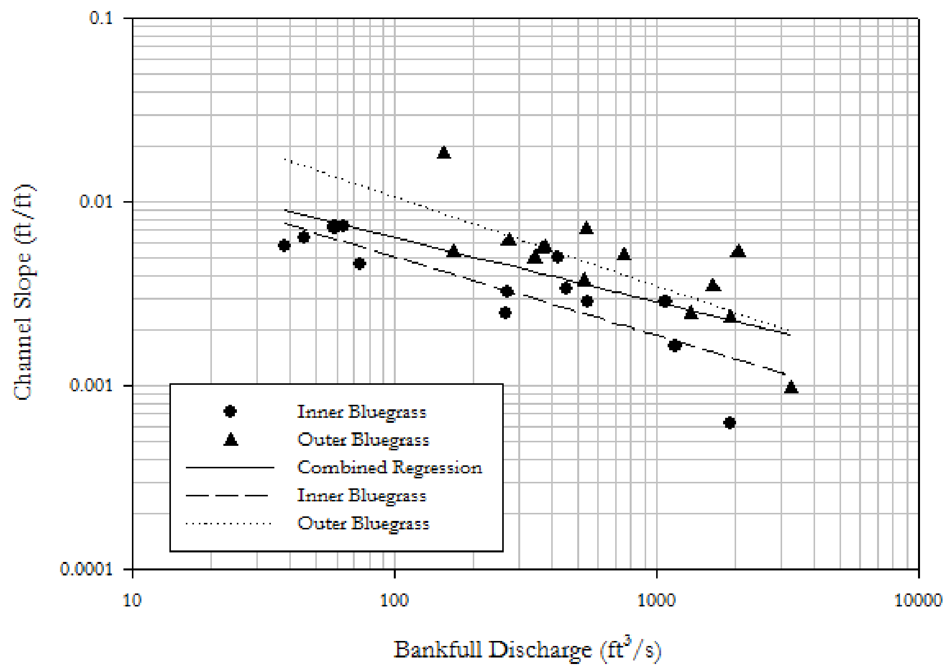

Figure 4.5 Channel Slope versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

The coefficients of the hydraulic geometry equations developed for the Inner and Outer Bluegrass Regions are different by a factor of three (0.03 versus 0.09). The result is seen in the separation of these equations and is not surprising when the topography of the regions is noted. The Inner Bluegrass has a more flat than the Outer Bluegrass.

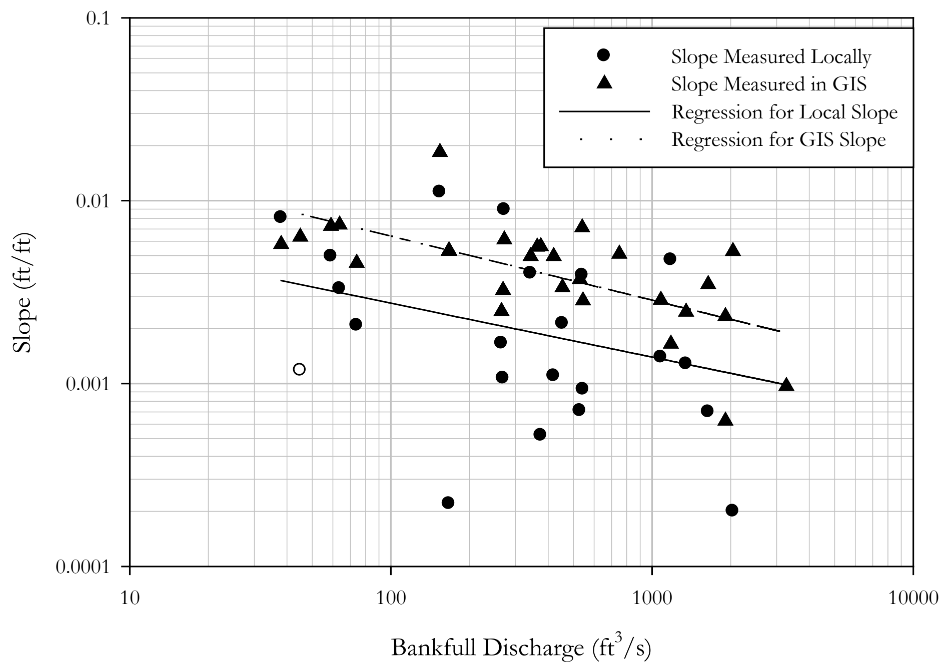

Figure 4.6 Comparison of Local Slope and Channel Slope Calculated in GIS.

Figure 4.6 is a plot of the hydraulic geometry relationships (combined regions) for the main channel slopes developed in GIS and the slopes measured locally. The slopes of the regression lines are similar though the locally measured slope (-0.295) is somewhat steeper than then GIS derived main channel slope (-0.350). This difference is not unexpected as the main channel slope was calculated over a larger length, and hence a greater elevation difference, than the locally measured slope. Overall, the difference in the channel slopes between the two methods was not significant.

4.1.6 Manning's n Hydraulic Geometry Relationships

Manning's n was plotted as a function of bankfull discharge. These hydraulic geometry relationships are presented in Table 4.7. The graphs of the data with regression equations are presented in Figure 4.6. Leopold *et al.* (1964) determined the theoretical value for the exponent of the hydraulic geometry relationship of Manning's n related to bankfull discharge to be -0.22; the values in this study are -0.081, -0.079 and -0.156. The separated curve for the Outer Bluegrass is the only equation with an exponent close to the theoretical value. Since Manning's n is back-calculated by discharge, depth and slope, these influence the value determined for this exponent. The discharge in the Inner Bluegrass is lower than the Outer Bluegrass; this could help explain the differences in the exponent developed for the Manning's n hydraulic geometry relationship. Manning's n values were checked with stream photos and known Manning's n values determined by the USGS for select gage sites.

Table 4.6 Hydraulic Geometry Relationships for Manning's n as a Function of Bankfull Discharge where Bankfull Discharge is Measured in Cubic Feet Per Second.

Region	Regression Equation	R^2
Combined Region	$n_{bkf}=0.0953Q_{bkf}^{-0.081}$	0.09
Inner Bluegrass	$n_{bkf}=0.0863Q_{bkf}^{-0.079}$	0.08
Outer Bluegrass	$n_{bkf}=0.1655Q_{bkf}^{-0.156}$	0.24

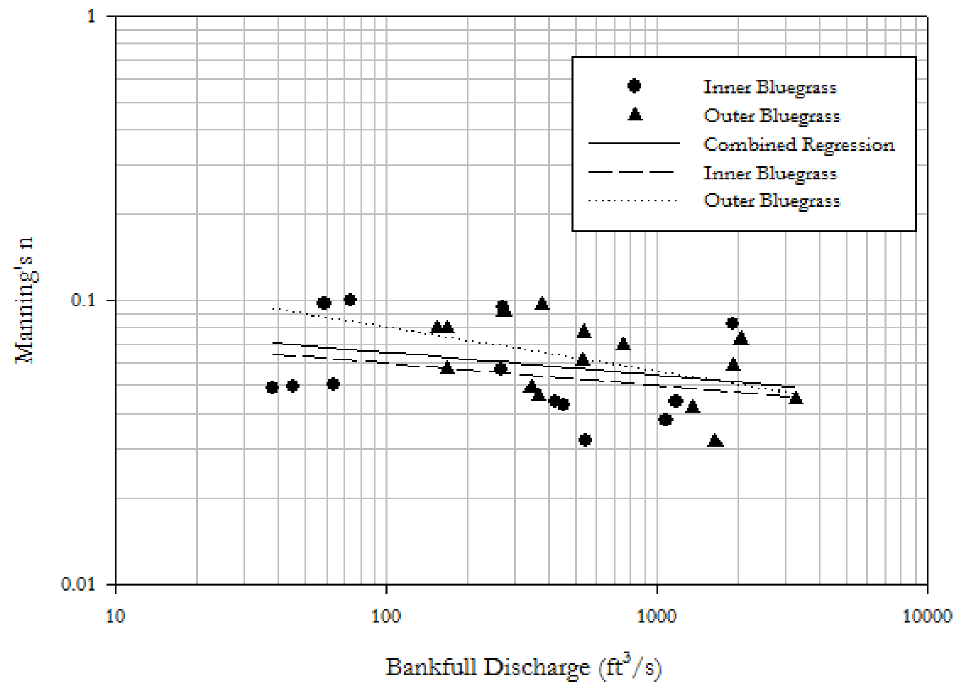

Figure 4.7 Manning's n versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

Figure 4.8 is a plot of the hydraulic geometry relationships (combined regions) for Manning's n values calculated using the main channel slopes developed in GIS and the slopes measured locally. The slopes of the regression lines do differ (-0.081 GIS; -0.240 local). This difference largely results in lower Manning's n values when using the local slopes; however, no changes in velocities were noted when using GIS derived slopes or locally measured slopes. The slightly steeper GIS slopes were accompanied by greater Manning's n values.

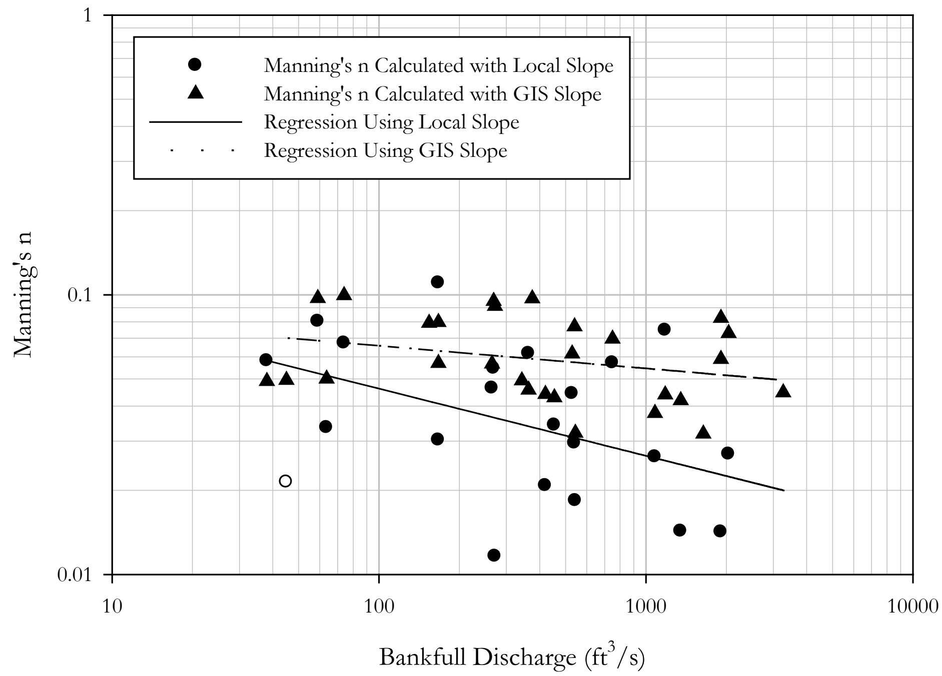

Figure 4.8 Manning's n versus Bankfull Discharge for the Combined, Inner Bluegrass and Outer Bluegrass Regions.

4.1.7 Comparison

4.1.7.1 Other Hydraulic Geometry Relationships

While there are many other studies that developed regional curves throughout the U.S., few examined hydraulic geometry relationships. There are however studies that developed only hydraulic geometry relationships. Table 4.7 is a sampling of hydraulic geometry relationships developed across the U.S. Figures 4.9, 4.10 and 4.11 show the graphical depictions of these relationships.

Table 4.7 Comparison of Hydraulic Geometry Relationships both Empirical and Theoretical where $A_{bkf}=gQ_{bkf}^{h}$, $W_{bkf}=aQ_{bkf}^{b}$, $D_{bkf}=cQ_{bkf}^{f}$, $V_{bkf}=kQ_{bkf}^{m}$, $n=x\ Q_{bkf}^{y}$, $S=t\ Q_{bkf}^{z}$, and Q_{bkf} is the Bankfull Discharge measured in cubic feet per second, A_{bkf} is the Bankfull Area measured in square feet, W_{bkf} is the Bankfull Width measured in feet, D_{bkf} is the Bankfull Depth measured in feet, V_{bkf} is the Bankfull Velocity measured in feet per second, n is Manning's n, and S is the slope.

Study	Bankfull Area			Bankfull Width			Bankfull Depth			Bankfull Velocity			Roughness			Slope		
	g	h	R^2	a	b	R^2	c	f	R^2	k	m	R^2	x	y	R^2	t	z	R^2
Combined Region	0.82	0.85	0.94	2.64	0.49	0.94	0.31	0.36	0.84	1.21	0.15	0.32	0.10	-0.08	0.09	0.03	-0.35	0.42
Inner Bluegrass	0.71	0.89	0.92	2.24	0.52	0.94	0.32	0.37	0.84	1.41	0.11	0.17	0.09	-0.08	0.08	0.04	-0.43	0.71
Outer Bluegrass	0.89	0.83	0.95	3.52	0.44	0.94	0.25	0.39	0.85	1.12	0.17	0.43	0.17	-0.16	0.24	0.10	-0.48	0.57
Leopold *et al.* (1964)[1]	-	-	-	-	0.53	-	-	0.37	-	-	0.10	-	-	-0.2	-	-	-0.7	-
Leopold *et al.* (1964)[3]	-	-	-		0.50	-	-	0.40	-	-	0.10	-	-	-	-		-	-
Knighton (1998)[4]	-	-	-	2.61	0.50	-	0.31	0.360	-	-	0.14	-	-	-	-	-	-0.2	-
McCandless (2003)a[5]	0.79	0.8	0.95	2.65	0.47	0.94	0.3	0.33	0.91	-	-	-	-	-	-	-	-	-
McCandless (2003)b[6]	0.89	0.87	0.91	2.82	0.47	0.80	0.32	0.4	0.86	-	-	-	-	-	-	-	-	-
Hey and Thorne (1986)[2,7]	-	-	-	2.17	0.52	0.96	0.20	0.390	0.86	2.54	0.10	0.79	-	-	-	-	-	-

1 - Theoretical Equations

2 - Equations developed in the Metric system

3 - River in downstream direction

4 - Indian and U.S. canals

5 - Bedrock cobble and gravel in Allegheny Plateau and Valley and Ridge Maryland, humid

6 - Coastal Plain Maryland

7 - Gravel bed rivers in the United Kingdom with >50% tree cover

The plots of bankfull cross-sectional area show that the equations are similar, as seen in Figure 4.8. For the combined regions in this study, an exponent of 0.85 was calculated for the relationship of bankfull discharge to bankfull area. This value compares well with those developed by McCandless (2003a, 2003b) which calculated 0.8 and 0.87 for the same relationships developed for streams in Maryland. The separated Inner and Outer Bluegrass's exponents, 0.89 and 0.83 respectively, compare well to the McCandless values as well. The coefficients of the equations compare well with each other too; the values for the combined, Inner and Outer Bluegrass are 0.82, 0.71 and 0.89 respectively. The values calculated for McCandless (2003a, 2003b) are 0.79 and 0.89.

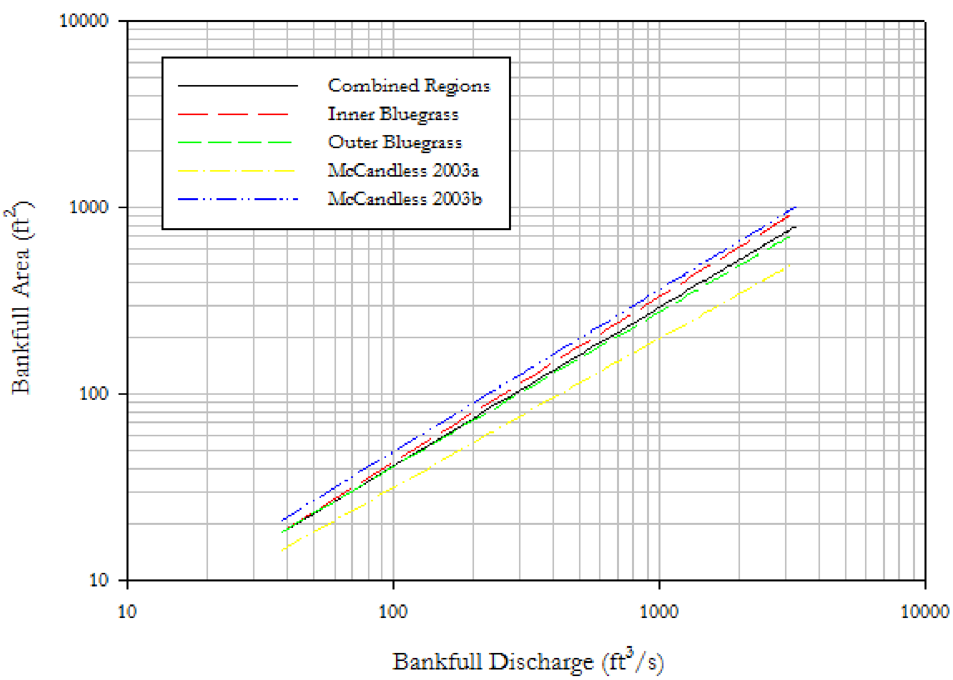

Figure 4.9 Comparison of Hydraulic Geometry Relationships of Bankfull Cross-sectional Area versus Bankfull Discharge.

The graph that shows the most significant relationship is the bankfull width, as seen in Figure 4.10; the studies seem to compare well in regards to the hydraulic geometry relationships of width. Exponents for the combined, Inner and Outer Bluegrass are 0.49, 0.52 and 0.44 respectively. These compare with theoretical values of 0.53 (Leopold *et al.*, 1964) and 0.50 (Knighton, 1998). They also compare will with other empirical values: 0.47 developed from three regions in Maryland (McCandless, 2003a, 2003b), 0.50 for rivers in the downstream direction (Knighton, 1998) and 0.52 (Hey and Thorne, 1986). The coefficients for these equations, 2.64 for the combined regions, 2.24 for the Inner Bluegrass and 3.52 for the Outer Bluegrass, are also similar to those found theoretically, 2.61 (Knighton 1998) and empirically, 2.65 and 2.82 (McCandless 2003a, b).

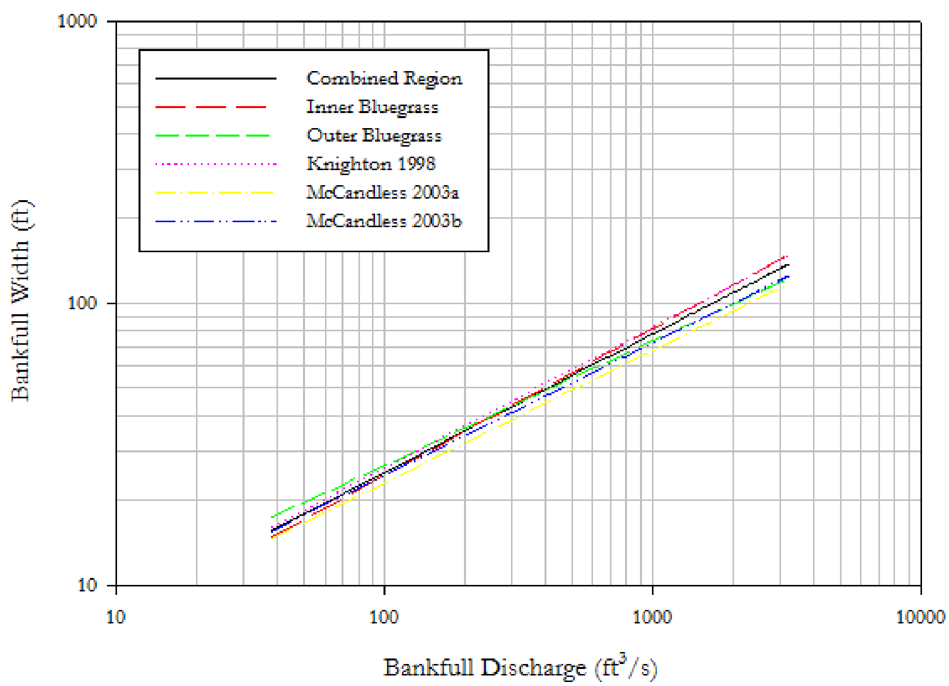

Figure 4.10 Comparison of Hydraulic Geometry Relationships of Bankfull Width versus Bankfull Discharge.

The plot of the hydraulic relationships for bankfull depth also shows that the hydraulic geometry relationships developed in this study compare well with those developed by others, as seen in Figure 4.11. The exponent's values of 0.36 for the combined regions, 0.37 for the Inner Bluegrass and 0.39 for the Outer Bluegrass are similar to those found theoretically; 0.37 (Leopold *et al.*, 1964) and 0.36 (Knighton, 1998). These exponents also compare well with other empirical studies: 0.33 and 0.4 in Maryland (McCandless, 2003a, 2003b) and 0.39 (Hey and Thorne, 1986).

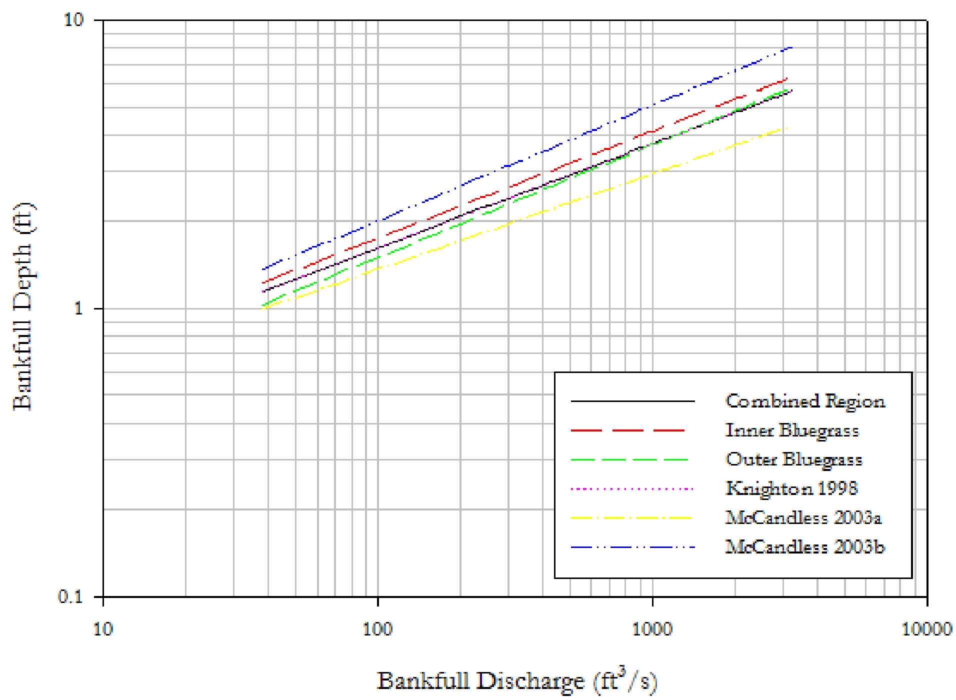

Figure 4.11 Comparison of Hydraulic Geometry Relationships of Bankfull Depth versus Bankfull Discharge.

The velocity equations were also compared to other equations both theoretical and empirical. The values of the exponents for the combined regions 0.15, the Inner Bluegrass 0.11 and the Outer Bluegrass 0.17 compare well with those developed theoretically: 0.10

(Leopold *et al.*, 1964) and 0.14 (Knighton, 1998). They are also similar to Hey and Thorne's (1986) value of 0.10.

The Manning's n (roughness) and slope equations are similar to theoretical equations, however there are not many to use in comparison. The Manning's n exponent for the Outer Bluegrass, -0.16, is close to the theoretical -0.2 found by Leopold *et al.* (1964). The exponents calculated in the slope equations, -0.35 for the combined regions, -0.43 for the Inner Bluegrass and -0.48 for the Outer Bluegrass, lie between the theoretical values of -0.2 (Leopold *et al.*, 1964) and -0.2 (Knighton, 1998).

4.2 Regional Curves

Regional curves were developed using data from 14 USGS gaged stations throughout the Inner Bluegrass for drainage areas ranging from 0.96 mi^2 to 147 mi^2, and using data from 15 USGS gaged stations throughout the Outer Bluegrass for drainage areas ranging from 3.10 mi^2 to 138 mi^2. A summary of the studied sites is presented in Table 4.8. Using standard convention for regional curves developed across the U.S., all data are presented in U.S customary units. Bank height ratios (BHR) ranged from 1.0 to 1.5 with all but three streams having a BHR of 1.3 or less. Metcalf *et al.* (2009) note that a BHR of 1.5 is considered stable for a gaged stream. A wide range of impervious areas were used for this study: percent impervious ranged from 0.5 to 29.6 percent (averaging 12.6 $\pm$ 9.5) for the Inner Bluegrass and 0.4 to 33.9 (averaging 8.7 $\pm$ 10) for the Outer Bluegrass. Regional curves developed throughout Pennsylvania and Maryland used sites with 20-25 impervious cover in a site's watershed (Cinotto, 2003; Chaplin, 2005). The reaches surveyed for this study were chosen

Table 4.8 Site Name, Location, Drainage Area, Bank Height Ratio and Percent Impervious for Inner and Outer Bluegrass Sites.

Gage Number	Site Location	Region Designation[1]	Latitude[2]	Longitude	DA[3] (mi^2)	BHR[4]	% Impervious
03284525	East Hickman Creek Tributary at Chilesburg Road near Lexington	IB	37°59'18"	84°24'40"	0.96	1.2	3.5
03284520	East Hickman Creek at Andover Village near Cadentown	IB	37°59'50"	84°24'20"	1.58	1.0	12.0
03287580	North Elkhorn Creek at Man O War Blvd near Cadentown	IB	38°01'42"	84°24'07"	2.20	1.2	3.2
03288500	Cave Creek near Fort Springs	IB	38°01'15"	84°35'38"	2.53	1.5	21.6
03287590	North Elkhorn Creek on Winchester near Lexington	IB	38°02'54"	84°24'40"	4.05	1.1	9.8
03289193	Wolf Run at Old Frankfort Pike, Lexington	IB	38°04'00"	84°33'16"	9.57	1.1	29.6
03284530	East Hickman Creek at Delong Road near East Hickman	IB	37°56'59"	84°27'19"	15.10	1.0	13.7
03284555	West Hickman Creek at Ash Grove Pike near East Hickman	IB	37°56'04"	84°30'08"	20.50	1.0	24.2
03287600	North Elkhorn at Bryan Station Road near Montrose	IB	38°04'35"	84°24'48"	21.50	1.5	12.0
03289000	South Elkhorn Creek at Fort Springs	IB	38°02'35"	84°37'35"	24.00	1.0	13.1
03289200	Town Branch at Yarnallton Rd at Yarnallton	IB	38°06'13"	84°35'17"	30.00	1.0	25.7
03291000	Eagle Creek at Sadieville	IB	38°23'22"	84°32'36"	42.90	1.0	0.5
03288000	North Elkhorn Creek near Georgetown	IB	38°12'20"	84°30'49"	119.00	1.3	2.8
03288100	North Elkhorn at Georgetown	IB	38°13'10"	84°33'47"	147.00	1.1	4.1
03238772	Fourmile Creek at Polar Bridge near Alexandria	OB-NKY	38°59'12"	84°21'55"	3.10	1.5	6.5
03254400	North Fork Grassy Creek near Piner	OB-NKY	38°47'31"	84°30'50"	13.60	1.2	1.0
03254480	Cruises Creek at Highway 17 near Piner	OB-NKY	38°50'40"	84°31'56"	18.00	1.3	1.2

Table 4.8 (continued)

Gage Number	Site Location	Region Designation[1]	Latitude[2]	Longitude	DA[3] (mi^2)	BHR[4]	% Impervious
03262001	Woolper Creek at Woolper Road near Burlington	OB-NKY	39°01'48"	84°48'15"	24.20	1.2	4.1
03254550	Banklick Creek at Highway 1829 near Erlanger	OB-NKY	38°58'48"	84°32'32"	30.00	1.1	4.5
03277075	Gunpowder Creek at Camp Ernst Road near Union	OB-NKY	38°59'39"	84°42'58"	36.60	1.1	16.7
03238745	Twelvemile Creek at Highway 1997 near Alexandria	OB-NKY	38°57'05"	84°20'18"	39.00	1.0	1.7
03298135	Chenoweth Run at Ruckriegel Parkway	OB-LOUIS	38°11'41"	85°33'26"	5.47	1.0	33.9
03292480	Little Goose near Harrods Creek	OB-LOUIS	38°18'45"	85°37'33"	5.80	1.0	18.7
03292474	Goose Creek at Old Westport Road near St Matthews	OB-LOUIS	38°16'33"	85°36'22"	6.00	1.2	11.1
03297800	Cedar Creek at Highway 1442 near Shepherdsville	OB-LOUIS	37°59'28"	85°38'28"	12.10	1.3	0.4
03293000	Middle Fork Beargrass Creek at Old Cannons Lane at Louisville	OB-LOUIS	38°14'14"	85°39'53"	18.90	1.0	24.4
03277130	Mud Lick at Highway 42 near Beaverlick	OB-LOUIS	38°50'42"	84°43'15"	36.40	1.2	3.4
03292470	Harrods Creek at Highway 329 near Goshen	OB-LOUIS	38°21'42"	85°34'30"	70.30	1.2	1.4
03298000	Floyd's Fork at Fisherville	OB-LOUIS	38°11'18"	85°27'37"	138.00	1.1	2.4

[1]IB refers to Inner Bluegrass; OB-NKY refers to Outer Bluegrass-Northern Kentucky; and OB-Louis refers to Outer Bluegrass-Louisville.
[2]NAD83.
[3]DA represents watershed drainage area.
[4]BHR represents bank height ratio

based on their stability; sites with active erosion, in stream structures, and high BHR were avoided.

All streams were classified using the Rosgen classification system. There were 3 E, 8 C, 2 Cc- and 1 Bc type channels in the Inner Bluegrass and 10 C and 5 Bc type channels in the Outer Bluegrass. The entrenchment ratios (ER), calculated as the width of the flood prone area divided by the bankfull width, are a key factor in determining stream type using the Rosgen classification system. The E and C type channels are slightly entrenched and have an entrenchment ratio greater than 2.2; B type channels are moderately entrenched and have an ER between 1.4 and 2.2. The next step in determining the Rosgen stream classification is the width to depth ratio (W/D) ratio. The Inner Bluegrass had W/D ratios ranging from 11.2 to 23.2, and the Outer Bluegrass had W/D ratios ranging from 15.5 to 29.1. A moderate W/D ratio, greater than 12, places a stream into the C or B type; a very low W/D ratio, less than 12, places a stream into the E type. To finalize the Rosgen stream category, the sinuosities were determined. The sinuosities for the Inner Bluegrass ranged from 1.16 to 3.34, and in the Outer Bluegrass they ranged from 1.03 to 2.01. When the channels' stream types were determined (e.g. B, C or E), the slope and bed material were used to further categorize them in the Rosgen classification system. Slopes for the Inner Bluegrass ranged from 0.006 to 0.0074 ft/ft; slopes ranged from 0.0010 to 0.0184 ft/ft in the Outer Bluegrass. Further information on the bed material can be found in Appendix B.

Table 4.9 Bankfull Characteristics and Rosgen Stream Classification for Inner and Outer Bluegrass.

USGS Gage Site[1]	ER[2]	W/D Ratio[3]	Sinuosity	Slope (ft/ft)	D_{50}[4] (mm)	Rosgen Stream Type[6]
East Hickman Creek Tributary at Chilesburg Road near Lexington	>2.2[5]	11.2	1.16	0.0063	4.6	E4
East Hickman Creek at Andover Village near Cadentown	>2.2[5]	11.4	1.45	0.0058	15.2	E4
North Elkhorn Creek at Man O War Blvd near Cadentown	17	11.4	1.33	0.0073	30.1	E4/1
Cave Creek near Fort Springs	3.8	13.3	1.16	0.0074	38.5	C4/1
North Elkhorn Creek on Winchester near Lexington	10.4	17.2	1.33	0.0046	30.8	C4/1
Wolf Run at Old Frankfort Pike, Lexington	>2.2[5]	14.7	1.22	0.0050	104.1	C3/1
East Hickman Creek at Delong Road near East Hickman	>2.2[5]	13.3	2.41	0.0025	53.4	C4/1
West Hickman Creek at Ash Grove Pike near East Hickman	6.53	23.0	1.77	0.0034	144.3	C3/1
North Elkhorn at Bryan Station Road near Montrose	>2.2[5]	20.3	1.38	0.0032	62.3	C4
South Elkhorn Creek at Fort Springs	1.7	23.1	1.79	0.0028	194.0	B3/1c
Town Branch at Yarnallton Rd at Yarnallton	>2.2[5]	22.0	2.14	0.0029	130.7	C3/1
Eagle Creek at Sadieville	>2.2[5]	21.3	3.34	0.0016	6.2	C4
North Elkhorn Creek near Georgetown	2.4	19.0	3.09	0.0008	79.2	C3/1c-
North Elkhorn at Georgetown	>2.2[5]	14.9	3.09	0.0006	NA	Cc-[7]
Fourmile Creek at Polar Bridge near Alexandria	1.4< and <2.2[5]	15.5	1.03	0.0184	60.7	B4c
North Fork Grassy Creek near Piner	>2.2[5]	19.8	1.56	0.0056	NA	C[7]
Cruises Creek at Highway 17 near Piner	1.4<[5]	16.9	1.76	0.0056	59.5	B4c
Woolper Creek at Woolper Road near Burlington	1.5	21.3	1.31	0.0071	45.5	B4c
Banklick Creek at Highway 1829 near Erlanger	>2.2[5]	22.5	1.83	0.0051	83.1	C3
Gunpowder Creek at Camp Ernst Road near Union	>2.2[5]	24.7	1.67	0.0035	84.8	C3
Twelvemile Creek at Highway 1997 near Alexandria	>2.2[5]	22.1	1.26	0.0025	131.7	C3/1

Table 4.9 (continued)

USGS Gage Site[1]	ER[2]	W/D Ratio[3]	Sinuosity	Slope (ft/ft)	D_{50}[4] (mm)	Rosgen Stream Type[6]
Chenoweth Run at Ruckriegel Parkway	>2.2[5]	29.1	1.24	0.0053	45.0	C4
Little Goose near Harrods Creek	>2.2[5]	17.2	1.07	0.0061	82.8	C3
Goose Creek at Old Westport Road near St Matthews	>2.2[5]	13.3	1.98	0.0053	56.4	C4
Cedar Creek at Highway 1442 near Shepherdsville	1.3	18.0	1.35	0.0050	47.7	B4c
Middle Fork Beargrass Creek at Old Cannons Lane at Louisville	>2.2[5]	17.0	1.10	0.0037	39.6	C4
Mud Lick at Highway 42 near Beaverlick	>2.2[5]	19.8	1.52	0.0053	78.7	C3
Harrods Creek at Highway 329 near Goshen	1.4< and <2.2[5]	16.5	1.51	0.0023	NA	Bc[7]
Floyd's Fork at Fisherville	>2.2[5]	17.6	2.01	0.0010	87.2	C3

1 - streams divided by region, see Table 4.1

2 - Entrenchment Ratio (ER)

3 - width to depth ratio (W/D)

4 - median particle size (D_{50})

5 - estimated flood prone area

6 - '4' denotes gravel bed material, '4/1' denotes gravel bed material with bedrock influence, '3' denotes cobble bed material, '3/1' denotes cobble bed material with bedrock influence

7 - no pebble count information is available due to high water levels

4.2.1 Discharge Regional Curves

Using the survey data, USGS real time data, or in field staff gages if no real time data were available, and USGS ratings depot curves, bankfull discharges were determined at all but one of the surveyed sites. Site number 03288000 North Elkhorn Creek near Georgetown did not have a staff gage at site and does not collect real time data as the site is inactive, so it was not considered in discharge calculations. This site was selected in part as it was included in Parola *et al.* (2007). The discharge regional curve equations are presented in Table 4.10. Graphs of the data points with the regression equations are presented in Figure 4.12. The combined regions refers to equations calculated from all data points; the Inner Bluegrass refers to equations calculated using only data from streams located in the Inner Bluegrass region, and the Outer Bluegrass refers to equations calculated using data from streams located in the Outer Bluegrass.

Table 4.10 Power Function Regression Relationships (Regional Curves) for Bankfull Discharge where Q_{bkf} is the Bankfull Discharge in ft^3/s and DA is the Watershed Drainage Area in mi^2.

Region	Regression Equation	R^2
Combined Region	$Q_{bkf}=35.071DA^{0.9149}$	0.92
Inner Bluegrass	$Q_{bkf}=33.62DA^{0.8645}$	0.93
Outer Bluegrass	$Q_{bkf}=39.982DA^{0.9165}$	0.91

The plots of bankfull discharge versus drainage area show that bankfull discharge is significantly related to drainage area with 92% of the variability explained by the drainage area for the combined Bluegrass Region. The exponents of these equations fall within range of other regional curves developed across the eastern U.S. Other studies have found exponents to be 0.63 to 0.94, averaging 0.76 (± 0.17), see Table 2.2 for examples.

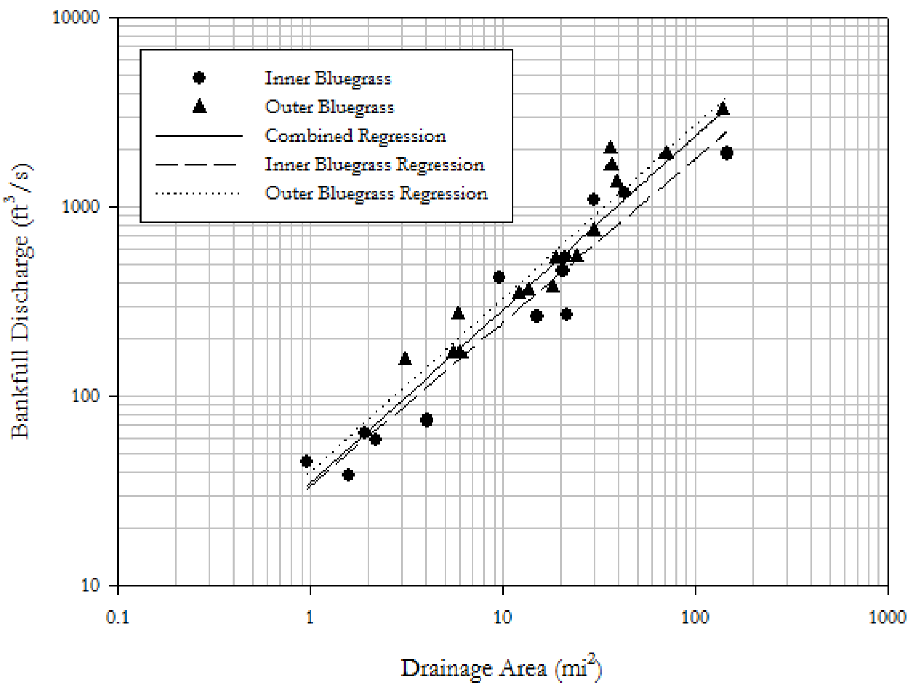

Figure 4.12 Bankfull Discharge as a Function of Drainage Area for the Combined Region, Inner Bluegrass and Outer Bluegrass Regions.

Separating the data into the Inner and Outer Bluegrass regions creates a difference in both the coefficient and exponent of the equation. The Inner Bluegrass has both a lower coefficient and exponent. This creates a lower prediction of discharge in the Inner Bluegrass. For instance, if the discharge for a watershed of 10 mi^2 was to be determined, the discharge for the Inner Bluegrass would be 246 ft^3/s and the discharge for the Outer Bluegrass would be 330 ft^3/s. There is a 25% difference in the calculated discharges for the Inner and Outer Bluegrass. The Inner Bluegrass has a higher percentage of impervious area than the Outer Bluegrass, indicating a higher percentage of urbanization. Regional curves developed in urban watersheds have shown higher coefficients and lower exponents than those developed in the same region with using data from rural watersheds (Harman *et al.*, 1999; Doll *et al.*, 2002). The Inner Bluegrass equation does share the lower exponent; however the coefficient is not higher than the exponent of the Outer Bluegrass. This could be attributed to the more intense karst watersheds found in the Inner Bluegrass; the additional discharge could be carried underground as opposed to in the channel.

There was variability in the bankfull discharges measured in each region; for instance, in the Inner Bluegrass region for a drainage area close to 20 mi^2, the discharge ranged from 269 ft^3/s to 544 ft^3/s. The Outer Bluegrass measurements had a similar type of variability around the 30 mi^2 to 40 mi^2 watershed drainage area; the discharges for these drainage areas ranged from 749 ft^3/s to 1,640 ft^3/s.

4.2.2 Area Regional Curves

Bankfull cross-sectional area was determined for all 29 surveyed sites. The regional curve equations for area are presented in Table 4.11. The graphs of the data points with the regression equation are presented in Figure 4.13.

Table 4.11 Power Function Regression Relationships (Regional Curves) for Bankfull Cross-sectional (A_{bkf}) in ft^2 and DA is the Watershed Drainage Area in mi^2.

Region	Regression Equation	R^2
Combined Region	$A_{bkf}=15.077DA^{0.8199}$	0.96
Inner Bluegrass	$A_{bkf}=14.002DA^{0.8239}$	0.98
Outer Bluegrass	$A_{bkf}=17.855DA^{0.7826}$	0.91

The power function relationships found for the bankfull area versus watershed drainage area produced strong relationships. Watershed drainage area explained 96% of the variability in the bankfull area. Separating the Inner and Outer Bluegrass Regions resulted in better predictability numbers for the Inner Bluegrass; the R^2 value increased from 0.96 to 0.98. The predictability numbers for the Outer Bluegrass did the opposite; the R^2 value decreased from 0.96 to 0.91. The separated equations for the Inner and Outer Bluegrass show the biggest difference on the smaller drainage areas. The difference in the curves is likely due to a lack of data for smaller watersheds in the Outer Bluegrass; there was only one watershed included with a drainage area less than five square miles.

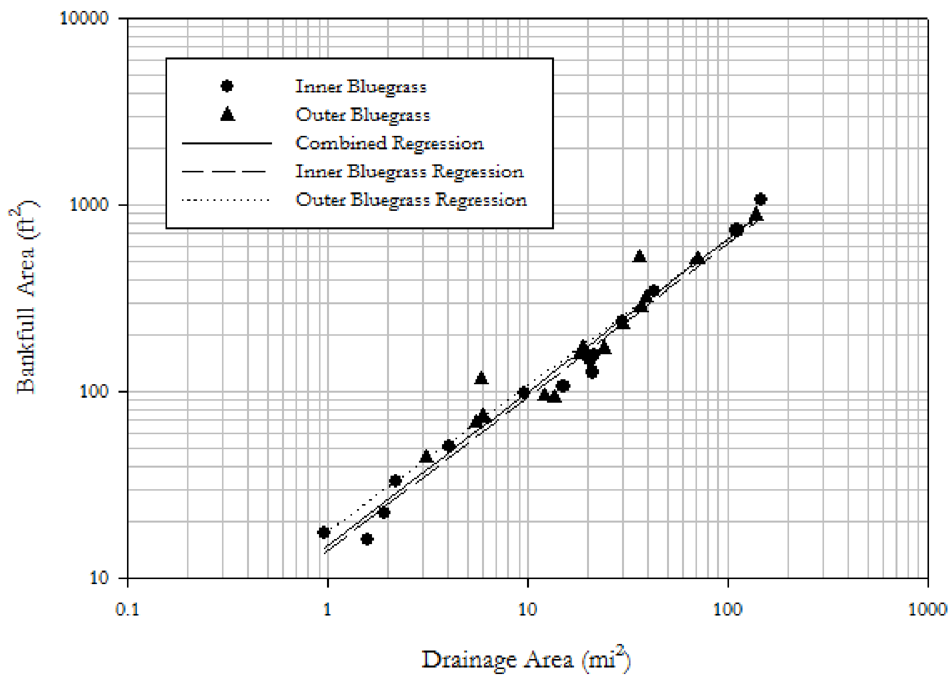

Figure 4.13 Bankfull Cross-section Area as a Function of Drainage Area for the Combined Region, Inner Bluegrass and Outer Bluegrass Regions.

The exponents found in all three equations fall within range of what is seen in other regions throughout the eastern U.S., as seen in Table 2.2. Bidelspach (2008) averaged 22 regional curves across the southeastern U.S. and found that the average exponent was 0.68; Dunne and Leopold (1978) also found a similar value for the eastern U.S. of 0.70.

4.2.3 Width Regional Curves

Bankfull widths were determined for all 29 surveyed sites. The regional curve equations for width are presented in Table 4.12. The graphs of the data points with the regression equation are presented in Figure 4.14.

Table 4.12 Power Function Regression Relationships (Regional Curves) for Bankfull Width (W_{bkf}) in ft and DA is the Watershed Drainage Area in mi^2.

Region	Regression Equation	R^2
Combined Region	$W_{bkf}=14.234DA^{0.4613}$	0.94
Inner Bluegrass	$W_{bkf}=13.015DA^{0.4717}$	0.98
Outer Bluegrass	$W_{bkf}=17.543DA^{0.410}$	0.88

The plots of bankfull width versus drainage area show that bankfull width is significantly related to drainage area with 94% of the variability explained by the drainage area for the combined Bluegrass Region. This relationship is very strong for the combined regions, but separating the regions shows different results. The Inner Bluegrass Region's R^2 value increases, indicating a better relationship than the combined region, but the Outer Bluegrass Region's R^2 value decreases.

The exponents found in all three equations fall within range of other regional curves developed throughout the eastern U.S., see Table 2.2. The exponent of the combined equation for bankfull width versus drainage area, 0.4613, is nearly identical to the value of 0.469 found by Cinotto (2003); their study also included watersheds with karst influence. It is also similar to the value of 0.399 found by Dunne and Leopold (1978) for streams across the eastern U.S. The largest deviation for these curves occurs with the lower drainage areas.

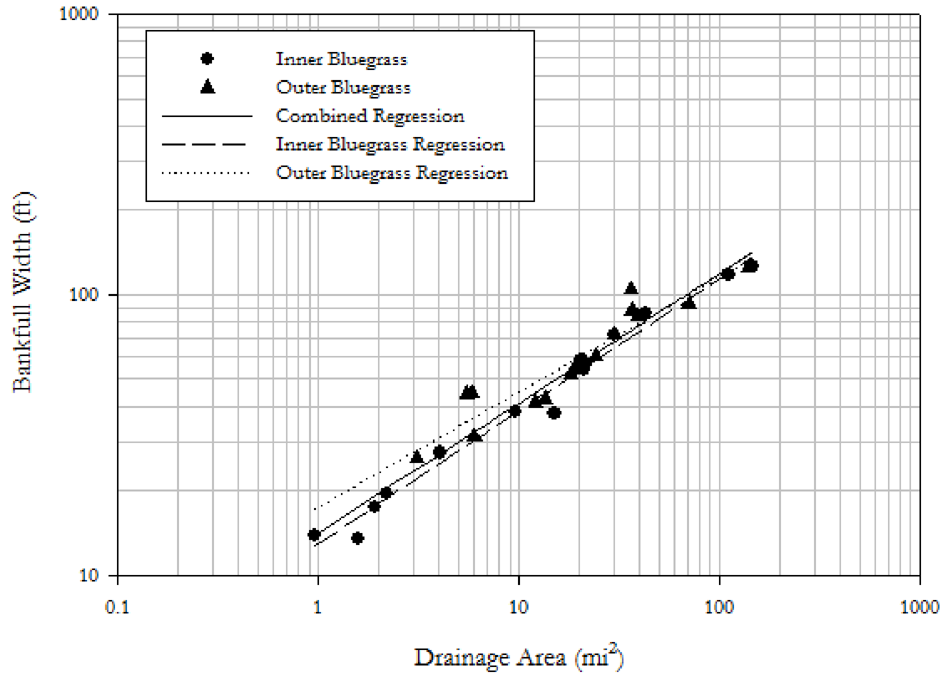

Figure 4.14 Bankfull Width as a Function of Drainage Area for the Combined Region, Inner Bluegrass and Outer Bluegrass Regions.

4.2.4 Depth Regional Curves

Bankfull depth determined from field measurements was determined for all 29 surveyed sites. The regional curve equations for depth are presented in Table 4.13. The graphs of the data points with the regression equation are presented in Figure 4.15.

Table 4.13 Power Function Regression Relationships (Regional Curves) for Bankfull Depth (D_{bkf}) in ft and DA is the Watershed Drainage Area in mi^2.

Region	Regression Equation	R^2
Combined Region	$D_{bkf}=1.0594DA^{0.3585}$	0.90
Inner Bluegrass	$D_{bkf}=1.076DA^{0.3521}$	0.93
Outer Bluegrass	$D_{bkf}=1.0176DA^{0.3723}$	0.84

In the combined equation for bankfull depth, 90% of the variability is explained by drainage area. The variability explained by drainage area increases for the Inner Bluegrass and decreases for the Outer Bluegrass when the curves are separated. The width and depth of a stream are influenced by the morphology of the stream; since streams in this study developed with different characteristics, such as the vegetation along stream banks or if a channel has bedrock influence, the width and depth may be different than other streams in the same region.

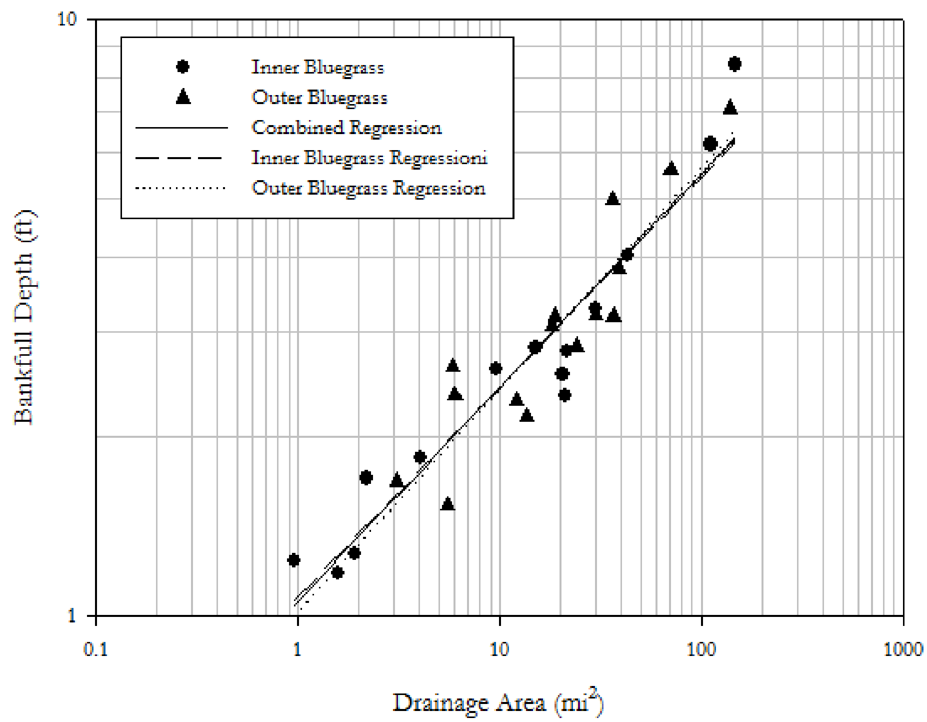

Figure 4.15 Bankfull Depth as a Function of Drainage Area for the Combined Region, Inner Bluegrass and Outer Bluegrass Regions.

The equations developed for the combined width and depth bankfull parameter, bankfull area, offers the best fit curve, followed by the width and then the depth. This can be seen in the combined equations for the regional curves developed for the Inner and Outer Bluegrass; the R^2 value for bankfull area is 0.96, while the value for bankfull width is 0.94 and bankfull depth is 0.90. Other studies show this same pattern of R^2 values; for example the regional curves developed by Miller and Davis in the New York Catskill Mountains found that the R^2 value for bankfull area was 0.90, for bankfull width was 0.88 and for bankfull depth was 0.85. Other curves that show this pattern include Doll *et al* . (2002), Doll *et al.* (2003), Cinotto (2003), McCandless (2003b), Sweet and Geratz (2003) and Metcalf *et al.* (2009).

4.2.5 Comparison

4.2.5.1 Other Regional Curves

Over 25 sets of regional curves have been developed across the eastern U.S. Perhaps the most interesting to this study are the curves developed by Parola *et al.* (Parola *et al.*, 2007) that included the Inner and Outer Bluegrass Regions and the Knobs Region of Kentucky and those developed by Cinotto (2003) that included watersheds that contained karst characteristics. Also interesting to this study are the curves developed by Dunne and Leopold (1978) that were developed for the entire eastern U.S. and average bankfull cross-sectional area curves (rural, urban, combined) developed by Bidelspach (2008) for the southeastern U.S. Table 4.14 is a comparison of these equations and Figures 4.16, 4.17, 4.18 and 4.19 are graphical representations of these curves.

Table 4.14 Comparison of Regional Curves in the Eastern United States where $Q_{bkf}=aDA^b$, $A_{bkf}=cDA^d$, $W_{bkf}=gDA^h$ and $D_{bkf}=jDA^k$ and DA is the Drainage Area measured in square miles, Q_{bkf} is the Bankfull Discharge measured in cubic feet per second, A_{bkf} is the Bankfull Area measured in square feet, W_{bkf} is the Bankfull Width measured in feet and D_{bkf} is the Bankfull Depth measured in feet.

Study	Bankfull Discharge			Bankfull Area			Bankfull Width			Bankfull Depth		
	a	b	R^2	c	d	R^2	g	h	R^2	j	k	R^2
Combined Region	35.071	0.9149	0.92	15.077	0.8199	0.96	14.234	0.4613	0.94	1.0594	0.3585	0.90
Inner Bluegrass	33.620	0.8645	0.93	14.002	0.8239	0.98	13.015	0.4717	0.98	1.0760	0.3521	0.93
Outer Bluegrass	39.982	0.9165	0.91	17.855	0.7826	0.91	17.543	0.4100	0.88	1.0176	0.3723	0.84
Parola *et al.* (2007)	27.9	0.98	0.96	7.71	0.99	0.99	10.97	0.48	0.97	0.70	0.51	0.93
Dunne and Leopold (Dunne and Leopold, 1978)	-	-	-	21.174	0.70	-	14	0.399	-	1.50	0.294	-
Bidelspach (2008)	-	-	-	19.549	0.6754	-	-	-	-	-	-	-
Cinotto (2003)	53.1	0.842	0.93	12.4	0.810	0.94	13.6	0.469	0.8	0.912	0.339	0.72

The developed regional curves relating drainage area to bankfull discharge were only developed in this study, the study by Parola *et al.* (2007), and by Cinotto (2003). The equations from this study and those by Cinotto (2003) have lower exponent values than those developed by Parola *et al.* (2007). This is apparent in the graph of the regression equations, found in Figure 4.15. A statistical comparison of the data developed in this study to the data developed by Parola *et al.* (2007) is in Section 4.2.5.2.

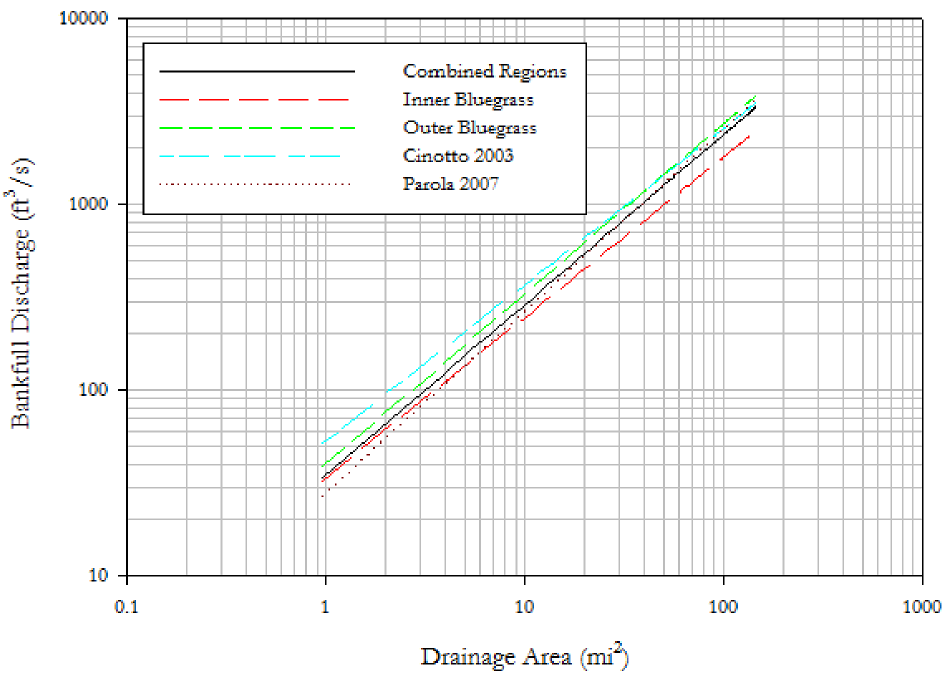

Figure 4.16 Comparison of Bankfull Discharge Regional Curves for the Humid Eastern U.S.

The regional curves developed for bankfull area were developed in all studies. An additional study by Bidelspach (2008) compared 22 curves across the southeastern U.S. The average equation for the southeastern U.S. is plotted with the other equations, as seen in Figure 4.16. The equations show similarities in the graph. The exponent from the 22 averaged sites, 0.6754, is are very close to the exponent developed by Dunne and Leopold (1978), 0.70; the exponents from this study, 0.8199, 0.8239 and 0.7826, are close to the exponent developed by Cinotto (2003), 0.81. The exponent for bankfull area developed by Parola *et al.* (2007) of 0.99 is higher than most of the similar studies in the eastern U.S. This value is unexpected and is similar only to that found in the regional curves developed for the coastal plain watersheds of Alabama; they also found this exponent to be 0.99 (Metcalf and Shaneyfelt, 2005).

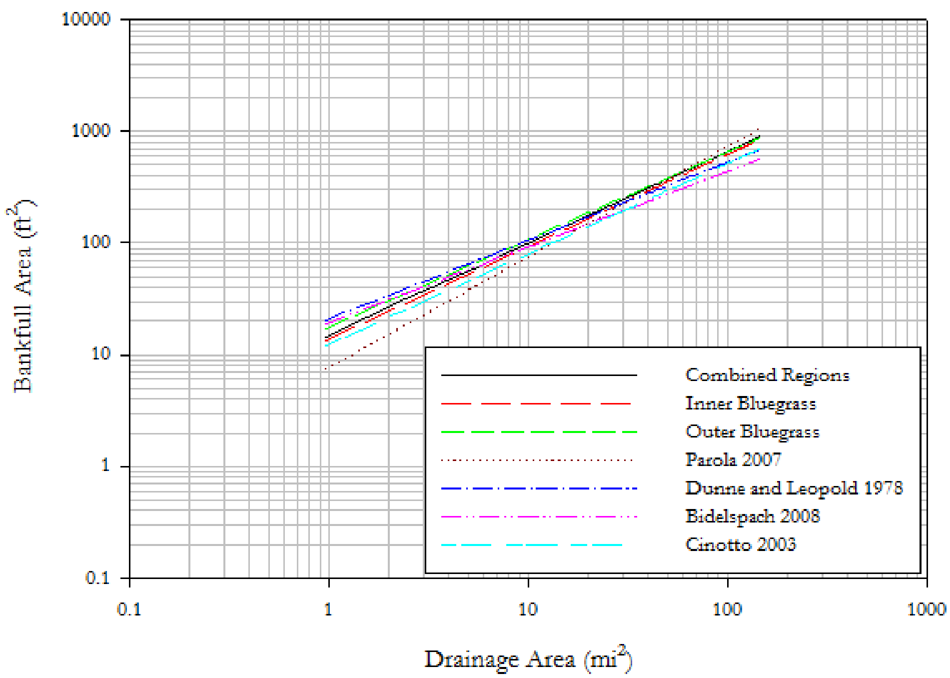

Figure 4.17 Comparison of Bankfull Cross-section Area Regional Curves for the Humid Eastern U.S.

The equations for the bankfull width are very interesting when compared among the different regional curves developed. The curve for this study nearly lies over that developed by Cinotto (2003). Both of these studies contain karst topography in the watersheds of the sites included. The study by Parola *et al.* (2007) eliminated sites that they could determine to be influenced by karst; while there is no way to reliably predict all watersheds that could be affected by karst, they tried to avoid them. The exponent of 0.48 from their study is closer to the exponents of the karst studies, 0.41 to 0.47 than that of Dunne and Leopold (1978). This could indicate that the watersheds in their study were influenced by karst, despite their efforts to avoid it. The equation developed by Parola *et al.* (2007) would predict a lower width than the karst studies, but would predict higher than the non-karst study conducted by Dunne and Leopold (1978).

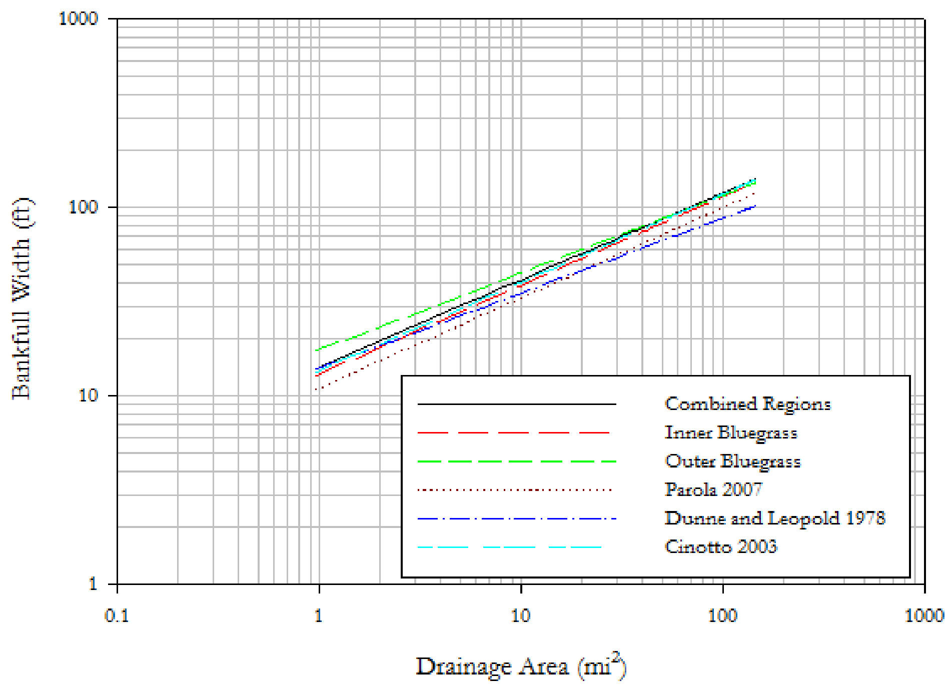

Figure 4.18 Comparison of Bankfull Width Regional Curves for the Humid Eastern U.S.

The opposite is true for the depth equations. The two studies that contain karst topography would predict a lower bankfull depth than the non-karst. The sites in the karst topography locations have higher widths, and lower depths; this would result in an overall higher W/D ratio. Since the area plots are comparable, this would be expected. The regional curve developed by Parola *et al.* (2007) has a different slope than all of the others; this indicates that the bankfull elevation could have been misidentified for some sites.

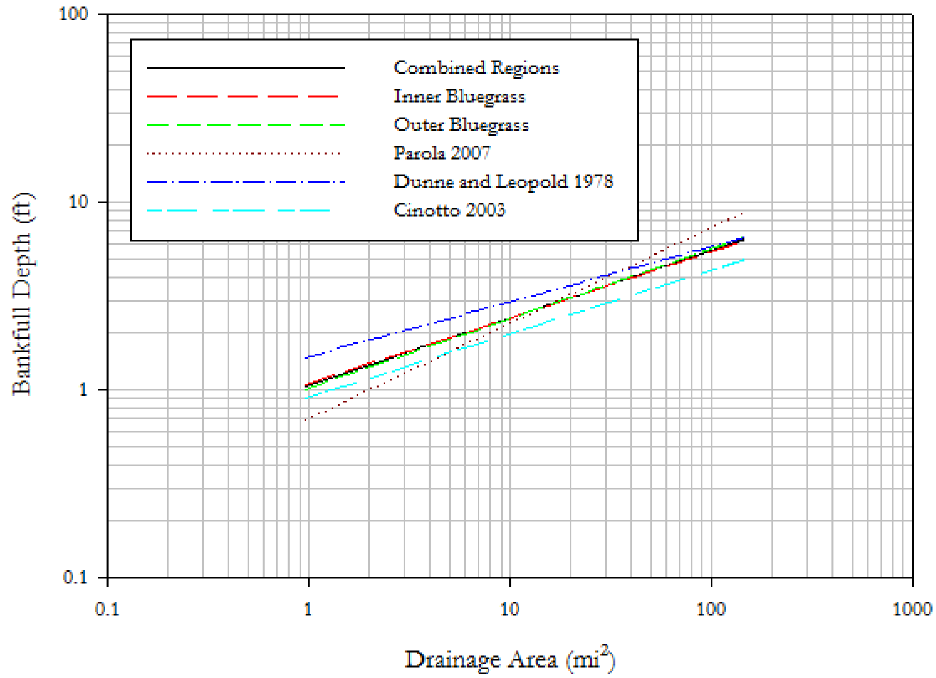

Figure 4.19 Comparison of Bankfull Depth Regional Curves for the Humid Eastern U.S.

4.2.5.2 Statistical Comparison to Parola et al. (2007)

The regional curve equations developed in this study were compared to those developed by Parola *et al.* (2007). Both studies included sites in the Inner and Outer Bluegrass Regions. The statistical analyses results (p-values) for each ANCOVA are presented in Table 4.15.

The bankfull width equations developed by Parola *et al.* (2007) and the combined regions show the strongest statistical similarity between the regression slopes with a p-value of 0.7989. Figure 4.20 is a plot of the data and regression equations for bankfull width.

Table 4.15 ANCOVA results for the comparison of the Combined Region to the data found by Parola (2007).

Bankfull Parameter	Number of Sites	P-value
Width	49	0.7989
Depth	49	<0.0001
Area	49	0.0068
Discharge	43	0.3015

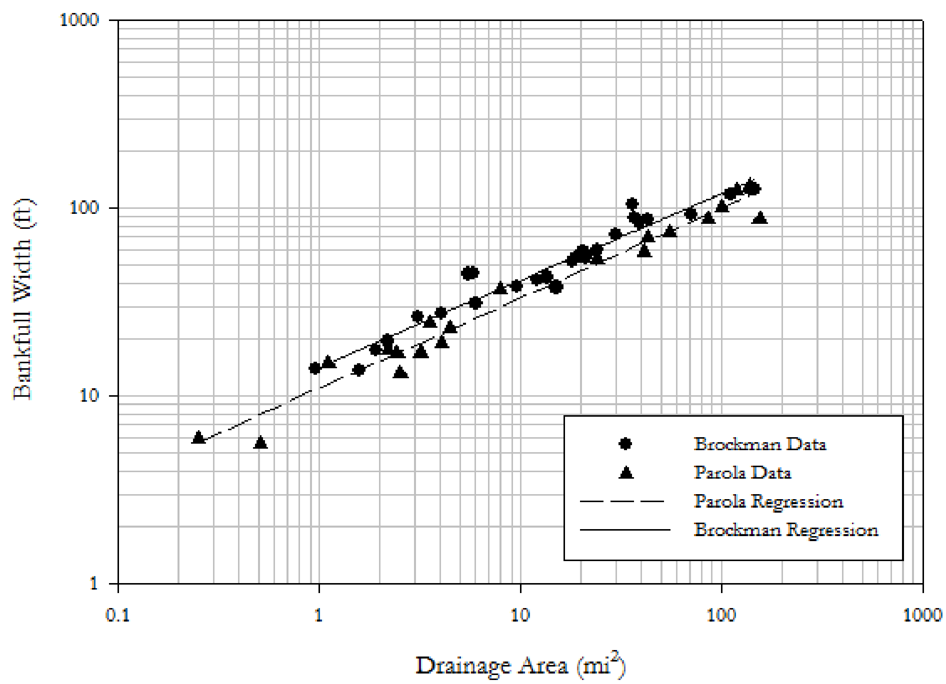

Figure 4.20 Comparison of Bankfull Width Regional Curves of the Combined Region and Parola *et al.* (2007).

The plots of the regression equations for the combined region and Parola *et al.* (2007) for the relationship of bankfull depth versus drainage area show the greatest difference. The statistical analysis demonstrates this as well with a p-value <0.0001. These plots are presented in Figure 4.21. The equation developed by Parola *et al.* (2007) predicts a lower bankfull depth than the combined regions for drainage areas under 20 square miles and a higher bankfull depth for drainage areas greater than 20 square miles. The difficulties in identifying bankfull could play a role in the differences in these data. Bankfull indicators, such as the flat depositional surface immediately adjacent to the stream, could be mistaken where there are inner berm features. Incorrectly identifying the inner berm as a bankfull elevation would result in a lower depth. A channel with uniform banks could produce similar bankfull width measurements at different elevations. Such could be the case with the North Elkhorn near Georgetown (03288000). The bankfull depth for this channel was found by Parola *et al.* (2007) to be 8.36 ft and by this study to be 6.17 ft. The widths for the North Elkhorn near Georgetown were similar. Parola *et al.* (2007) found the bankfull width to be 123 ft, and this study found the bankfull width to be 118 ft.

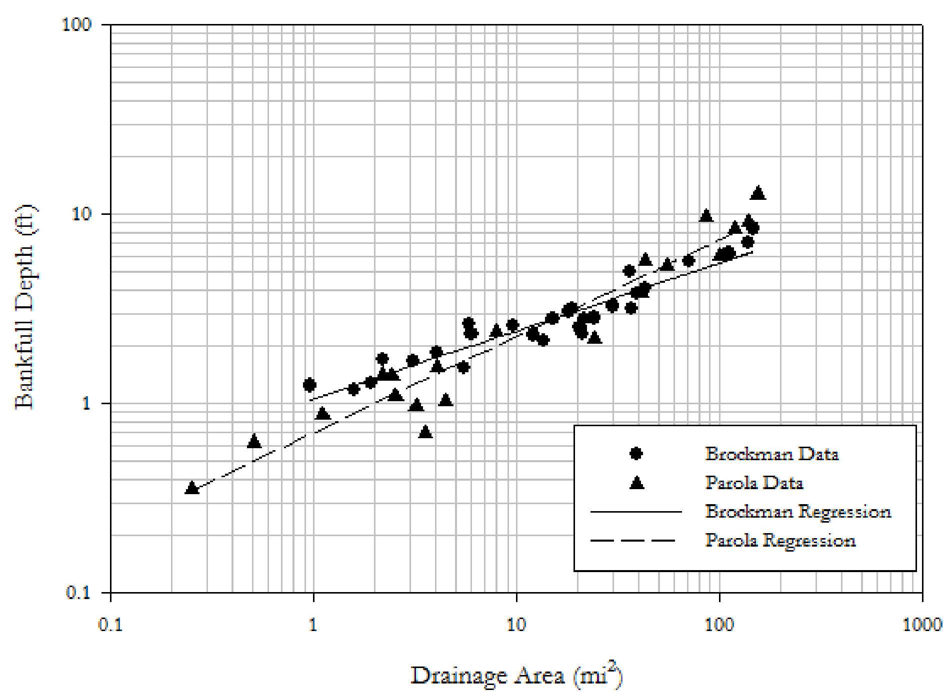

Figure 4.21 Comparison of Bankfull Depth Regional Curves of the Combined Region and Parola *et al.* (2007).

The plot of the regression equations for the combined region and the data developed by Parola *et al.* (2007) of the bankfull area versus drainage area shows a difference in the two equations. The statistics show a difference as well with a p-value of 0.0068. The data developed by Parola *et al.* (2007) predicts a smaller area than the combined region for drainage areas under approximately 40 square miles, and predicts an area larger for drainage areas greater than approximately 40 square miles. This difference could be attributed to the difference found in measuring the bankfull depth. Figure 4.22 presents these data.

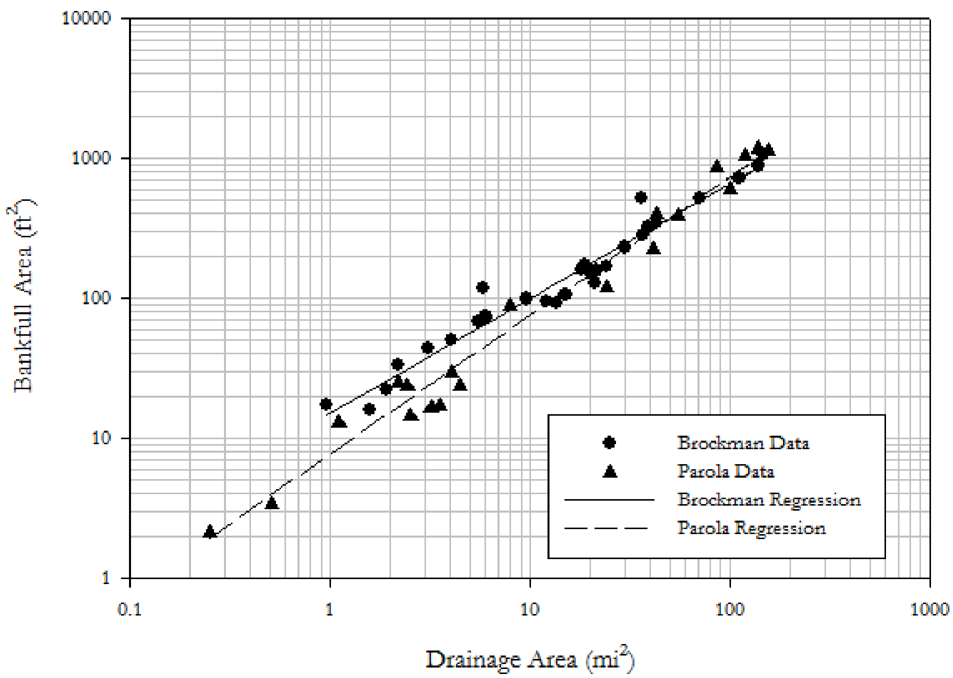

Figure 4.22 Comparison of Bankfull Area Regional Curves of the Combined Region and Parola *et al.* (2007).

Figure 4.23 presents a comparison of the bankfull discharges computed by Parla et al (2007) and the combined region. The plot of bankfull discharge versus drainage area shows a relationship between the regression equations developed for the combined region and by Parola *et al.* (2007). The statistical comparison of the data shows a relationship as well with a p-value of 0.3015. It is surprising that the regression relationships from the two studies show statistical similarities. The bankfull discharges presented in the study by Parola et al (2007) were compiled in a few different ways. Three were based on a staff gage reading used with data from the USGS ratings depot, two were based on bankfull flow events, and the other ten were modeled using HEC-RAS. When the measured and modeled discharges from the study by Parola *et al.* (2007) are separated, there is a difference in regression equations that would result. Figure 4.24 is a graph of the separated data. The regression equation for the modeled data produces an exponent of 1.0753. This exponent is unexpected. Because the bankfull depths measured (and consequently the bankfull areas) for the studies show statistical differences, it is suspicious that the discharges are similar.

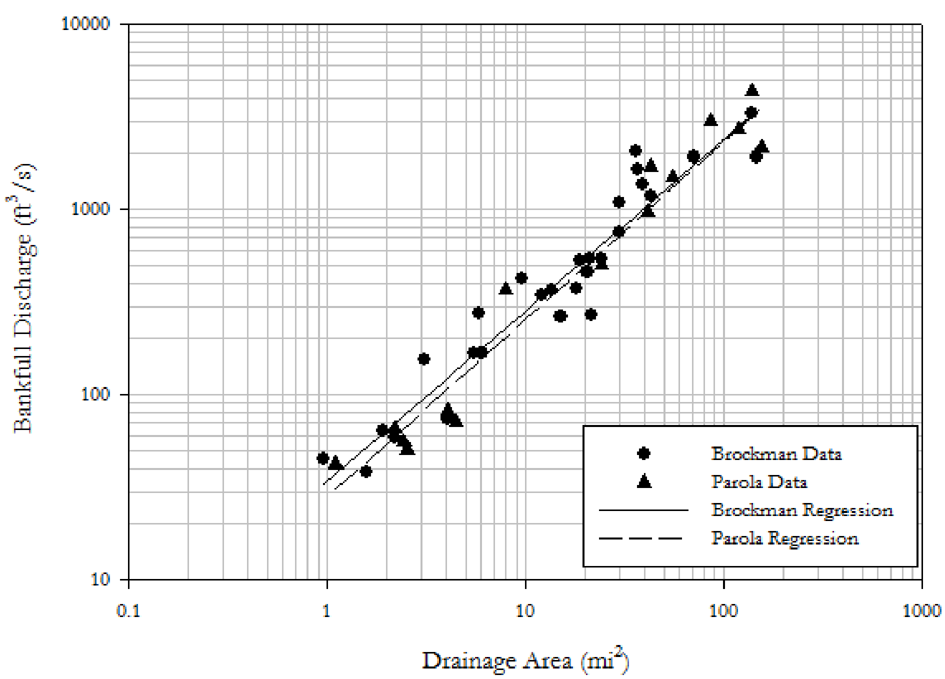

Figure 4.23 Comparison of Bankfull Discharge Regional Curves of the Combined Region and Parola *et al.* (2007).

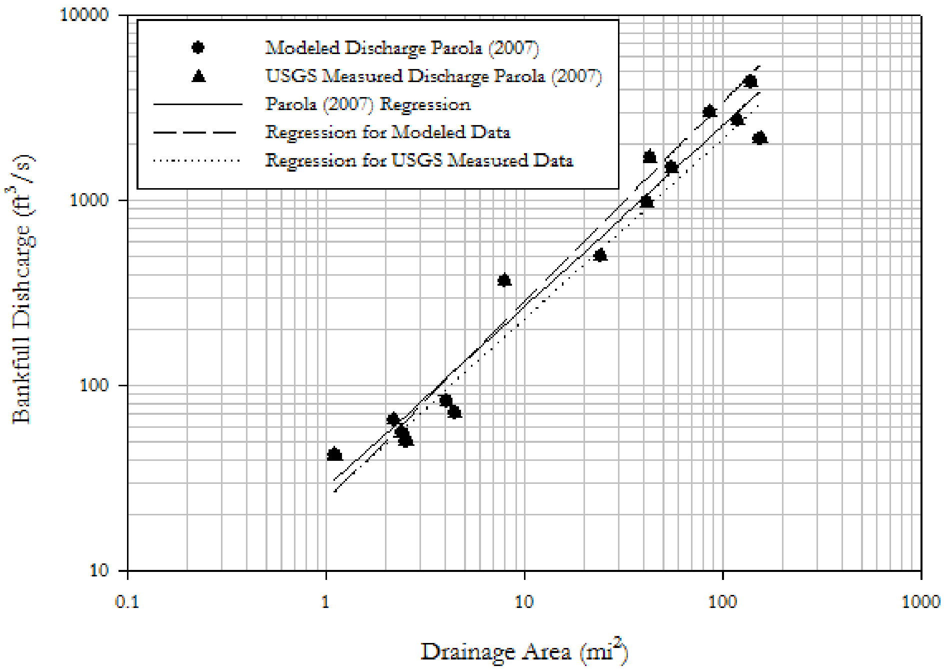

Table 4.24 Comparison of Modeled and Measured Bankfull Discharges for Parola *et al.* (2007).

4.2.5.3 Regional Curves Separated by Stream Type

One way of refining values developed for regional curves is to separate them by stream type (Rosgen, 1994). The regional curves developed in this study were not improved by separating them into stream type (E, C and B). The majority of streams included in this study classified as C type streams in the Rosgen Classification System. Their data were plotted separately. The data separation did not improve the predictability of the equations. This may be because there were only three E type channels to separate from the data, and all B type channels were actually Bc type channels.

4.3 Return Interval Analysis

The bankfull return intervals were calculated for all 28 sites which had bankfull discharge data; the exception was 03288000 N. Elkhorn near Georgetown (inactive gage without field staff gage). The values for these calculations, as well as the 1.5-year discharge, are presented in Table 4.16. The 1.5-year discharge allows for a comparison of the return periods computed in this study with those of the average return period for the U.S. as defined by Leopold *et al.* (1964). The average return interval for the Combined Bluegrass Regions is 0.94 years or 11.3 months; the Inner Bluegrass Region has an average of 1.04 years and the Outer Bluegrass has an average of 0.86 years or 10.3 months. These values are lower than the average return period of 1.5 years found in other studies (Miller and Davis, 2003).

Table 4.16 Bankfull Return Intervals and 1.5 Year Discharge for Inner and Outer Bluegrass Sites.

UGS Gage Number	Site	Bankfull Return Period (years)	Q_{bkf} (ft^3/s)	$Q_{1.5}$ (ft^3/s)
03284525	East Hickman Creek Tributary at Chilesburg Road near Lexington	1.0253	45	142
03284520	East Hickman Creek at Andover Village near Cadentown	0.9381	38	139
03287580	North Elkhorn Creek at Man O War Blvd near Cadentown	1.0581	59	113
03288500	Cave Creek near Fort Springs	1.2735	63.6	79
03287590	North Elkhorn Creek on Winchester near Lexington	0.9291	74	313
03289193	Wolf Run at Old Frankfort Pike, Lexington	0.9359	420	1415
03284530	East Hickman Creek at Delong Road near East Hickman	1.0112	265	783
03284555	West Hickman Creek at Ash Grove Pike near East Hickman	0.9001	454	2053
03287600	North Elkhorn at Bryan Station Road near Montrose	0.9462	269	1712
03289000	South Elkhorn Creek at Fort Springs	1.1668	544	791

Table 4.16 (continued)

UGS Gage Number	Site	Bankfull Return Period (years)	Q_{bkf} (ft³/s)	$Q_{1.5}$ (ft³/s)
03289200	Town Branch at Yarnallton Rd at Yarnallton	1.1534	1080	1906
03291000	Eagle Creek at Sadieville	1.2386	1180.1	2128
03288000	North Elkhorn Creek near Georgetown	-[3]	-	4635
03288100	North Elkhorn at Georgetown	0.9963	1910	4637
03238772[1]	Fourmile Creek at Polar Bridge near Alexandria	0.9083	154	439
03254400	North Fork Grassy Creek near Piner	0.9042	363.1	1845
03254480[1]	Cruises Creek at Highway 17 near Piner	0.7722	375	5533
03262001[2]	Woolper Creek at Woolper Road near Burlington	0.6336	540	3741
03254550	Banklick Creek at Highway 1829 near Erlanger	0.8803	749	4602
03277075	Gunpowder Creek at Camp Ernst Road near Union	0.3509	1640	4299
03238745[1]	Twelvemile Creek at Highway 1997 near Alexandria	0.4336	1350	4616
03298135	Chenoweth Run at Ruckriegel Parkway	0.9656	167	938
03292480	Little Goose near Harrods Creek	1.1480	272	439
03292474	Goose Creek at Old Westport Road near St Matthews	1.0901	167	448
03297800[2]	Cedar Creek at Highway 1442 near Shepherdsville	1.0155	343	1851
03293000	Middle Fork Beargrass Creek at Old Cannons Lane at Louisville	1.2310	529	856
03277130	Mud Lick at Highway 42 near Beaverlick	0.4999	2040	7260
03292470	Harrods Creek at Highway 329 near Goshen	1.0404	1910	5883
03298000	Floyd's Fork at Fisherville	0.9693	3270	4243

[1] represents a site with 9 years of USGS data collected
[2] represents a site with 8 years of USGS data collected
[3] represents an inactive site with no staff gage on site

The bankfull discharges are less than half of the calculated 1.5 year discharge; the Inner Bluegrass averaging 41% of the 1.5 year discharge, and the Outer Bluegrass averaging 33% of the 1.5 year discharge. Practitioners working in the Inner and Outer Bluegrass Regions found similar return periods (personal communication, George Athanasakes of Stantec Consulting, Inc., May 5, 2010). The bankfull discharges and their corresponding return periods found for the Inner and Outer Bluegrass play a significant role in the design of a channel. The recommended design at the 1.5-year return interval would be an over-estimate for the Bluegrass Region. The difference in the bankfull discharge and the 1.5-year discharge also implicates that the effective Manning's n is at a lower flow than the 1.5-year discharge.

4.4 Urbanization and Vegetation Influence Analysis

The stability of streams was determined in large part by field analysis and then by calculating the BHR from cross-section data. The majority of streams included in this study have a high percentage of trees lining the banks; the only two that do not were site number 03284520 East Hickman Creek at Andover Village near Cadentown, KY and site number 03288500 Cave Creek near Fort Springs, KY. Hession *et al.* (2003) conducted a study in the Piedmont region of Pennsylvania, northern Maryland, and Delaware and found that vegetation had an equal influence on channel morphology as watershed land use. Their study included 26 paired reaches where all factors except riparian vegetation were held constant. This study was able to show that "riparian vegetation is able to exert a strong control on channel size regardless of the level of urbanization" (Hession *et al.*, 2003).

While many of the sites, especially in the Inner Bluegrass, had greater than 10% impervious cover (determined from 2001 data), this was not seen to influence the stream's stability at the surveyed locations. Note while the upstream and downstream reaches of the streams were walked, in reference to the USGS gage, the entire stream network was not walked. For six of the streams included in the study, the historical rating's depot curves were examined. Only six sites were examined at the request of the USGS as considerable effort was involved in compiling historical rating curves. The steams in the Inner Bluegrass included were: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown with 3.2% impervious cover and 03289193 Wolf Run at Old Frankfort Pike, Lexington with 29.6% impervious cover. The streams in the Outer Bluegrass included were: 03254480 Cruises Creek at Highway 17 near Piner with 1.2% impervious cover, 03277075 Gunpowder Creek at Camp Ernst Road near Union with 16.7% impervious, 03292470 Harrods Creek at Highway 329 near Goshen with 1.4% impervious cover and 03298135 Chenoweth Run at Ruckriegel Parkway with 33.9% impervious cover. Figures 4.25 through 4.30 present the ratings depot data.

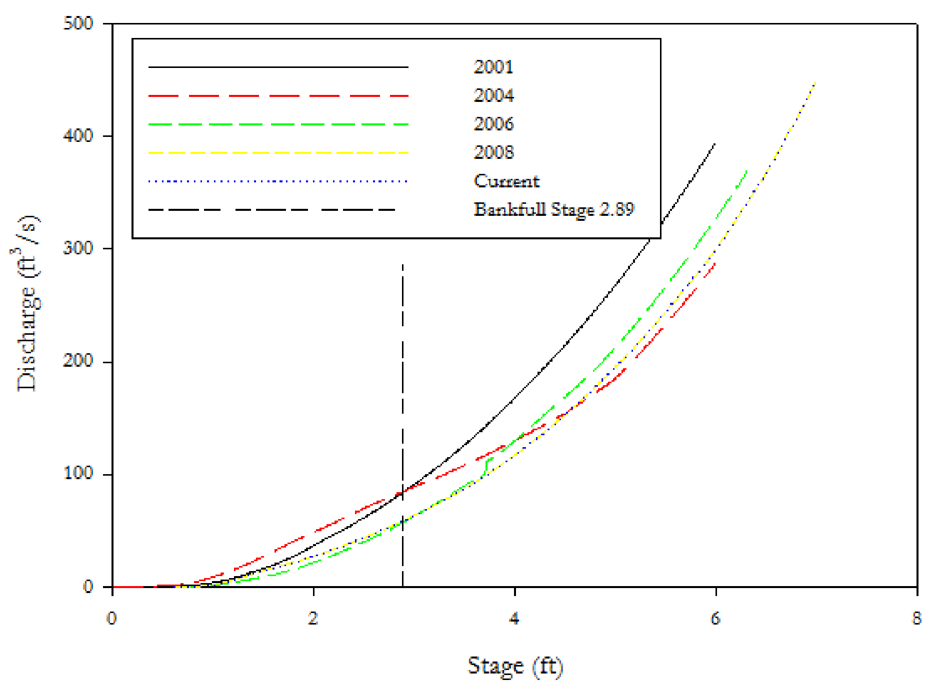

Figure 4.25 Rating's Depot Curve Comparison for 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown.

In the Inner Bluegrass, the graphs for the North Elkhorn on Man O War (Figure 4.24) and Wolf Run (Figure 4.25) show no significant changes in the stage-discharge relationships; they do show improvements in data however. The North Elkhorn on Man O War is situated close to the development of Hamburg Pavilion. This development does not show a significant change in the ratings depot curves for this location. The reach included in the study has tree-lined banks; these provide stability for the channel. The curves for Wolf Run also show no significant change. The watershed for Wolf Run is above the 10% impervious threshold, but this does not seem to have an influence on the stage-discharge curves for this stream. Both of these streams have tree-lined banks.

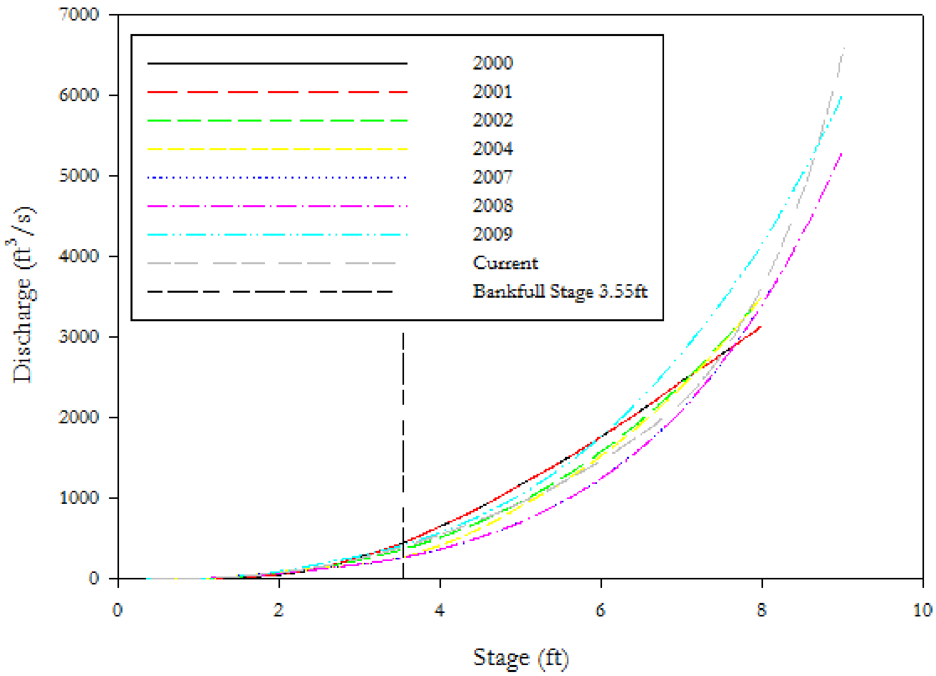

Figure 4.26 Rating's Depot Curve Comparison for 03289193 Wolf Run at Old Frankfort Pike, Lexington.

In the Outer Bluegrass, two streams with low impervious cover were examined via their ratings depot curves: Cruises Creek (Figure 4.26) and Harrods Creek (Figure 4.27) with 1.2% and 1.4% impervious cover respectively. The banks of these streams are lined with trees providing strong riparian vegetation. The rating's depot curves for Cruises Creek show a shift from 2005 to 2008 which may indicate a shift in the channel. The bankfull stage, however is lower than this shift, as depicted in Figure 4.26; a greater stage is required to produce the same discharge, so there was not concern about the impervious effects.

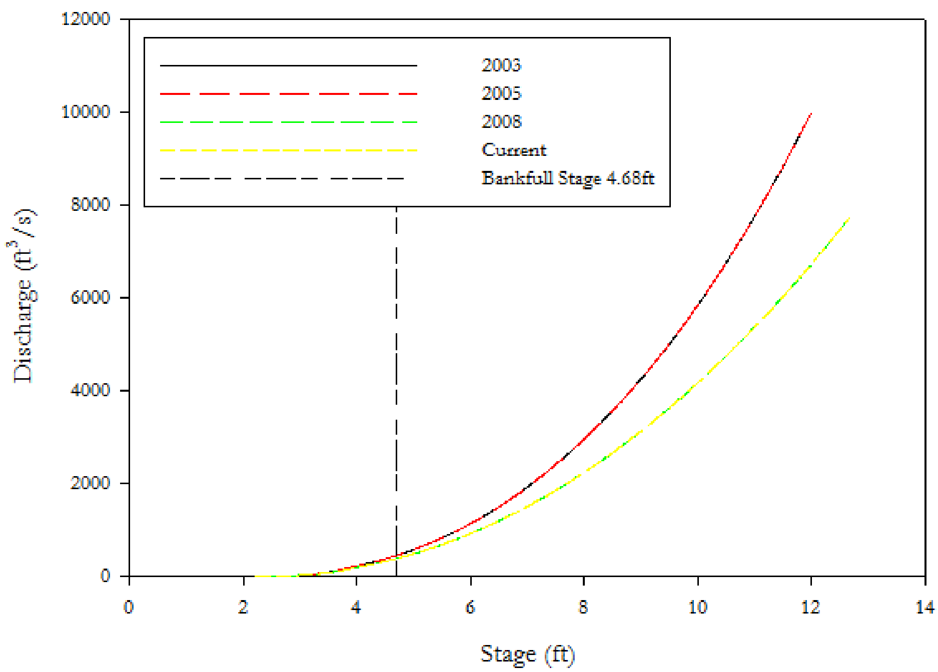

Figure 4.27 Rating's Depot Curve Comparison for 03254480 Cruises Creek at Highway 17 near Piner.

The other curves in the Outer Bluegrass, Gunpowder Creek (Figure 4.29) and Chennoweth Run (Figure 4.28), have shifts in the rating's depot curves as well. The reaches included in this study have tree-lined banks and the bankfull stage is lower than the shifts. This does not cause concern for the impervious effects on the channel at bankfull.

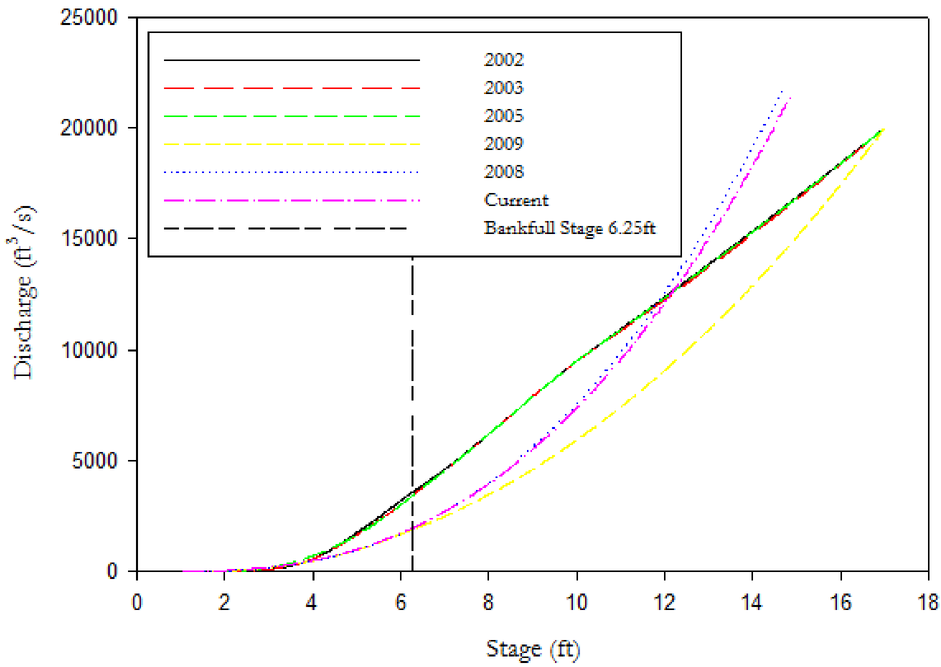

Figure 4.28 Rating's Depot Curve Comparison for 03292470 Harrods Creek at Highway 329 near Goshen.

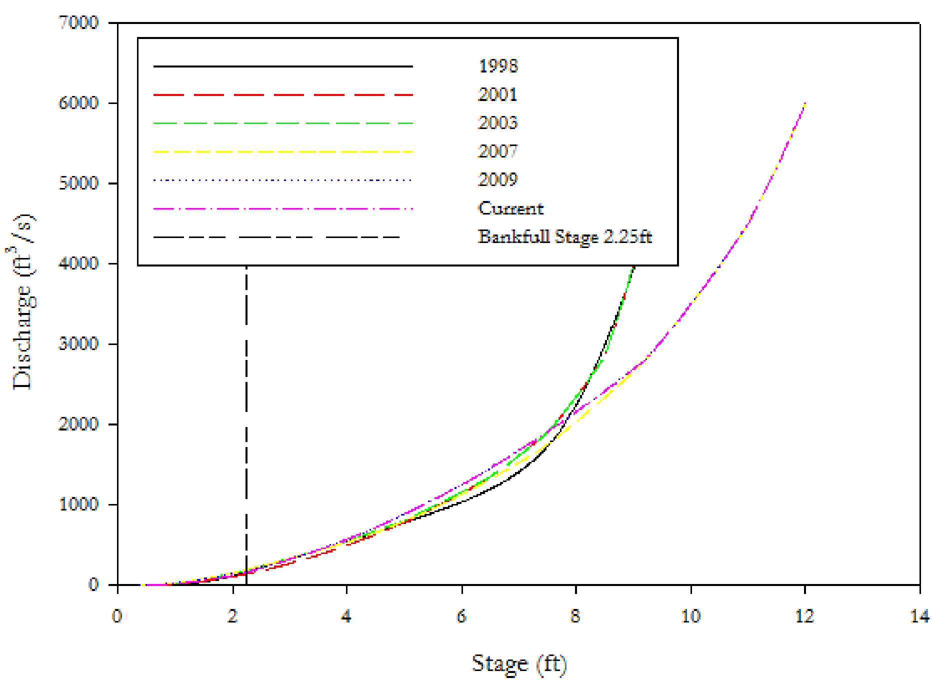

Figure 4.29 Rating's Depot Curve Comparison for 03298135 Chenoweth Run at Ruckriegel Parkway.

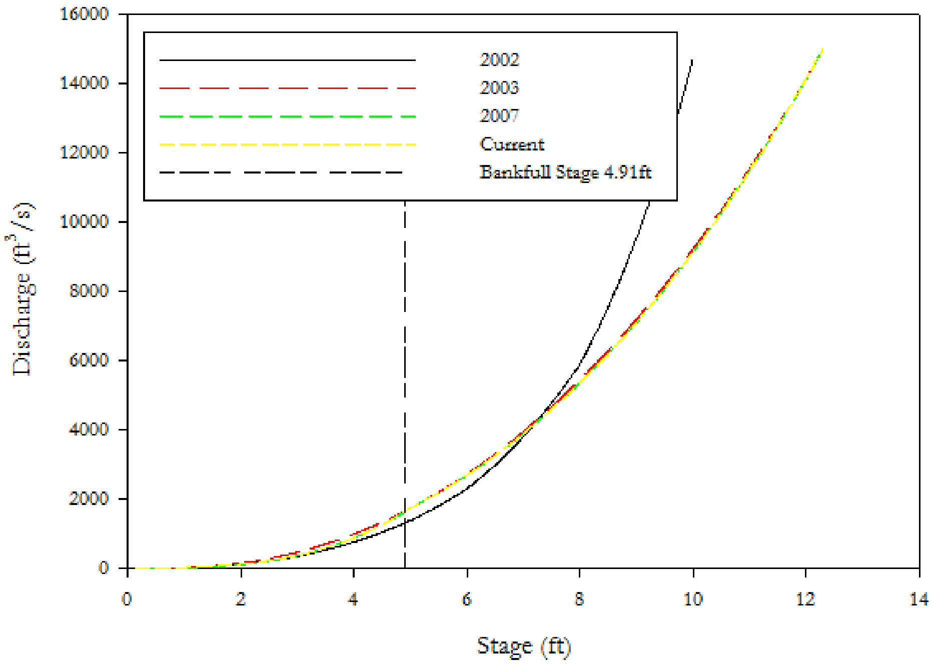

Figure 4.30 Rating's Depot Curve Comparison for 03277075 Gunpowder Creek at Camp Ernst Road.

The historic ratings depot curves plotted with the current ratings depot curve information suggests that the streams in the study maintain stability despite the amount of impervious cover.

Chapter 5: Conclusions

5.0 Conclusions

Twenty nine stream reaches were surveyed to determine their bankfull dimensions and bankfull discharge. From these data, regional curves and hydraulic geometry relationships were developed for the Inner and Outer Bluegrass regions in Kentucky. The regional curves significant relationships between bankfull parameters, such as cross-sectional area, width, depth and drainage area; R^2 values were 0.92, 0.94 and 0.90 respectively[ca1]. The hydraulic geometry relationships also show a significant relationship between bankfull parameters, such as cross-sectional area and width, and bankfull discharge; R^2 values for the hydraulic geometry relationships were as high as 0.95.

Engineers, specifically those involved in stream restoration, can use the relationships in practice to assist in the identification of bankfull and to aid in preliminary design efforts of determining bankfull channel dimensions. The regional curves developed in this study do not replace the need for field verification of bankfull stream channel dimensions.

Future work is recommended to determine the effects of vegetation in the Inner and Outer Bluegrass on karst versus non-karst areas. The influence vegetation asserts on a channel can overcome the effects of urbanization, but the morphology of a channel could possibly change, regardless of vegetation type, within karst influenced watersheds.

Appendix A: Cross Section Summary

Table A.1 Classification Data: 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	13.92	ft
D_{bkf}	1.24	ft
W_{fpa}	45	ft
D_{50}	4.5	mm
Slope	0.0063	ft/ft
Sinuosity	1.16	
Q_{bkf}	45	ft^3/s
V_{bkf}	2.92	ft/s
A_{bkf}	17.26	ft^2
ER	3.23	
W/D Ratio	11.23	
Rosgen Stream Type	E1	

Table A.2 Classification Data: 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	13.53	ft
D_{bkf}	1.18	ft
W_{fpa}	34	ft
D_{50}	15.2	mm
Slope	0.0058	ft/ft
Sinuosity	1.45	
Q_{bkf}	38	ft^3/s
V_{bkf}	2.38	ft/s
A_{bkf}	15.98	ft^2
ER	2.51	
W/D Ratio	11.47	
Rosgen Stream Type	E1	

Table A.3 Classification Data: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	19.5	ft
D_{bkf}	1.7	ft
W_{fpa}	50	ft
D_{50}	30.1	mm
Slope	0.0073	ft/ft
Sinuosity	1.33	
Q_{bkf}	59	ft^3/s
V_{bkf}	1.78	ft/s
A_{bkf}	33.09	ft^2
ER	2.56	
W/D Ratio	11.47	
Rosgen Stream Type	E4/1	

Table A.4 Classification Data: 03288500 Cave Creek near Fort Springs, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	17.45	ft
D_{bkf}	1.27	ft
W_{fpa}	67	ft
D_{50}	38.5	mm
Slope	0.0074	ft/ft
Sinuosity	1.16	
Q_{bkf}	63.3	ft^3/s
V_{bkf}	2.85	ft/s
A_{bkf}	22.2	ft^2
ER	3.84	
W/D Ratio	13.74	
Rosgen Stream Type	C4/1	

Table A.5 Classification Data: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	27.88	ft
D_{bkf}	1.62	ft
W_{fpa}	77.02	ft
D_{50}	30.83	mm
Slope	0.0046	ft/ft
Sinuosity	1.33	
Q_{bkf}	74	ft^3/s
V_{bkf}	1.47	ft/s
A_{bkf}	45.28	ft^2
ER	2.76	
W/D Ratio	17.21	
Rosgen Stream Type	C4/1	

Table A.6 Classification Data: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	38.07	ft
D_{bkf}	2.59	ft
W_{fpa}	100	ft
D_{50}	104.07	mm
Slope	0.005	ft/ft
Sinuosity	1.22	
Q_{bkf}	420	ft^3/s
V_{bkf}	4.27	ft/s
A_{bkf}	98.47	ft^2
ER	2.63	
W/D Ratio	14.7	
Rosgen Stream Type	C3/1	

Table A.7 Classification Data: 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	37.74	ft
D_{bkf}	2.82	ft
W_{fpa}	100	ft
D_{50}	53.4	mm
Slope	0.0025	ft/ft
Sinuosity	2.41	
Q_{bkf}	265	ft^3/s
V_{bkf}	2.49	ft/s
A_{bkf}	106.44	ft^2
ER	2.65	
W/D Ratio	13.38	
Rosgen Stream Type	C1/1	

Table A.8 Classification Data: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	58.51	ft
D_{bkf}	2.54	ft
W_{fpa}	350	ft
D_{50}	144.25	mm
Slope	0.0034	ft/ft
Sinuosity	1.77	
Q_{bkf}	454	ft^3/s
V_{bkf}	3.05	ft/s
A_{bkf}	148.64	ft^2
ER	5.98	
W/D Ratio	23.04	
Rosgen Stream Type	C3/1	

Table A.9 Classification Data: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	56.59	ft
D_{bkf}	2.78	ft
W_{fpa}	150	ft
D_{50}	62.3	mm
Slope	0.0032	ft/ft
Sinuosity	1.38	
Q_{bkf}	269	ft^3/s
V_{bkf}	1.71	ft/s
A_{bkf}	157.57	ft^2
ER	2.65	
W/D Ratio	20.36	
Rosgen Stream Type	C1	

Table A.10 Classification Data: 03289000 South Elkhorn Creek at Fort Springs, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	54.23	ft
D_{bkf}	2.34	ft
W_{fpa}	79.78	ft
D_{50}	194	mm
Slope	0.0028	ft/ft
Sinuosity	1.79	
Q_{bkf}	544	ft^3/s
V_{bkf}	4.29	ft/s
A_{bkf}	126.76	ft^2
ER	1.47	
W/D Ratio	23.18	
Rosgen Stream Type	B3/1c	

Table A.11 Classification Data: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	71.96	ft
D_{bkf}	3.27	ft
W_{fpa}	200	ft
D_{50}	130.74	mm
Slope	0.0029	ft/ft
Sinuosity	2.14	
Q_{bkf}	1080	ft^3/s
V_{bkf}	4.58	ft/s
A_{bkf}	235.59	ft^2
ER	2.78	
W/D Ratio	22.01	
Rosgen Stream Type	C3/1	

Table A.12 Classification Data: 03291000 Eagle Creek at Sadieville, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	85.91	ft
D_{bkf}	4.03	ft
W_{fpa}	200	ft
D_{50}	6.21	mm
Slope	0.0016	ft/ft
Sinuosity	3.34	
Q_{bkf}	1180	ft^3/s
V_{bkf}	3.41	ft/s
A_{bkf}	346	ft^2
ER	2.33	
W/D Ratio	21.32	
Rosgen Stream Type	C4	

Table A.13 Classification Data: 03288000 North Elkhorn Creek near Georgetown, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	117.66	ft
D_{bkf}	6.17	ft
W_{fpa}	275	ft
D_{50}	79.17	mm
Slope	0.0008	ft/ft
Sinuosity	3.09	
Q_{bkf}	-	ft^3/s
V_{bkf}	-	ft/s
A_{bkf}	726.46	ft^2
ER	2.34	
W/D Ratio	19.07	
Rosgen Stream Type	C3/1c-	

Table A.14 Classification Data: 03288100 North Elkhorn Creek at Georgetown, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	125.57	ft
D_{bkf}	8.4	ft
W_{fpa}	300	ft
D_{50}	-	mm
Slope	0.0006	ft/ft
Sinuosity	3.09	
Q_{bkf}	1910	ft^3/s
V_{bkf}	1.81	ft/s
A_{bkf}	1054.81	ft^2
ER	2.39	
W/D Ratio	14.95	
Rosgen Stream Type	C1c-	

Table A.15 Classification Data: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	26.08	ft
D_{bkf}	1.68	ft
W_{fpa}	50	ft
D_{50}	60.65	mm
Slope	0.0184	ft/ft
Sinuosity	1.03	
Q_{bkf}	154	ft^3/s
V_{bkf}	3.51	ft/s
A_{bkf}	43.91	ft^2
ER	1.92	
W/D Ratio	15.52	
Rosgen Stream Type	B4c	

Table A.16 Classification Data: 03254400 North Fork Grassy Creek near Piner, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	42.66	ft
D_{bkf}	2.16	ft
W_{fpa}	150	ft
D_{50}	-	mm
Slope	0.0056	ft/ft
Sinuosity	1.56	
Q_{bkf}	363.1	ft^3/s
V_{bkf}	3.94	ft/s
A_{bkf}	92.08	ft^2
ER	3.52	
W/D Ratio	19.75	
Rosgen Stream Type	C1	

Table A.17 Classification Data: 03254480 Cruises Creek at Highway 17 near Piner, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	51.79	ft
D_{bkf}	3.07	ft
W_{fpa}	100	ft
D_{50}	59.53	mm
Slope	0.0056	ft/ft
Sinuosity	1.76	
Q_{bkf}	375	ft^3/s
V_{bkf}	2.36	ft/s
A_{bkf}	158.91	ft^2
ER	1.93	
W/D Ratio	16.87	
Rosgen Stream Type	B4c	

Table A.18 Classification Data: 03262001 Woolper Creek at Woolper Road near Burlington, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	60.2	ft
D_{bkf}	2.83	ft
W_{fpa}	89.32	ft
D_{50}	45.5	mm
Slope	0.0071	ft/ft
Sinuosity	1.31	
Q_{bkf}	540	ft^3/s
V_{bkf}	3.17	ft/s
A_{bkf}	170.09	ft^2
ER	1.48	
W/D Ratio	21.27	
Rosgen Stream Type	B4c	

Table A.19 Classification Data: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	72.06	ft
D_{bkf}	3.2	ft
W_{fpa}	200	ft
D_{50}	83.07	mm
Slope	0.0051	ft/ft
Sinuosity	1.83	
Q_{bkf}	749	ft^3/s
V_{bkf}	3.25	ft/s
A_{bkf}	230.79	ft^2
ER	2.78	
W/D Ratio	22.52	
Rosgen Stream Type	C3	

Table A.20 Classification Data: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	78.7	ft
D_{bkf}	3.19	ft
W_{fpa}	200	ft
D_{50}	84.8	mm
Slope	0.0035	ft/ft
Sinuosity	1.67	
Q_{bkf}	1310	ft^3/s
V_{bkf}	5.22	ft/s
A_{bkf}	250.94	ft^2
ER	2.54	
W/D Ratio	24.67	
Rosgen Stream Type	C3	

Table A.21 Classification Data: 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	84.05	ft
D_{bkf}	3.81	ft
W_{fpa}	200	ft
D_{50}	131.71	mm
Slope	0.0025	ft/ft
Sinuosity	1.26	
Q_{bkf}	1350	ft^3/s
V_{bkf}	4.22	ft/s
A_{bkf}	320.06	ft^2
ER	2.38	
W/D Ratio	22.06	
Rosgen Stream Type	C3/1	

Table A.22 Classification Data: 03298135 Chenoweth Run at Ruckriegal Parkway, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	44.44	ft
D_{bkf}	1.53	ft
W_{fpa}	100	ft
D_{50}	45	mm
Slope	0.0053	ft/ft
Sinuosity	1.24	
Q_{bkf}	167	ft^3/s
V_{bkf}	2.5	ft/s
A_{bkf}	67.98	ft^2
ER	2.25	
W/D Ratio	29.05	
Rosgen Stream Type	C1	

Table A.23 Classification Data: 03292480 Little Goose near Harrods Creek, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	44.77	ft
D_{bkf}	2.61	ft
W_{fpa}	150	ft
D_{50}	82.8	mm
Slope	0.0061	ft/ft
Sinuosity	1.07	
Q_{bkf}	272	ft^3/s
V_{bkf}	2.33	ft/s
A_{bkf}	116.74	ft^2
ER	3.35	
W/D Ratio	17.15	
Rosgen Stream Type	C1	

Table A.24 Classification Data: 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	31.2	ft
D_{bkf}	2.34	ft
W_{fpa}	100	ft
D_{50}	56.4	mm
Slope	0.0053	ft/ft
Sinuosity	1.35	
Q_{bkf}	167	ft^3/s
V_{bkf}	2.29	ft/s
A_{bkf}	73	ft^2
ER	3.21	
W/D Ratio	13.33	
Rosgen Stream Type	C1	

Table A.25 Classification Data: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	41.46	ft
D_{bkf}	2.3	ft
W_{fpa}	51.64	ft
D_{50}	47.71	mm
Slope	0.005	ft/ft
Sinuosity	1.35	
Q_{bkf}	343	ft^3/s
V_{bkf}	3.6	ft/s
A_{bkf}	95.26	ft^2
ER	1.25	
W/D Ratio	18.03	
Rosgen Stream Type	B4c	

Table A.26 Classification Data: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	54.01	ft
D_{bkf}	3.18	ft
W_{fpa}	150	ft
D_{50}	39.6	mm
Slope	0.0037	ft/ft
Sinuosity	1.1	
Q_{bkf}	529	ft^3/s
V_{bkf}	3.08	ft/s
A_{bkf}	171.72	ft^2
ER	2.78	
W/D Ratio	16.98	
Rosgen Stream Type	C1	

Table A.27 Classification Data: 03277130 Mud Lick at Highway 42 near Beaverlick, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	88.35	ft
D_{bkf}	4.47	ft
W_{fpa}	200	ft
D_{50}	78.7	mm
Slope	0.0053	ft/ft
Sinuosity	1.52	
Q_{bkf}	813	ft^3/s
V_{bkf}	2.06	ft/s
A_{bkf}	395.31	ft^2
ER	2.26	
W/D Ratio	19.77	
Rosgen Stream Type	C3	

Table A.28 Classification Data: 03292470 Harrods Creek at Highway 329 near Goshen, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	92.25	ft
D_{bkf}	5.59	ft
W_{fpa}	150	ft
D_{50}	-	mm
Slope	0.0023	ft/ft
Sinuosity	1.51	
Q_{bkf}	1910	ft^3/s
V_{bkf}	3.7	ft/s
A_{bkf}	515.87	ft^2
ER	1.63	
W/D Ratio	16.5	
Rosgen Stream Type	B1c	

Table A.29 Classification Data: 03298000 Floyd's Fork at Fisherville, KY.

Bankfull Parameter	Bankfull Dimension	
W_{bkf}	124.72	ft
D_{bkf}	7.09	ft
W_{fpa}	350	ft
D_{50}	87.2	mm
Slope	0.001	ft/ft
Sinuosity	2.01	
Q_{bkf}	3270	ft^3/s
V_{bkf}	3.7	ft/s
A_{bkf}	883.99	ft^2
ER	2.81	
W/D Ratio	17.59	
Rosgen Stream Type	C1	

Table A.30 Survey Data: 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY (all elevations relative to BS elevation = 100ft).

STA	FS (ft)	Elevation (ft)	Note
0	4.125	195.88	
1	4.14	195.86	
2	4.08	195.92	
3	4.025	195.98	
4	4.01	195.99	
5	4.06	195.94	
6	3.96	196.04	
7	4.06	195.94	
8	3.95	196.05	
9	3.95	196.05	
10	3.9	196.1	
11	3.885	196.12	
12	3.86	196.14	
13	3.85	196.15	
14	3.92	196.08	
15	3.94	196.06	

Table A.30 (continued)

STA	FS (ft)	Elevation (ft)	Note
15.5	3.96	196.04	
15.8	4.04	195.96	
16	4.09	195.91	
16.3	4.12	195.88	
16.65	4.29	195.71	
16.8	4.41	195.59	
17	4.46	195.54	
17.3	4.57	195.43	
17.6	4.75	195.25	
18	5.17	194.83	
18.5	5.89	194.11	
18.8	6.26	193.74	LEW
19	6.22	193.78	
19.5	6.35	193.65	
20	6.355	193.65	
20.5	6.34	193.66	
21	6.33	193.67	
21.5	6.32	193.68	
22	6.32	193.68	
22.5	6.31	193.69	
23	6.3	193.7	
23.5	6.27	193.73	
24	6.26	193.74	
24.5	6.27	193.73	
25	6.27	193.73	
25.5	6.27	193.73	
26	6.28	193.72	
26.5	6.29	193.71	
27	6.31	193.69	
27.5	6.32	193.68	
28	6.36	193.64	
28.5	6.38	193.62	
29	6.38	193.62	
29.5	6.37	193.63	
30	6.38	193.62	TW
30.45	6.15	193.85	REW
30.8	5.785	194.22	
31.1	5.265	194.74	

Table A.30 (continued)

STA	FS (ft)	Elevation (ft)	Note
31.4	5.045	194.96	
31.7	4.94	195.06	BKF
31.9	4.8	195.2	
32.1	4.72	195.28	
32.3	4.64	195.36	FP
32.6	4.63	195.37	
33	4.61	195.39	
33.5	4.56	195.44	
34	4.585	195.42	
35	4.565	195.44	
36	4.55	195.45	
37	4.5	195.5	
38	4.49	195.51	
39	4.34	195.66	
40	4.245	195.76	
41	4.245	195.76	
42	4.17	195.83	
43	4.06	195.94	
44	4.03	195.97	
45	3.86	196.14	

Table A.31 Survey Data: 03284520 East Hickman Creek at Andover Village near Cadentown, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	6.43	193.57	
1	6.43	193.57	
2	6.48	193.52	
3	6.565	193.44	
4	6.66	193.34	
5	6.83	193.17	
6	6.86	193.14	
7	6.85	193.15	BKF
8	6.93	193.07	
8.3	6.99	193.01	
8.6	7.02	192.98	
8.9	7.08	192.92	

Table A.31 (continued)

STA	FS (ft)	Elevation (ft)	Note
9.1	7.19	192.81	
9.4	7.44	192.56	
9.8	8.13	191.87	
10.1	8.35	191.65	LEW
10.5	8.4	191.6	
11	8.52	191.48	
11.5	8.53	191.47	
12	8.56	191.44	
12.6	8.615	191.39	
13.1	8.72	191.28	
13.5	8.7	191.3	
14	8.565	191.44	
14.5	8.715	191.29	
15	8.665	191.34	
15.5	8.55	191.45	
16.2	8.69	191.31	
16.9	8.565	191.44	
17.6	8.67	191.33	
18	8.58	191.42	
18.4	8.13	191.87	
18.6	7.545	192.46	
19.1	6.98	193.02	
19.2	6.845	193.16	BKF
19.6	6.75	193.25	
20	6.7	193.3	
21	6.55	193.45	
22	6.39	193.61	
23	6.23	193.77	
24	6.08	193.92	
25	5.98	194.02	
26	5.82	194.18	
27	5.69	194.31	
28	5.625	194.38	
29	5.51	194.49	
30	5.38	194.62	
31	5.27	194.73	
32	5.205	194.8	
33	5.075	194.93	

Table A.31 (continued)

STA	FS (ft)	Elevation (ft)	Note
34	4.98	195.02	

Table A.32 Survey Data: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.47	195.53	
3	4.32	195.68	
6	4.35	195.65	
8	4.62	195.38	
9.5	4.73	195.27	FP
11	5.24	194.76	BKF
11.6	5.61	194.39	
12.3	5.86	194.14	
13.3	6.41	193.59	
14.3	7.41	192.59	REW
15.5	7.47	192.53	
16.5	7.48	192.52	
17.5	7.46	192.54	
18.5	7.48	192.52	TW
19.5	7.4	192.6	WS0.24
20.5	7.4	192.6	
21.5	7.42	192.58	
22.5	7.34	192.66	
23.5	7.4	192.6	
24.5	7.37	192.63	
25.6	7.28	192.72	LEW
26.6	6.95	193.05	
27.6	6.59	193.41	
29	6.07	193.93	
29.8	5.55	194.45	
30.5	5.24	194.76	BKF
30.8	5.01	194.99	
31.6	4	196	
32.3	3.48	196.52	
34	3.47	196.53	

Table A.33 Survey Data: 03288500 Cave Creek near Fort Springs, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	0.67	199.33	
2	0.82	199.18	
4	1.02	198.98	
6	1.24	198.76	
8	1.485	198.52	
10	1.95	198.05	
12	2.52	197.48	
14	2.89	197.11	
16	3.27	196.73	
18	3.48	196.52	
20	3.55	196.45	
22	3.67	196.33	
24	4	196	
26.5	4.27	195.73	
27.5	4.23	195.77	
28	4.29	195.71	
29.5	4.64	195.36	
30	4.75	195.25	
30.7	5.1	194.9	
31.6	5.5	194.5	
33	6.91	193.09	REW
33.8	6.75	193.25	
34.8	6.75	193.25	
36	6.69	193.31	
37.3	6.78	193.22	
38.7	6.95	193.05	
39.7	6.79	193.21	
40.8	6.925	193.08	
42	6.85	193.15	
43.2	6.915	193.09	
44.3	7.03	192.97	
45.4	7.15	192.85	TW

Table A.33 (continued)

STA	FS (ft)	Elevation (ft)	Note
47	7.11	192.89	LEW
48.2	6	194	
48.6	5.64	194.36	
49	5.48	194.52	BKF
49.5	5.45	194.55	
50	5.36	194.64	
51	5.1	194.9	
53	4.84	195.16	
55	4.645	195.36	FP
57	4.615	195.39	
59	4.7	195.3	
61	4.72	195.28	
63	4.39	195.61	
65	4.51	195.49	
67	4.36	195.64	
69	4.4	195.6	
71	4.41	195.59	
72	4.45	195.55	

Table A.34 Survey Data: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	1.76	198.24	
1	1.85	198.15	
2	2.18	197.82	
3	2.52	197.48	
4	2.86	197.14	
4.8	3.34	196.66	
5.8	3.87	196.13	
6.8	4.36	195.64	
7.7	4.685	195.32	REW
8.6	4.81	195.19	
10	4.86	195.14	WS0.22
11	4.845	195.16	
12	4.75	195.25	

Table A.34 (continued)

STA	FS (ft)	Elevation (ft)	Note
13	4.75	195.25	
14.4	4.77	195.23	
15.4	4.72	195.28	
16.4	4.8	195.2	
17.4	4.77	195.23	
18.4	4.85	195.15	
19.6	4.925	195.08	
20.6	4.94	195.06	
21.6	4.84	195.16	
22.6	4.945	195.06	
23.6	4.97	195.03	TW
24.6	4.885	195.12	
26	4.72	195.28	LEW
26.8	4.44	195.56	
27.5	3.54	196.46	
28	3.22	196.78	
29	2.98	197.02	
29.5	2.82	197.18	
30	2.66	197.34	
30.5	2.56	197.44	BKF
31	2.47	197.53	
32	2.405	197.6	FP

Table A.35 Survey Data: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	3.14	196.86	
1	3.06	196.94	
2	3.48	196.52	
2.2	3.58	196.42	
2.8	3.63	196.37	
3.8	4.01	195.99	
5	4.47	195.53	BKF
5.9	5.31	194.69	
7.2	7.46	192.54	LEW
8.2	7.37	192.63	
9.7	7.4	192.6	

Table A.35 (continued)

STA	FS (ft)	Elevation (ft)	Note
11	7.46	192.54	
12.1	7.61	192.39	
13.1	7.66	192.34	
14.3	7.66	192.34	TW
15.9	7.43	192.57	
16.7	7.55	192.45	
18.4	7.43	192.57	
19.8	7.34	192.66	
21	7.25	192.75	
22	7.18	192.82	
23	7.12	192.88	
24	7.13	192.87	
25	7.12	192.88	
26	7.03	192.97	
27	7.01	192.99	
28	6.97	193.03	
29	7.01	192.99	
30	6.97	193.03	
31	6.96	193.04	
32	6.99	193.01	
33	7.02	192.98	
34	7.15	192.85	
35	7.29	192.71	
36	7.33	192.67	
37	7.31	192.69	
38	7.34	192.66	
39	7.43	192.57	
40	7.37	192.63	
41	7.03	192.97	REW
41.7	6.39	193.61	
42.4	5.49	194.51	
43	4.58	195.42	BKF
43.4	4.43	195.57	
44	4.38	195.62	
45	4.26	195.74	
46	4.14	195.86	FP
47	4.13	195.87	

Table A.36 Survey Data: 03284530 East Hickman Creek at Delong Road near East Hickman, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.905	195.1	
1	4.985	195.02	
2	5.1	194.9	
3	5.23	194.77	
4	5.39	194.61	
5	5.51	194.49	
6	5.56	194.44	
7	5.62	194.38	
8	5.67	194.33	
9	5.64	194.36	
10	5.66	194.34	
11	5.85	194.15	
11.5	8.26	191.74	
12	8.765	191.24	
12.3	9.72	190.28	
13	9.83	190.17	
14	9.9	190.1	
15	9.935	190.07	
16	9.84	190.16	
17	9.94	190.06	
18	10.045	189.96	
19	10.045	189.96	
20	10.1	189.9	
21	10.19	189.81	
22	10.205	189.8	
23	10.04	189.96	
24	10.21	189.79	
25	10.15	189.85	
26	10.245	189.76	
27	10.27	189.73	
28	10.52	189.48	
29	10.575	189.43	TW
30	10.53	189.47	
31	10.52	189.48	

Table A.36 (continued)

STA	FS (ft)	Elevation (ft)	Note
32	10.43	189.57	
33	10.36	189.64	
34	10.31	189.69	
35	10.36	189.64	
36	10.27	189.73	
37	10.3	189.7	
38	10.25	189.75	
39	10.25	189.75	
40	10.21	189.79	
41	10.12	189.88	
42	10	190	
43	9.905	190.1	
44	9.77	190.23	
45	9.69	190.31	
45.5	9.43	190.57	
45.8	9.27	190.73	REW
46.15	8.98	191.02	
46.4	8.86	191.14	
47.1	8.36	191.64	
47.6	8.13	191.87	
48	7.95	192.05	
48.3	7.64	192.36	
48.7	7.45	192.55	
49	7.12	192.88	BKF
49.4	7.01	192.99	
49.8	6.95	193.05	
50	6.9	193.1	
50.4	6.8	193.2	
50.8	6.65	193.35	
51.2	6.59	193.41	
51.6	6.53	193.47	
52	6.44	193.56	
53	6.36	193.64	
54	6.25	193.75	
55	6.11	193.89	
56	6	194	

Table A.37 Survey Data: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	6.71	193.29	
1	6.81	193.19	
2	6.99	193.01	
3	7.1	192.9	
4	7.105	192.9	
5	7.33	192.67	
6	7.36	192.64	
6.5	7.36	192.64	BKF
7	7.55	192.45	
7.3	7.71	192.29	
7.6	7.79	192.21	
8	7.91	192.09	
8.2	7.98	192.02	
8.5	8.7	191.3	LEW
9	8.96	191.04	
10	9.7	190.3	
11	9.13	190.87	
12	9.1	190.9	
13	9.35	190.65	
14	9.51	190.49	
15	9.78	190.22	
16	9.75	190.25	
17	9.81	190.19	
18	9.845	190.16	
19	9.87	190.13	
20	10.57	189.43	
21	10.61	189.39	
22	10.54	189.46	
23	10.605	189.4	
24	10.69	189.31	
25	10.69	189.31	
26	10.67	189.33	
27	10.69	189.31	
28	10.73	189.27	

Table A.37 (continued)

STA	FS (ft)	Elevation (ft)	Note
29	10.74	189.26	TW
30	10.66	189.34	
31	10.73	189.27	
32	10.67	189.33	
33	10.66	189.34	
34	10.625	189.38	
35	10.57	189.43	
36	10.46	189.54	
37	10.28	189.72	
38	10.2	189.8	
39	9.87	190.13	
40	9.81	190.19	
41.3	9.48	190.52	
42	9.38	190.62	
43	9.45	190.55	
44	9.55	190.45	
45	9.66	190.34	
46	9.9	190.1	
47	10.11	189.89	
48	10.19	189.81	
49	10.17	189.83	
50	10.09	189.91	
51	10.16	189.84	
52	10.19	189.81	
53	10.19	189.81	
54	10.27	189.73	
55	10.17	189.83	
56	10	190	
57	9.93	190.07	
58	9.725	190.28	
59	9.665	190.34	
61.6	9.52	190.48	
62	9.3	190.7	
63	9.26	190.74	
63.5	9.13	190.87	REW
63.85	7.94	192.06	
64.4	7.69	192.31	
64.9	7.425	192.58	

Table A.37 (continued)

STA	FS (ft)	Elevation (ft)	Note
65.4	7.15	192.85	
65.9	6.98	193.02	
66.2	6.76	193.24	
66.8	6.65	193.35	
67	6.63	193.37	
67.5	6.51	193.49	
68	6.36	193.64	
68.3	6.34	193.66	
68.9	6.32	193.68	
69	6.29	193.71	
69.5	6.26	193.74	
70	6.17	193.83	
71	6.11	193.89	
72	6.11	193.89	
73	6.03	193.97	
74	5.83	194.17	
75	5.73	194.27	
76	5.53	194.47	
77	5.45	194.55	
78	5.34	194.66	
79	5.18	194.82	
80	4.97	195.03	

Table A.38 Survey Data: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	3.75	196.25	
1	3.63	196.37	
2	3.56	196.44	
3	3.59	196.41	
4	3.59	196.41	
5	3.63	196.37	
6	3.72	196.28	
7	3.78	196.22	
8	3.84	196.16	

Table A.38 (continued)

STA	FS (ft)	Elevation (ft)	Note
9	3.94	196.06	
10	3.99	196.01	
11	4.1	195.9	
12	4.22	195.78	
13	4.45	195.55	
14	4.86	195.14	
15	5.25	194.75	
15.7	5.5	194.5	
15.8	6.43	193.57	
16.3	6.99	193.01	
16.5	7.14	192.86	
17	7.46	192.54	
17.5	8.27	191.73	
17.7	8.31	191.69	LEW
18	8.63	191.37	
18.5	8.85	191.15	
19	8.9	191.1	
20	9.37	190.63	
20.6	9.45	190.55	
21	10.01	189.99	
22	10.4	189.6	
24	10.35	189.65	
25	10.24	189.76	
26	10.15	189.85	
27	10.22	189.78	
28	10.05	189.95	
29	10.01	189.99	
30	9.99	190.01	
31	9.83	190.17	
32	9.77	190.23	
33	9.67	190.33	
34	9.56	190.44	
35	9.51	190.49	
36	9.54	190.46	
37	9.43	190.57	

Table A.38 (continued)

STA	FS (ft)	Elevation (ft)	Note
38	9.46	190.54	
39	9.46	190.54	
40	9.43	190.57	
41	9.51	190.49	
42	9.53	190.47	
43	9.63	190.37	
44	9.71	190.29	
45	9.81	190.19	
46	9.82	190.18	
47	9.87	190.13	
48	9.97	190.03	
49	10.1	189.9	
50	10.25	189.75	
51	10.33	189.67	
52	10.43	189.57	
53	10.8	189.2	
54	10.94	189.06	
55	11.17	188.83	
56	11.23	188.77	
57	11.46	188.54	
58	11.46	188.54	TW
59	11.2	188.8	
60	11.16	188.84	
61	11.165	188.84	
62	11.04	188.96	
63	10.93	189.07	
64	10.83	189.17	
65	10.39	189.61	
66	10.28	189.72	
67	10.09	189.91	
68	9.83	190.17	
69	9.53	190.47	
70	9.28	190.72	
71	9.1	190.9	
72.2	8.95	191.05	REW
72.3	7.89	192.11	
72.6	7.49	192.51	

Table A.32 (continued)

STA	FS (ft)	Elevation (ft)	Note
72.8	7.35	192.65	
73.2	7.21	192.79	BKF
74	7.2	192.8	
74.5	7.05	192.95	
75	6.94	193.06	
76	6.87	193.13	
77	6.77	193.23	
78	6.62	193.38	
79	6.47	193.53	
80	6.39	193.61	
81	6.28	193.72	
82	6.14	193.86	
83	5.98	194.02	
84	5.68	194.32	
85	5.52	194.48	
86	5.31	194.69	
87	5.265	194.74	
88	5.09	194.91	FP
89	4.86	195.14	
90	5.03	194.97	
91	4.97	195.03	
92	4.83	195.17	
93	4.8	195.2	
94	4.75	195.25	
95	4.81	195.19	
96	4.82	195.18	
97	4.82	195.18	
98	4.84	195.16	
99	4.8	195.2	

Table A.39 Survey Data: 03289000 South Elkhorn Creek at Fort Springs, KY (all elevations relative).

STA	Elevation (ft)	Note
0	103.08474	
11.87	100.97043	BKF
13.83	99.05075	
15.71	98.64284	
22.92	98.1502	
27.97	97.85438	
32.62	97.82779	
36.3	97.85809	
39.65	97.81496	TW
42.26	97.91709	
49.71	98.55233	
53.99	98.76686	
58.51	99.74729	
61.13	100.69582	
66.43	101.04662	BKF
72.41	102.41592	
75.78	103.381	
81.01	104.45957	

Table A.40 Survey Data: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY (all elevations relative).

STA	Elevation (ft)	Note
0	91.0	FP
6.2	86.9	
27.46	86.1	
48.58	86.1	TW
61.7	86.6	
73.26	90.0	BKF
97.53	90.9	
125.55	92.0	

Table A.41 Survey Data: 03291000 Eagle Creek at Sadieville, KY(all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	2.82	197.18	
1	2.905	197.1	
2	3.24	196.76	
3	3.79	196.21	
4	4.29	195.71	
5	4.77	195.23	
6	5.48	194.52	
7	6.06	193.94	
8	6.42	193.58	
9	6.9	193.1	
10	7.33	192.67	
11	7.77	192.23	
12	8.06	191.94	
13	8.81	191.19	
14	9.03	190.97	
15	9.87	190.13	
16	10.24	189.76	
17	10.52	189.48	
18	10.91	189.09	
19	11.29	188.71	

Table A.41 (continued)

STA	FS (ft)	Elevation (ft)	Note
20	11.48	188.52	
21	11.47	188.53	
22	11.68	188.32	
23	11.82	188.18	
24.5	12.21	187.79	
26	12.31	187.69	
27	12.39	187.61	
28	12.64	187.36	
29	12.7	187.3	
30	12.73	187.27	
30.8	12.68	187.32	
32	12.62	187.38	
33	12.59	187.41	
34	12.59	187.41	
35	12.55	187.45	
36	12.55	187.45	
37	12.48	187.52	
38	12.36	187.64	
39	12.13	187.87	
40.3	12.14	187.86	
41	12.19	187.81	
42	12.18	187.82	
43	12.22	187.78	
44	12.265	187.74	
45	12.325	187.68	
46	12.39	187.61	
47	12.46	187.54	
48	12.43	187.57	
49	12.4	187.6	

Table A.41 (continued)

STA	FS (ft)	Elevation (ft)	Note
50	12.42	187.58	
51	12.345	187.66	
52	12.305	187.7	
53	12.225	187.78	
54	12.43	187.57	
55	12.405	187.6	
56	12.445	187.56	
57	12.385	187.62	
58	12.315	187.69	
59	12.23	187.77	
60	12.435	187.57	
61	12.355	187.65	
62	12.495	187.51	
63	12.425	187.58	
65	12.62	187.38	
66	12.52	187.48	
67	12.505	187.5	
68.7	12.6	187.4	
70	12.605	187.4	
71	12.805	187.2	
72	12.785	187.22	
73	12.845	187.16	
74	12.905	187.1	TW
75	12.885	187.12	
76	12.755	187.25	
76.9	12.455	187.55	
78	11.615	188.39	
79	10.975	189.03	
80	10.445	189.56	
81	10.385	189.62	
82	10.335	189.67	
83	10.035	189.97	
84	9.84	190.16	
85	9.635	190.37	
86	9.195	190.81	
87	8.985	191.02	
88	8.825	191.18	

Table A.41 (continued)

STA	FS (ft)	Elevation (ft)	Note
89	8.635	191.37	
90	8.385	191.62	
91	8.255	191.75	
92	7.98	192.02	
93	7.81	192.19	
94	7.7	192.3	
95	7.48	192.52	
96	7.37	192.63	BKF
97.3	6.94	193.06	
98	6.75	193.25	
99	6.46	193.54	
100	6.16	193.84	
101	5.81	194.19	
102	5.455	194.55	
103	5.09	194.91	
104	4.86	195.14	
105	4.67	195.33	
106.2	4.425	195.58	
107	4.345	195.66	
108	4.17	195.83	
109	4.08	195.92	
110	3.97	196.03	
111	3.87	196.13	
112	3.85	196.15	
113	3.81	196.19	
114	3.79	196.21	
115	3.65	196.35	
116	3.69	196.31	
117	3.57	196.43	
117.7	3.56	196.44	

Table A.42 Survey Data: 03288000 North Elkhorn Creek near Georgetown, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.405	195.6	BKF
3	5.125	194.88	
6	5.785	194.22	
9	6.235	193.77	
12	6.92	193.08	

Table A.42 (continued)

STA	FS (ft)	Elevation (ft)	Note
15	7.79	192.21	
18	8.805	191.2	
20.2	9.93	190.07	
20.6	10.62	189.38	LEW
21	11.67	188.33	WS
23	11.925	188.08	
25	11.6	188.4	
27	12.05	187.95	
29	12.02	187.98	
31	11.87	188.13	
33	11.78	188.22	
35	11.78	188.22	
37	11.7	188.3	
39	11.67	188.33	
41	11.78	188.22	
43	11.76	188.24	
45.5	11.88	188.12	
47	11.92	188.08	
49	12.003	188	
51	12	188	
54	11.99	188.01	
56	12.02	187.98	
59	11.92	188.08	
62	11.61	188.39	
65	11.71	188.29	
67	11.8	188.2	
69.2	11.76	188.24	
71.5	11.72	188.28	
74	11.89	188.11	
76	11.82	188.18	
78	11.78	188.22	
80	11.77	188.23	
82	11.97	188.03	
84	11.95	188.05	
86	12.05	187.95	

Table A.42 (continued)

STA	FS (ft)	Elevation (ft)	Note
88.1	11.96	188.04	
90	11.9	188.1	
92	11.86	188.14	
94	11.6	188.4	
96	11.19	188.81	
98	10.33	189.67	
100	9.82	190.18	
101	9.73	190.27	
103	9.15	190.85	
104.5	8.3	191.7	
106	7.21	192.79	
109.5	5.79	194.21	
112	4.265	195.74	

Table A.43 Survey Data: 03288100 North Elkhorn Creek at Georgetown, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	5.07	194.93	
1	5.05	194.95	
3	4.86	195.14	
5	4.76	195.24	
7	4.82	195.18	
9	4.97	195.03	
11	5.11	194.89	
13	4.94	195.06	
15	4.99	195.01	
16	5.11	194.89	FP
17	5.19	194.81	
18	5.32	194.68	
18.4	5.4	194.6	
19	5.63	194.37	
19.5	5.81	194.19	
20	5.92	194.08	
20.5	6.11	193.89	

Table A.43 (continued)

STA	FS (ft)	Elevation (ft)	Note
21	6.28	193.72	
21.5	6.45	193.55	
22	6.54	193.46	
22.5	6.61	193.39	
23	6.73	193.27	
23.5	6.71	193.29	BKF
24.1	6.91	193.09	
24.5	7.29	192.71	
25.5	7.61	192.39	
26	8.51	191.49	
26.8	9.2	190.8	LEW
28	9.85	190.15	
29	10.21	189.79	
30	10.38	189.62	
31	10.59	189.41	
32	10.77	189.23	
33	10.94	189.06	
34	11.16	188.84	
36	11.64	188.36	
38	12.35	187.65	
40	13.07	186.93	
42.2	13.45	186.55	
44.4	14.45	185.55	
46	14.84	185.16	
48	15.39	184.61	
49.9	15.63	184.37	
51	15.95	184.05	
52.5	16.6	183.4	
54.7	17.41	182.59	
57	17.85	182.15	
60	17.83	182.17	
63.8	17.86	182.14	TW
66.6	17.77	182.23	
69.2	17.72	182.28	
71.6	17.68	182.32	
74	17.59	182.41	
76.8	17.64	182.36	

Table A.43 (continued)

STA	FS (ft)	Elevation (ft)	Note
79.4	17.43	182.57	
81.75	17.34	182.66	
85	17.18	182.82	
87.5	17.17	182.83	
89.8	17.16	182.84	
92.15	17.15	182.85	
95.9	17.07	182.93	
97.7	16.94	183.06	
100.2	16.86	183.14	
102.8	16.74	183.26	
104.8	16.55	183.45	
107	16.46	183.54	
109.35	16.35	183.65	
111.8	16.37	183.63	
114	16.12	183.88	
117.1	16.1	183.9	
119.9	15.76	184.24	
123	15.62	184.38	
125.2	15.44	184.56	
126.75	15.39	184.61	
129.1	15.25	184.75	
131.4	14.97	185.03	
133.3	14.5	185.5	
135.4	13.89	186.11	
138.1	13.09	186.91	
140	12.26	187.74	
143	10.8	189.2	
143.5	10.57	189.43	
144.8	10.18	189.82	
145.6	9.58	190.42	
146.9	9.44	190.56	
148	7.51	192.49	
148.5	6.69	193.31	
149	5.69	194.31	
150	5.31	194.69	
151	5.31	194.69	
152	5.09	194.91	

Table A.43 (continued)

STA	FS (ft)	Elevation (ft)	Note
153	4.93	195.07	
154	4.79	195.21	
155	4.59	195.41	
156	4.38	195.62	
157	4.17	195.83	
158	3.92	196.08	
159	3.69	196.31	
160	3.56	196.44	
161	3.39	196.61	
162	3.345	196.66	
163	3.29	196.71	
164	3.26	196.74	
165	3.24	196.76	
166	3.22	196.78	
167	3.22	196.78	
168	3.19	196.81	
169	3.21	196.79	
170	3.22	196.78	
171	3.19	196.81	
172	3.22	196.78	

Table A.44 Survey Data: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	5.6	194.4	
1	6.12	193.88	FP
2	6.77	193.23	
3	7.4	192.6	
3.9	7.82	192.18	
4.5	7.98	192.02	
5	8.12	191.88	
5.5	8.25	191.75	
5.7	8.37	191.63	
6	8.47	191.53	
6.4	8.59	191.41	

Table A.44 (continued)

STA	FS (ft)	Elevation (ft)	Note
7.2	8.94	191.06	
8	9.12	190.88	
9	9.42	190.58	LEW
10.1	9.69	190.31	
10.5	9.69	190.31	
11	9.71	190.29	
11.5	9.75	190.25	TW
12	9.67	190.33	
12.5	9.65	190.35	
13	9.68	190.32	
13.5	9.73	190.27	
14	9.73	190.27	
14.5	9.7	190.3	
15	9.72	190.28	
15.5	9.67	190.33	
16	9.66	190.34	
16.5	9.65	190.35	
17	9.6	190.4	
17.5	9.52	190.48	
18	9.54	190.46	
18.5	9.54	190.46	
19	9.59	190.41	
19.5	9.45	190.55	
20	9.57	190.43	
20.5	9.57	190.43	
21	9.57	190.43	
21.5	9.56	190.44	
22	9.54	190.46	
22.5	9.55	190.45	
23	9.36	190.64	
23.4	9.33	190.67	REW
24	9.18	190.82	
24.4	8.92	191.08	
24.7	8.87	191.13	
24.8	8.44	191.56	
25	8.39	191.61	
25.5	8.25	191.75	

Table A.44 (continued)

STA	FS (ft)	Elevation (ft)	Note
26	8.14	191.86	
26.5	7.97	192.03	
27	7.86	192.14	
27.5	7.72	192.28	
28	7.63	192.37	
28.5	7.48	192.52	
29	7.35	192.65	BKF
30	6.83	193.17	
31	6.23	193.77	
32	5.75	194.25	
33	5.39	194.61	

Table A.45 Survey Data: 03254400 North Fork Grassy Creek near Piner, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.89	195.11	
1.3	4.75	195.25	
2.6	4.77	195.23	
3.4	4.9	195.1	
4.8	4.77	195.23	
5.8	4.93	195.07	FP
7.4	5.025	194.98	
7.7	5.24	194.76	
8.8	5.15	194.85	
9.8	5.12	194.88	
10.8	5.1	194.9	
12	5.26	194.74	
13	5.4	194.6	
14	5.45	194.55	
15	5.53	194.47	
16	5.5	194.5	
17.5	5.64	194.36	
18.4	5.57	194.43	BKF
19.3	6.09	193.91	
20	6.22	193.78	

Table A.45 (continued)

STA	FS (ft)	Elevation (ft)	Note
21	6.41	193.59	
22	6.61	193.39	
23	6.52	193.48	
24.3	7.37	192.63	LEW
25	7.57	192.43	
26	7.92	192.08	
27	8.06	191.94	
28	8.1	191.9	
29	8.28	191.72	
30	8.43	191.57	
31	8.36	191.64	
32	8.4	191.6	
33	8.33	191.67	
34	8.34	191.66	
35	8.33	191.67	
35.8	8.49	191.51	
37	8.63	191.37	
38	8.63	191.37	
39	8.7	191.3	
40	8.72	191.28	
41	8.74	191.26	TW
42	8.65	191.35	
43	8.44	191.56	
44	8.3	191.7	
45	8.27	191.73	
46	8.26	191.74	
47	8.27	191.73	
48	8.32	191.68	
49	8.13	191.87	
50	8.11	191.89	
51	8.02	191.98	
52	8.02	191.98	
53	8	192	
53.9	7.89	192.11	REW
54.3	6.89	193.11	
55	7	193	
56	7	193	

Table A.45 (continued)

STA	FS (ft)	Elevation (ft)	Note
57	6.93	193.07	
58	6.39	193.61	
58.5	6.38	193.62	
58.9	5.91	194.09	
59.4	5.61	194.39	
59.8	3.37	196.63	
60.5	3.13	196.87	
61	2.77	197.23	

Table A.46 Survey Data: 03254480 Cruises Creek at Highway 17 near Piner, KY(all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	2.51	197.49	
1	4.07	195.93	
1.4	4.29	195.71	
1.7	4.41	195.59	
2	4.5	195.5	
2.4	4.68	195.32	
2.8	4.78	195.22	
3	4.81	195.19	
3.3	4.89	195.11	
3.7	4.97	195.03	
4	5.06	194.94	
4.2	5.2	194.8	
4.5	5.28	194.72	
4.8	5.39	194.61	
5	5.46	194.54	
5.2	5.6	194.4	
5.4	5.67	194.33	
5.8	5.87	194.13	
6	5.95	194.05	
6.6	6.18	193.82	
7.1	6.51	193.49	
7.7	6.81	193.19	
8.1	7.06	192.94	LEW

Table A.46 (continued)

STA	FS (ft)	Elevation (ft)	Note
8.8	7.56	192.44	
9.3	7.82	192.18	
9.7	8.31	191.69	
10	8.36	191.64	
11	8.57	191.43	
12	8.82	191.18	
13	8.95	191.05	
14	8.96	191.04	
15	8.89	191.11	
16	9.05	190.95	
17	9.09	190.91	
18	9.36	190.64	
19	9.32	190.68	
20	9.3	190.7	
21	9.28	190.72	
22	9.29	190.71	
23	9.31	190.69	
24	9.17	190.83	
25	9.1	190.9	
26	9.28	190.72	
27	9.33	190.67	
28	9.41	190.59	
29	9.36	190.64	
30	9.18	190.82	
31	9.32	190.68	
32	9.33	190.67	
33	9.32	190.68	
34	9.3	190.7	
35	9.27	190.73	
36	9.19	190.81	
37	9.14	190.86	
38	9.09	190.91	
39	9.17	190.83	
40	9.32	190.68	
41	9.31	190.69	
42	9.25	190.75	
43	9.04	190.96	

Table A.46 (continued)

STA	FS (ft)	Elevation (ft)	Note
44	9.03	190.97	
45	8.94	191.06	
46	8.88	191.12	
47	8.74	191.26	
48	8.78	191.22	
49	8.74	191.26	
50	8.54	191.46	
51	8.42	191.58	
52	8.43	191.57	
53	8.41	191.59	
54	8.07	191.93	
55	8.26	191.74	
56	8.01	191.99	
57	7.85	192.15	
58	7.66	192.34	
59.3	7.16	192.84	REW
60	6.64	193.36	
60.6	6.28	193.72	
61.2	5.96	194.04	
61.6	5.625	194.38	
62.1	5.45	194.55	
62.5	5.22	194.78	
62.8	5.12	194.88	
63.1	4.86	195.14	
63.6	4.59	195.41	
64	4.48	195.52	BKF
64.4	4.43	195.57	
64.7	4.39	195.61	
65.1	4.25	195.75	
65.6	4.07	195.93	
65.8	4.01	195.99	
66	3.83	196.17	
66.5	3.64	196.36	

Table A.47 Survey Data: 03262001 Woolper Creek at Woolper Road near Burlington, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
2	4.69	195.31	
3	4.78	195.22	
4	4.78	195.22	
5	4.87	195.13	
6	4.93	195.07	
7	5.02	194.98	
8	5.02	194.98	
9	5.16	194.84	
10	5.09	194.91	
11	5.13	194.87	
12	5	195	
13	4.88	195.12	
14	4.84	195.16	
14.5	4.68	195.32	
15	4.61	195.39	
15.5	4.64	195.36	
16	4.63	195.37	
16.5	4.9	195.1	
17	4.99	195.01	
17.5	5.19	194.81	
18	5.42	194.58	
19	5.965	194.04	
19.5	6.02	193.98	
20	6.18	193.82	
20.5	6.42	193.58	
21	6.49	193.51	
21.5	6.81	193.19	
22	6.89	193.11	

Table A.47 (continued)

STA	FS (ft)	Elevation (ft)	Note
22.5	7.02	192.98	
23	7.16	192.84	
23.5	7.19	192.81	
24	7.25	192.75	
24.5	7.58	192.42	
25	7.62	192.38	
25.5	7.78	192.22	
26	7.81	192.19	
26.5	7.98	192.02	
28.5	8.59	191.41	
29	8.59	191.41	
29.5	8.84	191.16	
30	8.85	191.15	
30.5	9.01	190.99	
31	9.05	190.95	
31.6	9.15	190.85	
31.8	9.17	190.83	
32	9.25	190.75	
32.3	9.33	190.67	
32.6	9.41	190.59	
32.9	9.45	190.55	
33.3	9.56	190.44	
33.6	9.67	190.33	
33.9	9.73	190.27	
34.3	9.95	190.05	
34.6	9.99	190.01	
35	10.28	189.72	
35.5	10.4	189.6	BKF
35.8	10.99	189.01	
36.2	11.91	188.09	
36.7	12.21	187.79	
37.1	12.76	187.24	LEW
38	13.19	186.81	
39	13.45	186.55	
40	13.55	186.45	
41	13.72	186.28	

Table A.47 (continued)

STA	FS (ft)	Elevation (ft)	Note
42	13.7	186.3	
43	13.96	186.04	
44	13.85	186.15	
45	13.95	186.05	
46	13.99	186.01	
47	13.97	186.03	
48	13.83	186.17	
49	13.74	186.26	
50	13.86	186.14	
51	13.9	186.1	
52	14	186	
53	13.96	186.04	
54	14.03	185.97	
55	13.94	186.06	
56	13.82	186.18	
57	13.89	186.11	
58	13.85	186.15	
59	14.06	185.94	
60	13.98	186.02	
61	14.01	185.99	
62	14.04	185.96	
63	14.09	185.91	
64	14.1	185.9	
65	14.02	185.98	
66	14.03	185.97	
67	14.04	185.96	
68	14.19	185.81	
69	14.28	185.72	TW
70	13.98	186.02	
71	14.05	185.95	
72	13.98	186.02	
73	14.06	185.94	
74	13.87	186.13	

Table A.47 (continued)

STA	FS (ft)	Elevation (ft)	Note
75	13.9	186.1	
76	13.82	186.18	
77	13.79	186.21	
78	13.61	186.39	
79	13.55	186.45	
80	13.72	186.28	
81	13.74	186.26	
82	13.63	186.37	
83	13.45	186.55	
84	13.42	186.58	
85	13.21	186.79	
86	12.94	187.06	
87	12.82	187.18	REW
88	12.5	187.5	
88.5	11.59	188.41	
89	11.64	188.36	
90	11.35	188.65	
90.5	11.2	188.8	
91	11.04	188.96	
91.5	10.91	189.09	
92	10.87	189.13	
92.5	10.86	189.14	
93	10.73	189.27	BKF
93.5	10.69	189.31	
94	10.76	189.24	
95	10.63	189.37	
96	10.54	189.46	
97	10.39	189.61	
98	10.22	189.78	
99	10.01	189.99	FP
100	9.98	190.02	
101	9.62	190.38	
102	9.29	190.71	
103	9.11	190.89	
104	8.79	191.21	

Table A.47 (continued)

STA	FS (ft)	Elevation (ft)	Note
105	8.65	191.35	
106	8.4	191.6	
107	8.25	191.75	
108	7.98	192.02	
109	7.75	192.25	
110	7.38	192.62	
111	6.85	193.15	
112	6.01	193.99	
113	5.91	194.09	
114	4.21	195.79	
115	3.47	196.53	

Table A.48 Survey Data: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	5.89	194.11	
1	6.19	193.81	
2	6.66	193.34	
3	6.91	193.09	
4	7.24	192.76	
5	7.45	192.55	
6	7.55	192.45	
7	7.63	192.37	
7.3	7.7	192.3	BKF
7.7	7.93	192.07	
8	8.06	191.94	
8.4	8.24	191.76	
8.9	8.41	191.59	
9.1	8.53	191.47	
9.3	8.71	191.29	
9.7	9.03	190.97	
10.4	9.23	190.77	
10.8	9.66	190.34	
11	9.88	190.12	LEW

Table A.48 (continued)

STA	FS (ft)	Elevation (ft)	Note
12	10.41	189.59	
13	10.53	189.47	
14	10.65	189.35	
15	10.66	189.34	
16	10.63	189.37	
17	10.68	189.32	
18	10.67	189.33	
19	10.65	189.35	
20	10.65	189.35	
20.85	10.78	189.22	
21	10.97	189.03	
22	11.09	188.91	
23	11.38	188.62	
24	11.41	188.59	
25	11.41	188.59	
26	11.56	188.44	
27.3	11.63	188.37	
27.5	12.08	187.92	
28	12.44	187.56	
29	12.42	187.58	
30	12.73	187.27	
31	12.9	187.1	
32	12.91	187.09	
33	12.91	187.09	
34	12.89	187.11	
35	12.88	187.12	
36	12.85	187.15	
37	12.85	187.15	
38	12.82	187.18	
39	12.91	187.09	TW
40	12.72	187.28	
41	12.64	187.36	
42	12.52	187.48	
43	12.35	187.65	
44	12.24	187.76	
45	12.07	187.93	

Table A.48 (continued)

STA	FS (ft)	Elevation (ft)	Note
46	11.87	188.13	
46.9	11.86	188.14	
48	11.75	188.25	
49	11.62	188.38	
50	11.41	188.59	
51	11.25	188.75	
52	11.09	188.91	
53	11.17	188.83	
54	11.21	188.79	
55	11.19	188.81	
56	10.86	189.14	
57	10.63	189.37	
58	10.95	189.05	
59	10.98	189.02	
60	11	189	
61	11.01	188.99	
62	11.02	188.98	
63	11	189	
64	10.76	189.24	
65	10.89	189.11	
66	10.87	189.13	
67	10.81	189.19	
68	10.63	189.37	
69.2	9.96	190.04	REW
70	9.52	190.48	
70.5	9.33	190.67	
71.1	9.08	190.92	
71.5	8.87	191.13	
72.1	8.62	191.38	
72.6	8.58	191.42	
73	8.53	191.47	
73.8	8.25	191.75	
74.3	8.18	191.82	
75	8.14	191.86	
75.5	8.13	191.87	

Table A.48 (continued)

STA	FS (ft)	Elevation (ft)	Note
76	8.11	191.89	
77	8.02	191.98	
78	7.79	192.21	BKF
79	7.77	192.23	
80	7.7	192.3	
81	7.61	192.39	
82	7.5	192.5	
83	7.41	192.59	
84	7.29	192.71	
85	7.23	192.77	
86	7.2	192.8	FP
87	7.13	192.87	
88	7.18	192.82	
89	7.28	192.72	
90	7.27	192.73	
91	7.39	192.61	
92	7.28	192.72	
94	6.98	193.02	
95	6.76	193.24	
96	6.49	193.51	
97	6.25	193.75	
98	6.17	193.83	
99	6.04	193.96	
100	5.8	194.2	
101	5.72	194.28	
102	5.63	194.37	
103	5.54	194.46	
104	5.51	194.49	
105	5.55	194.45	
106	5.5	194.5	
107	5.46	194.54	

Table A.49 Survey Data: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	5.12	194.88	
1	5.3	194.7	
2	5.52	194.48	
3	5.75	194.25	
4	5.85	194.15	
5	6.02	193.98	
6	6.14	193.86	
7	6.21	193.79	
8	6.23	193.77	
9	6.32	193.68	
10	6.31	193.69	BKF
11	6.41	193.59	
12	6.52	193.48	
13	6.66	193.34	
13.5	6.76	193.24	
14	6.92	193.08	
14.4	7	193	
14.6	7.07	192.93	
14.9	7.16	192.84	
15.2	7.33	192.67	
15.5	7.49	192.51	
15.9	7.66	192.34	
16.3	7.78	192.22	
16.5	8.08	191.92	
16.9	8.39	191.61	
17.2	8.64	191.36	
17.6	8.83	191.17	
18.5	9.19	190.81	
19	9.43	190.57	
20	9.8	190.2	
20.2	9.95	190.05	LEW
21	10.2	189.8	
22	10.23	189.77	
23	10.32	189.68	
24	10.18	189.82	
25	10.09	189.91	

Table A.49 (continued)

STA	FS (ft)	Elevation (ft)	Note
25.5	10.18	189.82	
26	10.53	189.47	
27	10.61	189.39	
28	10.56	189.44	
29	10.25	189.75	
30	10.57	189.43	
31	10.37	189.63	
32	10.46	189.54	
33	10.32	189.68	
34	10.36	189.64	
35	10.61	189.39	
36	10.51	189.49	
37	10.44	189.56	
38	10.56	189.44	
39	10.67	189.33	
40	10.64	189.36	
41	10.7	189.3	
42	10.63	189.37	
43	10.79	189.21	
44	10.79	189.21	
45	10.93	189.07	
46	11.05	188.95	
47	11.18	188.82	TW
48	11.17	188.83	
49	10.89	189.11	
50	10.69	189.31	
51	10.6	189.4	
52	10.67	189.33	
53	10.78	189.22	
54	10.59	189.41	
55	10.47	189.53	
56	10.6	189.4	
57	10.62	189.38	
58	10.34	189.66	
59	10.25	189.75	
60	10.52	189.48	

Table A.49 (continued)

STA	FS (ft)	Elevation (ft)	Note
61	10.63	189.37	
62	10.46	189.54	
63	10.46	189.54	
64	10.52	189.48	
65	10.39	189.61	
66	10.31	189.69	
67	10.25	189.75	
68	10.2	189.8	
69.2	10.6	189.4	
70	10.6	189.4	
71	10.66	189.34	
72	10.62	189.38	
73	10.61	189.39	
74	10.58	189.42	
75	10.54	189.46	
76	10.44	189.56	
77.3	10.05	189.95	REW
77.6	9.61	190.39	
78	9.55	190.45	
79	9.26	190.74	
79.5	9.19	190.81	
80	9.18	190.82	
80.5	8.95	191.05	
81	8.9	191.1	
81.9	8.66	191.34	
82.3	8.49	191.51	
83.1	8.31	191.69	
83.6	8.18	191.82	
84	7.91	192.09	
85	7.68	192.32	
86	7.49	192.51	
87	7.31	192.69	
88	7.22	192.78	
89	7.03	192.97	
90	6.91	193.09	

Table A.49 (continued)

STA	FS (ft)	Elevation (ft)	Note
90.4	6.92	193.08	
90.5	6.67	193.33	
91	6.73	193.27	
92	6.65	193.35	
93	6.61	193.39	
94	6.5	193.5	
95	6.46	193.54	
96	6.34	193.66	
97	6.33	193.67	
98	6.15	193.85	
99	6.08	193.92	
100	5.98	194.02	
101.4	5.84	194.16	
103.3	5.5	194.5	
105.9	5.08	194.92	
109	4.39	195.61	
111.1	3.69	196.31	

Table A.50 Survey Data: 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	3.6	196.4	
1	3.79	196.21	
2	3.89	196.11	
3	3.94	196.06	
4	4.08	195.92	
5	4.25	195.75	
6	4.47	195.53	
6.8	4.74	195.26	
7.3	4.88	195.12	
9	5.15	194.85	
9.5	5.22	194.78	
10	5.25	194.75	
10.5	5.34	194.66	
11	5.37	194.63	
11.5	5.4	194.6	
12	5.56	194.44	
12.5	5.67	194.33	
13	5.76	194.24	
14	6	194	
14.6	6.26	193.74	
15.15	6.62	193.38	
15.8	7.29	192.71	LEW
17	7.77	192.23	
18	8	192	
19	8.03	191.97	
20	8.07	191.93	
21	8	192	
22	8.21	191.79	
23	8.35	191.65	
24	8.42	191.58	
25	8.46	191.54	
26	8.55	191.45	
27	8.57	191.43	
28	8.67	191.33	

Table A.50 (continued)

STA	FS (ft)	Elevation (ft)	Note
29	8.79	191.21	
30	8.83	191.17	
31	8.83	191.17	
32	8.78	191.22	
33	8.63	191.37	
34	8.83	191.17	
35	8.91	191.09	
36	9.14	190.86	
37	9.31	190.69	
38	9.35	190.65	
39	9.62	190.38	
40	9.79	190.21	
41	9.8	190.2	
42	9.89	190.11	
43	9.92	190.08	
44	9.89	190.11	
45	9.98	190.02	
46	9.84	190.16	
47	9.95	190.05	
48	9.96	190.04	
49	10.05	189.95	
50	10	190	
51	9.88	190.12	
52	9.97	190.03	
53	9.8	190.2	
54	9.88	190.12	
55	9.86	190.14	
56	10.04	189.96	
57	9.7	190.3	
58	9.66	190.34	
59	9.81	190.19	
60	9.79	190.21	
61	9.8	190.2	
62	9.28	190.72	
63	9.31	190.69	
64	9.33	190.67	

Table A.50 (continued)

STA	FS (ft)	Elevation (ft)	Note
65	9.34	190.66	
66	9.27	190.73	
67	9.24	190.76	
68	9.23	190.77	
69	9.18	190.82	
70	9.12	190.88	
71	8.82	191.18	
72	8.79	191.21	
73	8.88	191.12	
74	8.81	191.19	
75	8.79	191.21	
76	8.64	191.36	
77	8.65	191.35	
78	8.55	191.45	
79	8.26	191.74	
80.4	7.36	192.64	REW
81	6.98	193.02	
81.5	6.46	193.54	
82	6.12	193.88	
82.5	5.88	194.12	
83	5.75	194.25	
83.5	5.65	194.35	
84	5.53	194.47	
84.5	5.44	194.56	
85	5.28	194.72	
86	5.1	194.9	
87	4.91	195.09	
88	4.74	195.26	
89	4.61	195.39	
90	4.46	195.54	BKF
91	4.43	195.57	
92	4.4	195.6	
93	4.35	195.65	
94	4.36	195.64	

Table A.50 (continued)

STA	FS (ft)	Elevation (ft)	Note
95	4.36	195.64	
96	4.39	195.61	
97	4.41	195.59	
98	4.4	195.6	
99	4.33	195.67	
100	4.39	195.61	
101	4.32	195.68	
102	4.4	195.6	
103	4.35	195.65	
104	4.36	195.64	
105	4.35	195.65	
106	4.36	195.64	

Table A.51 Survey Data: 03298135 Chenoweth Run at Ruckriegal Parkway, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.12	195.88	
1	4.22	195.78	
2	4.53	195.47	
3	4.68	195.32	
4	4.61	195.39	
5	4.54	195.46	
5.5	4.465	195.54	
6	4.46	195.54	
6.5	4.47	195.53	
7	4.54	195.46	
7.5	4.61	195.39	
7.8	4.705	195.3	
8	4.79	195.21	
8.3	4.93	195.07	
8.5	5.14	194.86	
8.8	5.42	194.58	

Table A.51 (continued)

STA	FS (ft)	Elevation (ft)	Note
8.9	6.07	193.93	LEW
9.9	6.13	193.87	
11	6.39	193.61	
12	6.39	193.61	
13	6.6	193.4	
14	6.465	193.54	
15	6.625	193.38	
16	6.71	193.29	
17	6.45	193.55	
18	6.48	193.52	
19	6.49	193.51	
20	6.37	193.63	
21	6.39	193.61	
22	6.36	193.64	
23	6.37	193.63	
24	6.36	193.64	
25	6.41	193.59	
26	6.4	193.6	
27	6.47	193.53	
28	6.39	193.61	
28.35	6.31	193.69	
28.55	6.11	193.89	
29	6.1	193.9	
30	6.08	193.92	
31	6.11	193.89	
32	6.11	193.89	
33	6.15	193.85	
34	6.22	193.78	
35	6.18	193.82	
36	6.17	193.83	
36.7	6.15	193.85	REW
36.95	5.67	194.33	
38	5.66	194.34	
39	5.34	194.66	
39.4	5.29	194.71	
39.9	4.83	195.17	

Table A.51 (continued)

STA	FS (ft)	Elevation (ft)	Note
40	4.59	195.41	
40.15	4.56	195.44	
40.5	4.535	195.47	
41	4.62	195.38	
41.4	4.49	195.51	
41.8	4.38	195.62	
42.1	4.3	195.7	
42.7	4.2	195.8	BKF
43.4	4.19	195.81	
44	4.15	195.85	
44.5	4.33	195.67	
45	4.42	195.58	
46	4.43	195.57	
47	4.09	195.91	
48	3.945	196.06	
49	3.795	196.21	

Table A.52 Survey Data: 03292480 Little Goose near Harrods Creek, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.54	195.46	
1	4.5	195.5	
2	4.52	195.48	
3	4.56	195.44	
4	4.55	195.45	
5	4.68	195.32	
6	4.57	195.43	
7	4.42	195.58	
8	4.3	195.7	
9	4.26	195.74	
10	4.19	195.81	
11	4.27	195.73	
12	4.42	195.58	
13	4.38	195.62	

Table A.52 (continued)

STA	FS (ft)	Elevation (ft)	Note
14	4.38	195.62	
15	4.36	195.64	
16	4.37	195.63	
17	4.36	195.64	
18	4.41	195.59	
19	4.55	195.45	
20	4.73	195.27	
21	4.67	195.33	
22	4.59	195.41	
23	4.62	195.38	
24	4.59	195.41	
25	4.77	195.23	
26	4.78	195.22	
27	4.87	195.13	
28	4.92	195.08	
29	4.89	195.11	FP
30	4.95	195.05	
30.5	5.01	194.99	BKF
30.9	5.1	194.9	
31.1	5.21	194.79	
31.2	5.24	194.76	
31.5	5.47	194.53	
31.8	5.61	194.39	
32	5.74	194.26	
32.3	5.89	194.11	
32.7	6.1	193.9	
33	6.24	193.76	
33.5	7.24	192.76	LEW
34	7.68	192.32	
35	8.02	191.98	
36	8.2	191.8	
37	8.18	191.82	
37.5	8.13	191.87	
38	8.08	191.92	
39	7.96	192.04	
40	7.92	192.08	

Table A.52 (continued)

STA	FS (ft)	Elevation (ft)	Note
41	7.84	192.16	
42	7.77	192.23	
43	7.79	192.21	
44	7.88	192.12	
45	7.85	192.15	
46	7.91	192.09	
47	7.91	192.09	
48	8.07	191.93	
49	7.93	192.07	
50	7.8	192.2	
51	7.67	192.33	
52	8.03	191.97	
53	8.1	191.9	
54	8.17	191.83	
55	8.13	191.87	
56	8.27	191.73	
57	8.13	191.87	
58	8.16	191.84	
59	8.15	191.85	
60	8.28	191.72	TW
61	8.2	191.8	
62	8.25	191.75	
62.5	8.17	191.83	
63	8.2	191.8	
64	8.16	191.84	
65	8.21	191.79	
66	7.8	192.2	
67	8.14	191.86	
68	8.15	191.85	
69	8.09	191.91	
70	7.22	192.78	REW
70.3	6.79	193.21	
70.7	6.42	193.58	
71.1	6.19	193.81	
71.7	6.11	193.89	
72.2	5.98	194.02	

Table A.52 (continued)

STA	FS (ft)	Elevation (ft)	Note
72.6	5.97	194.03	
73	5.91	194.09	
73.6	5.73	194.27	
74	5.56	194.44	
74	5.56	194.44	
74.2	5.37	194.63	
74.5	5.3	194.7	
74.8	5.15	194.85	
75	5.07	194.93	
76	4.85	195.15	
77	4.56	195.44	
78	4.29	195.71	
79	3.96	196.04	
80	3.65	196.35	
80.4	3.49	196.51	

Table A.53 Survey Data: 03292474 Goose Creek at Old Westport Road near St. Matthews, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.94	195.06	
1	4.85	195.15	
2	4.94	195.06	
3	5	195	
4	4.97	195.03	
5	4.99	195.01	
6	4.99	195.01	
7	5.2	194.8	
8	5.35	194.65	
9	5.53	194.47	
10	5.75	194.25	
11	6.04	193.96	
12	6.35	193.65	
13	6.66	193.34	
13.2	6.99	193.01	

Table A.53 (continued)

STA	FS (ft)	Elevation (ft)	Note
14	7.28	192.72	
14.4	7.65	192.35	
15	7.64	192.36	
15.3	8.11	191.89	
15.9	8.18	191.82	
16.1	8.61	191.39	LEW
17	8.86	191.14	
18	8.78	191.22	
19	9.07	190.93	
20	9.05	190.95	
21	9.22	190.78	
22	9.41	190.59	
23	9.51	190.49	
24	9.3	190.7	
25	9.8	190.2	
26	9.93	190.07	
27	10.03	189.97	
28	10.12	189.88	
29	10.22	189.78	
30	10.33	189.67	
31	10.34	189.66	TW
32	10.28	189.72	
33	10.17	189.83	
34	10.21	189.79	
35	10.24	189.76	
36	10.25	189.75	
37	10.15	189.85	
38	10.05	189.95	
39	9.97	190.03	
40	9.85	190.15	
40.7	9.79	190.21	
40.9	9.1	190.9	
42	8.98	191.02	
43	8.75	191.25	
43.2	8.44	191.56	
43.7	7.96	192.04	

Table A.53 (continued)

STA	FS (ft)	Elevation (ft)	Note
44.2	7.24	192.76	
44.7	7.1	192.9	BKF
45	7.06	192.94	
45.5	7.03	192.97	
46	7.01	192.99	
46.5	7.05	192.95	
47	7.03	192.97	
48	6.86	193.14	
49	6.73	193.27	
50	6.41	193.59	FP
51	6.32	193.68	
52.7	6.06	193.94	
54	5.88	194.12	
55	5.77	194.23	
56	5.69	194.31	
57	5.52	194.48	
58	5.45	194.55	
59	5.46	194.54	
60	5.31	194.69	
61	5.27	194.73	

Table A.54 Survey Data: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	3.4	196.6	
1	4.47	195.53	
1.9	5.03	194.97	
2.3	5.8	194.2	
3	6.4	193.6	
3.4	6.66	193.34	
3.8	6.9	193.1	
4.1	7.34	192.66	
4.9	7.85	192.15	
5.5	8.26	191.74	
6	8.5	191.5	

Table A.54 (continued)

STA	FS (ft)	Elevation (ft)	Note
7	8.95	191.05	
8	9.21	190.79	
9	9.3	190.7	
10	9.39	190.61	
11	9.53	190.47	
12	9.6	190.4	
13	9.65	190.35	
13.8	9.75	190.25	
14.4	10.1	189.9	
14.6	10.54	189.46	LEW
15	10.73	189.27	
16	10.78	189.22	
17	10.78	189.22	
18	10.85	189.15	TW
19	10.73	189.27	
20	10.82	189.18	
21	10.78	189.22	
22	10.79	189.21	
23	10.75	189.25	
24	10.75	189.25	
25	10.76	189.24	
26.1	10.77	189.23	
27	10.78	189.22	
28.1	10.68	189.32	
29.1	10.46	189.54	
30	10.35	189.65	
31.2	10.33	189.67	
32	10.19	189.81	
33.6	10.34	189.66	
34	10.34	189.66	
35	10.25	189.75	
36	10.33	189.67	
37	10.44	189.56	
38	10.45	189.55	
39.1	10.56	189.44	
40	10.55	189.45	

Table A.54 (continued)

STA	FS (ft)	Elevation (ft)	Note
41.2	10.32	189.68	REW
41.8	9.95	190.05	
42.1	9.84	190.16	
42.5	9.69	190.31	
42.8	9.51	190.49	
43.2	9.48	190.52	
44.3	9.42	190.58	
44.8	9.02	190.98	
45.4	8.59	191.41	
45.6	8.46	191.54	
46	7.91	192.09	
46.3	7.81	192.19	BKF
46.9	7.64	192.36	
47.5	7.55	192.45	
48	7.45	192.55	
48.5	7.38	192.62	
49	7.26	192.74	
49.5	7.15	192.85	
50	7.01	192.99	
50.5	6.87	193.13	FP
51	6.51	193.49	
51.5	6.23	193.77	
52	5.86	194.14	
53	4.87	195.13	
54	4.07	195.93	
55	3.83	196.17	
56	3.46	196.54	
57	3.23	196.77	
58	3.1	196.9	
59	3.04	196.96	
60	3.13	196.87	
61	3.22	196.78	
62	3.3	196.7	
63	3.33	196.67	
64	3.43	196.57	
65	3.45	196.55	

Table A.54 (continued)

STA	FS (ft)	Elevation (ft)	Note
66	3.48	196.52	

Table A.55 Survey Data: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	5.03	194.97	
1	5.02	194.98	
2	4.99	195.01	
3	4.93	195.07	
4	4.95	195.05	
5	4.97	195.03	
6	5	195	
7	5.07	194.93	
7.4	5.23	194.77	
7.7	5.37	194.63	
8	5.46	194.54	
8.5	5.74	194.26	
8.8	5.95	194.05	
9	6.12	193.88	
9.5	6.48	193.52	
10	6.95	193.05	
10.5	7.42	192.58	
10.8	7.57	192.43	
11	7.79	192.21	
11.5	8.3	191.7	
12	8.53	191.47	
12.5	9.19	190.81	
13	9.39	190.61	
14	9.65	190.35	
15	9.72	190.28	
16	9.78	190.22	

Table A.55 (continued)

STA	FS (ft)	Elevation (ft)	Note
17	9.77	190.23	
17.7	9.83	190.17	LEW
18	9.88	190.12	
19	10.02	189.98	
20	10.12	189.88	
21	10.22	189.78	
22	10.29	189.71	
23	10.07	189.93	
24	10.38	189.62	
25	10.35	189.65	
26	10.38	189.62	
27	10.49	189.51	
28	10.4	189.6	
29	10.48	189.52	
30	10.56	189.44	
31	10.52	189.48	
32	10.52	189.48	
33	10.53	189.47	
34	10.5	189.5	
35	10.66	189.34	
36	10.72	189.28	
37	10.81	189.19	
38	10.77	189.23	
39	10.84	189.16	
40	10.83	189.17	
41	10.88	189.12	
42	10.91	189.09	
43	10.91	189.09	
44	10.91	189.09	
45	10.83	189.17	
46	10.4	189.6	
47	10.41	189.59	
48	10.12	189.88	

Table A.55 (continued)

STA	FS (ft)	Elevation (ft)	Note
49	10.17	189.83	
50	9.96	190.04	
51	10	190	
51.5	9.84	190.16	REW
52	9.48	190.52	
52.5	8.85	191.15	
53	8.81	191.19	
53.2	8.12	191.88	
53.4	7.95	192.05	
53.8	7.88	192.12	
53.9	7.87	192.13	
54.4	7.6	192.4	
54.6	7.53	192.47	
55	7.47	192.53	
55.5	7.43	192.57	
55.9	7.29	192.71	
56.5	7.19	192.81	
57	7.11	192.89	
57.5	7.05	192.95	
58	6.94	193.06	
58.5	6.85	193.15	
59	6.75	193.25	
60	6.66	193.34	
61	6.49	193.51	
62	6.35	193.65	BKF
63	6.36	193.64	
64	6.33	193.67	

Table A.56 Survey Data: 03277130 Mud Lick at Highway 42 near Beaverlick, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	3.4	196.6	
2	3.24	196.76	
4	3.135	196.87	
6	3.11	196.89	
8	3.18	196.82	
9	3.3	196.7	
10	3.45	196.55	
11	3.64	196.36	
12	3.8	196.2	
13	4.09	195.91	
14	4.33	195.67	
15	4.51	195.49	
16	4.63	195.37	
17	4.85	195.15	
18	4.99	195.01	
19	5.21	194.79	
20	5.41	194.59	
21	5.54	194.46	
22	5.87	194.13	
23	6.14	193.86	
24	6.56	193.44	
24.4	6.68	193.32	
25.3	8.96	191.04	LEW
26	9.74	190.26	
27	9.9	190.1	
28	10.19	189.81	
29	10.16	189.84	
30	10.46	189.54	
32	10.72	189.28	
34	10.76	189.24	
36	10.79	189.21	
38	10.9	189.1	

Table A.56 (continued)

STA	FS (ft)	Elevation (ft)	Note
40	10.73	189.27	
42	10.37	189.63	
44	10.55	189.45	
46	10.78	189.22	
48	10.98	189.02	
50	10.93	189.07	
52	11.12	188.88	
54	11.13	188.87	
56	11.05	188.95	
58	11.01	188.99	
60	10.93	189.07	
62	11.42	188.58	
64	11.37	188.63	
66	11.45	188.55	
68	11.53	188.47	
70	11.27	188.73	
72	11.55	188.45	
74	11.79	188.21	
76	11.98	188.02	
78	12.11	187.89	
80	11.94	188.06	
82	11.9	188.1	
84	12.19	187.81	TW
86	11.95	188.05	
88	12.01	187.99	
90	12.13	187.87	
92	12.08	187.92	
94	11.97	188.03	
96	12.04	187.96	
98	11.99	188.01	
100	11.96	188.04	
102	12	188	
104	11.15	188.85	
106	10.73	189.27	
108	10.44	189.56	

Table A.56 (continued)

STA	FS (ft)	Elevation (ft)	Note
110	9.86	190.14	
111	8.98	191.02	REW
112	8.79	191.21	
112.4	6.93	193.07	
113	6.5	193.5	
114	6.25	193.75	
115	6.09	193.91	
117	5.64	194.36	
119	5.31	194.69	BKF
121	5.51	194.49	
123	5.62	194.38	
125	5.2	194.8	
127	5.29	194.71	
129	4.92	195.08	
130	4.89	195.11	

Table A.57 Survey Data: 03292470 Harrods Creek at Highway 329 near Goshen, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	4.14	195.86	
1	4.1	195.9	
2	4.19	195.81	
3	4.34	195.66	
4	4.74	195.26	
5	5.09	194.91	
6	5.31	194.69	
7	5.64	194.36	
8	6.12	193.88	
9	6.44	193.56	
10	7.06	192.94	
11	7.57	192.43	
12	8.09	191.91	
12.6	8.28	191.72	
13.2	8.33	191.67	BKF

Table A.57 (continued)

STA	FS (ft)	Elevation (ft)	Note
13.7	8.87	191.13	
14.3	9.12	190.88	
14.8	9.52	190.48	
15.1	9.58	190.42	
15.3	9.84	190.16	
15.6	10.16	189.84	
16.3	10.53	189.47	
17.4	11.34	188.66	
18	11.71	188.29	
18.7	11.54	188.46	
19.6	12.26	187.74	
20	12.36	187.64	
21	13.16	186.84	
22	13.69	186.31	
23	13.87	186.13	
24	14.33	185.67	
25	14.54	185.46	
26	14.36	185.64	
27	14.68	185.32	
28	14.65	185.35	
29	14.72	185.28	
30	14.79	185.21	
31	14.82	185.18	
32	14.86	185.14	
33	14.24	185.76	
34.5	14.48	185.52	
36.5	14.58	185.42	
39	15	185	
40	14.96	185.04	
41	15.1	184.9	
42	15.11	184.89	
43.5	14.94	185.06	
45	14.72	185.28	
46	14.62	185.38	
47	14.77	185.23	
48	14.58	185.42	

Table A.57 (continued)

STA	FS (ft)	Elevation (ft)	Note
49	15.02	184.98	
50	14.98	185.02	
51	15.04	184.96	
52	15.08	184.92	
53	14.92	185.08	
54	15.33	184.67	TW
55	15.12	184.88	
56	14.95	185.05	
57	14.92	185.08	
58	14.89	185.11	
59	14.68	185.32	
60	14.84	185.16	
61	14.9	185.1	
62	14.86	185.14	
63	14.55	185.45	
64	14.83	185.17	
65	14.47	185.53	
66	15.11	184.89	
67	14.92	185.08	
68	14.64	185.36	
69	14.32	185.68	
70	14.37	185.63	
71	14.86	185.14	
72	14.77	185.23	
73	14.54	185.46	
74	14.85	185.15	
75	14.8	185.2	
76	14.79	185.21	
77	14.42	185.58	
78	14.6	185.4	
79	14.53	185.47	
80	14.36	185.64	
82	14.2	185.8	
83	14.06	185.94	
84.2	14.19	185.81	
85	14.22	185.78	

Table A.57 (continued)

STA	FS (ft)	Elevation (ft)	Note
86	14.22	185.78	
87	14.04	185.96	
88	14	186	
89	14.03	185.97	
90	14.02	185.98	
91	13.86	186.14	
92	14	186	
93	13.91	186.09	
94	13.8	186.2	
95	13.61	186.39	
95.8	13.41	186.59	
97.6	13.03	186.97	
98.6	12.86	187.14	REW
99.8	12.47	187.53	
100.7	11.92	188.08	
101	11.31	188.69	
101.6	10.83	189.17	
102	10.77	189.23	
102.7	10.41	189.59	
103.2	9.67	190.33	
103.9	9.21	190.79	
104.5	8.81	191.19	
105.2	8.43	191.57	
105.6	8.27	191.73	
106	7.89	192.11	
106.5	7.73	192.27	
107	7.49	192.51	
107.6	7.26	192.74	FP
108	7.26	192.74	
109	7.36	192.64	
111.7	6.54	193.46	

Table A.58 Survey Data: 03298000 Floyd's Fork at Fisherville, KY (all elevations relative).

STA	FS (ft)	Elevation (ft)	Note
0	6.05	193.95	
1	6.41	193.59	
2	6.45	193.55	
3	6.4	193.6	
4	6.37	193.63	
5	6.4	193.6	FP
6	6.55	193.45	
7	6.65	193.35	
8	6.7	193.3	
9	6.97	193.03	
10	7.08	192.92	
11	7.16	192.84	
12	7.16	192.84	BKF
13	7.29	192.71	
14	7.46	192.54	
15	7.65	192.35	
15.7	7.93	192.07	
16	8.16	191.84	
16.3	9.81	190.19	
16.7	9.94	190.06	
17.3	10.93	189.07	
18	11.01	188.99	
19	12	188	
20	12.55	187.45	
21	12.91	187.09	
22	13.04	186.96	
23	13.13	186.87	
23.3	13.4	186.6	LEW

Table A.58 (continued)

STA	FS (ft)	Elevation (ft)	Note
24	14.33	185.67	
25	14.59	185.41	
25.8	15.01	184.99	
26	15.13	184.87	
27	15.25	184.75	
28	15.33	184.67	
29	15.44	184.56	
30	15.45	184.55	
31	15.58	184.42	
32	15.62	184.38	
33	15.64	184.36	
34	15.73	184.27	
35	15.89	184.11	
36	15.95	184.05	
37	15.97	184.03	
38	15.99	184.01	
39	16	184	TW
40	15.95	184.05	
41	15.95	184.05	
43	15.94	184.06	
45	15.89	184.11	
47	15.84	184.16	
49	15.84	184.16	
51	15.82	184.18	
53	15.73	184.27	
55	15.73	184.27	
57	15.71	184.29	
59	15.59	184.41	
61	15.58	184.42	
63	15.59	184.41	
65	15.58	184.42	
67	15.46	184.54	
69	15.23	184.77	
70	15.23	184.77	
71	15.2	184.8	
72	15.19	184.81	

Table A.58 (continued)

STA	FS (ft)	Elevation (ft)	Note
73	15.16	184.84	
75	15.18	184.82	
77	15.16	184.84	
79	15.18	184.82	
81	15.17	184.83	
83	15.19	184.81	
84	15.15	184.85	
85	15.11	184.89	
86	15.1	184.9	
87	15.13	184.87	
88	15.12	184.88	
89	15.1	184.9	
90	15.02	184.98	
91	15.03	184.97	
92	14.92	185.08	
93	14.98	185.02	
94	14.97	185.03	
95	15.02	184.98	
96	15.05	184.95	
97	15.06	184.94	
98	15.05	184.95	
99	15	185	
100	15.03	184.97	
102	14.99	185.01	
103	14.86	185.14	
104	14.75	185.25	
106	14.69	185.31	
107	14.55	185.45	
108	14.45	185.55	
109	14.31	185.69	
110	14.23	185.77	
111	14.22	185.78	
112	14.27	185.73	

Table A.58 (continued)

STA	FS (ft)	Elevation (ft)	Note
113	14.2	185.8	
114	14.05	185.95	
115	13.8	186.2	
116	13.39	186.61	
116.9	13.24	186.76	REW
118	12.99	187.01	
119	12.88	187.12	
120	12.85	187.15	
121	12.8	187.2	
122	12.76	187.24	
123	12.66	187.34	
124	12.65	187.35	
125	12.6	187.4	
126	12.56	187.44	
127	12.46	187.54	
128	12.32	187.68	
129	12.02	187.98	
130	11.7	188.3	
131	11.29	188.71	
132	11	189	
134	10.36	189.64	
135	9.8	190.2	
135.7	8.66	191.34	
136.8	7.05	192.95	
137.1	6.08	193.92	
137.7	5.75	194.25	
138	5.6	194.4	
138.6	5.31	194.69	
139	5.1	194.9	
139.5	4.92	195.08	
140	4.81	195.19	

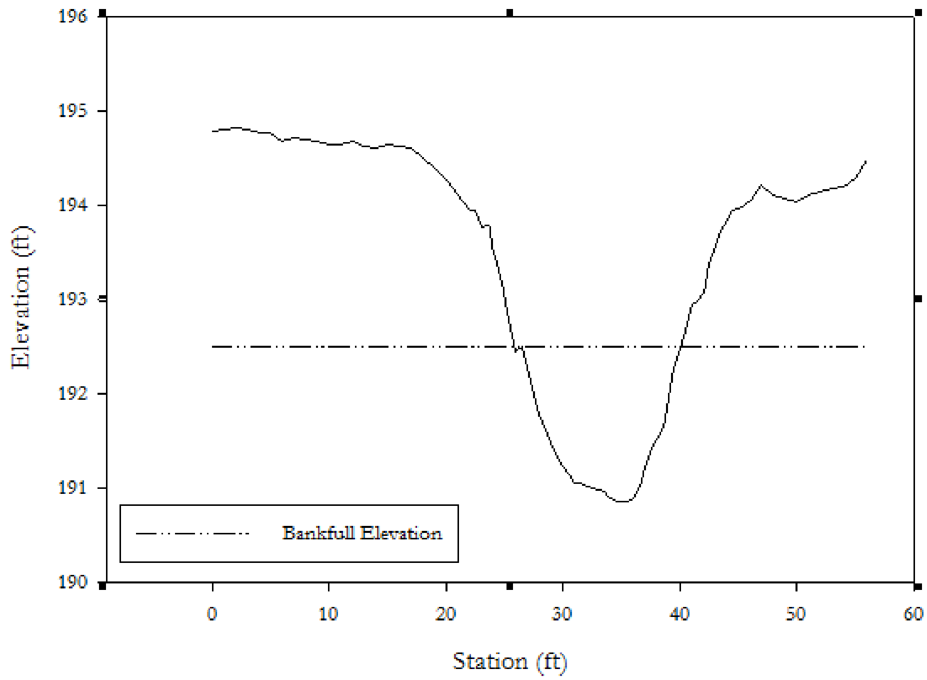

Figure A.1 Graph of Cross-section at: East Hickman trib at Chilesburg.

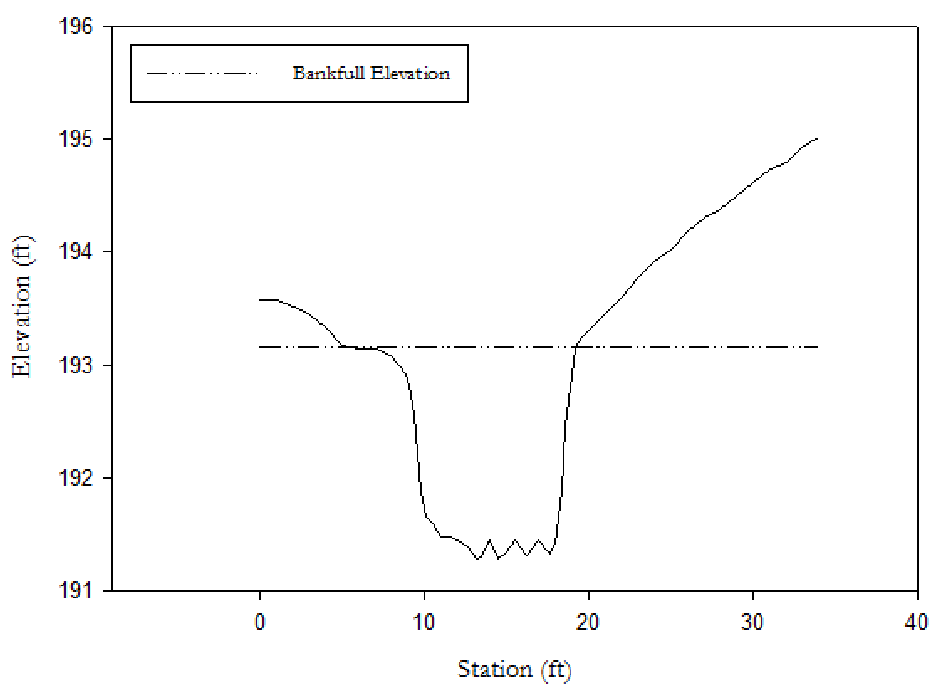

Figure A.2 Graph of Cross-section at: 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

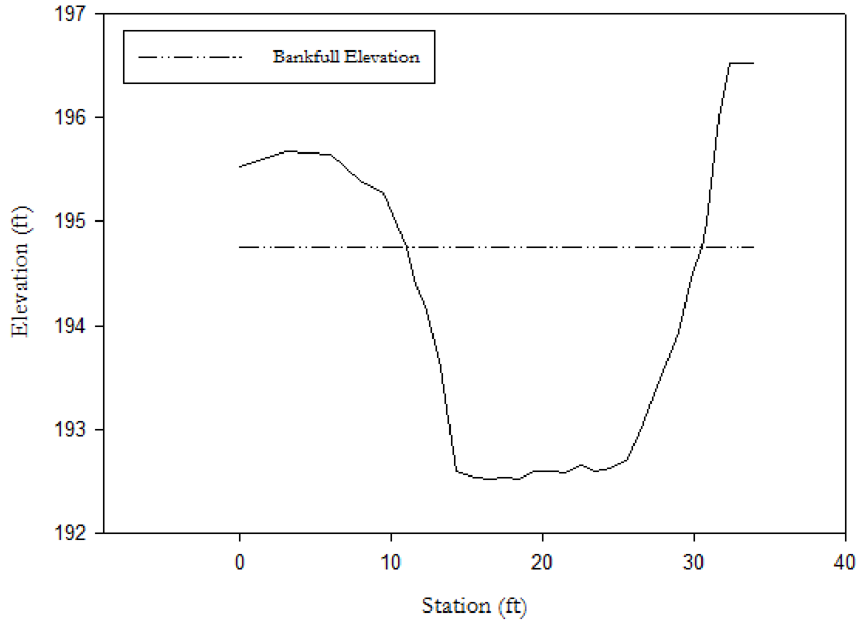

Figure A.3 Graph of Cross-section at: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

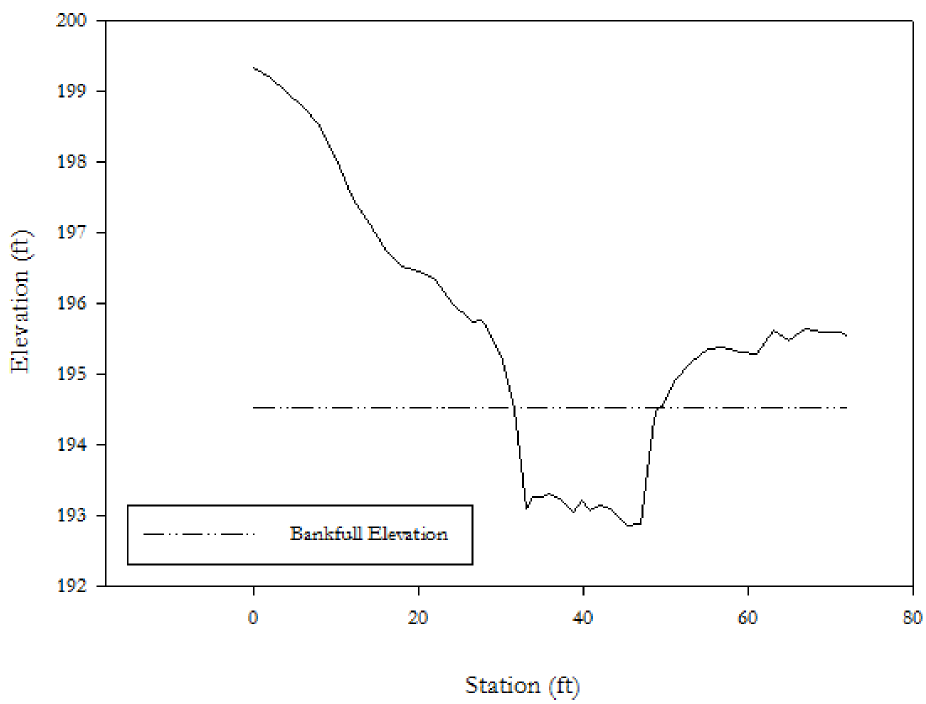

Figure A.4 Graph of Cross-section at: 03288500 Cave Creek near Fort Springs, KY.

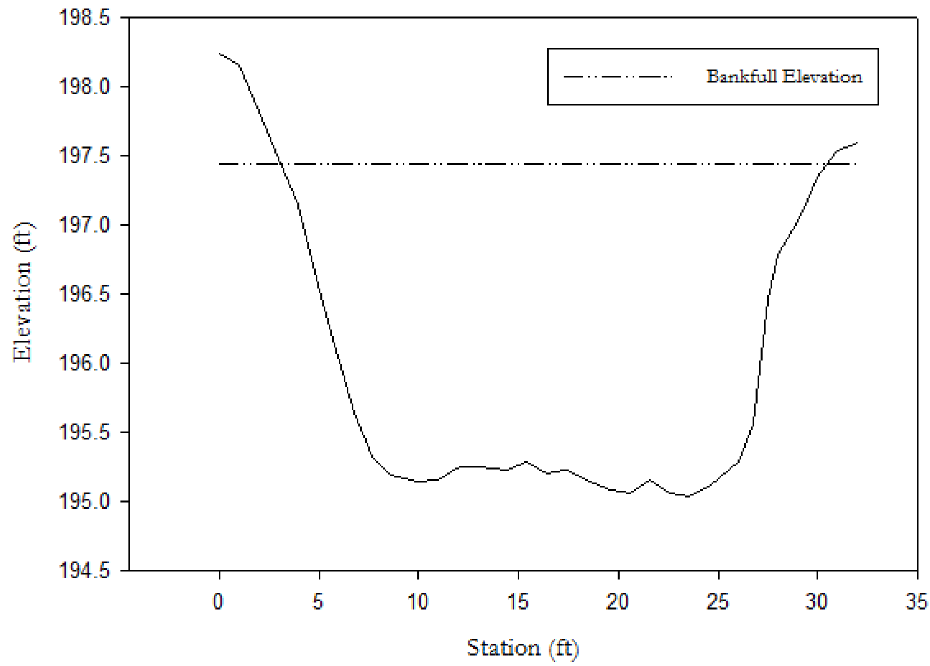

Figure A.5 Graph of Cross-section at: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

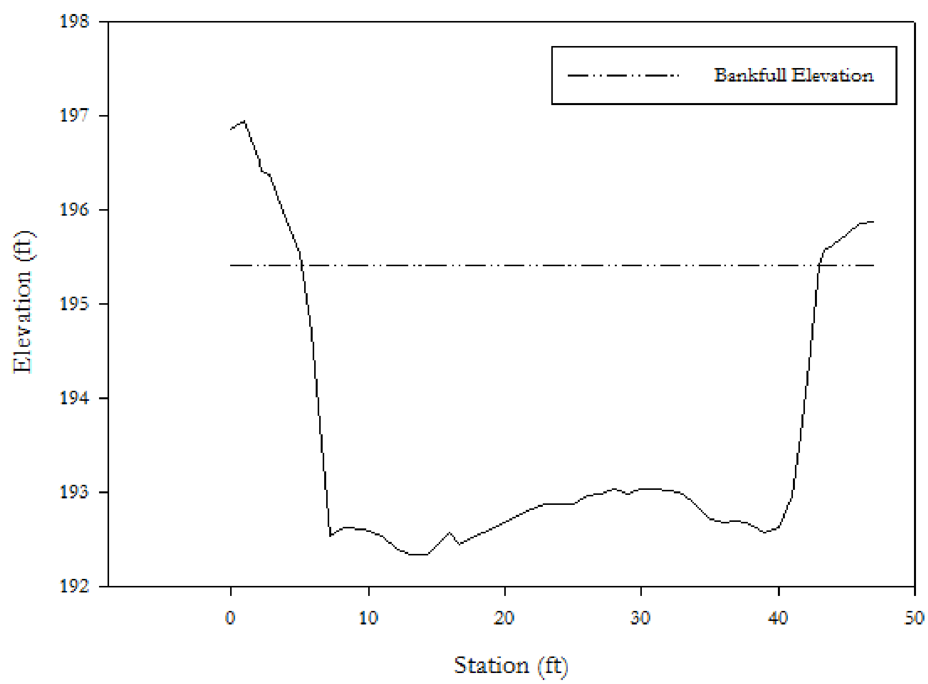

Figure A.6 Graph of Cross-section at: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

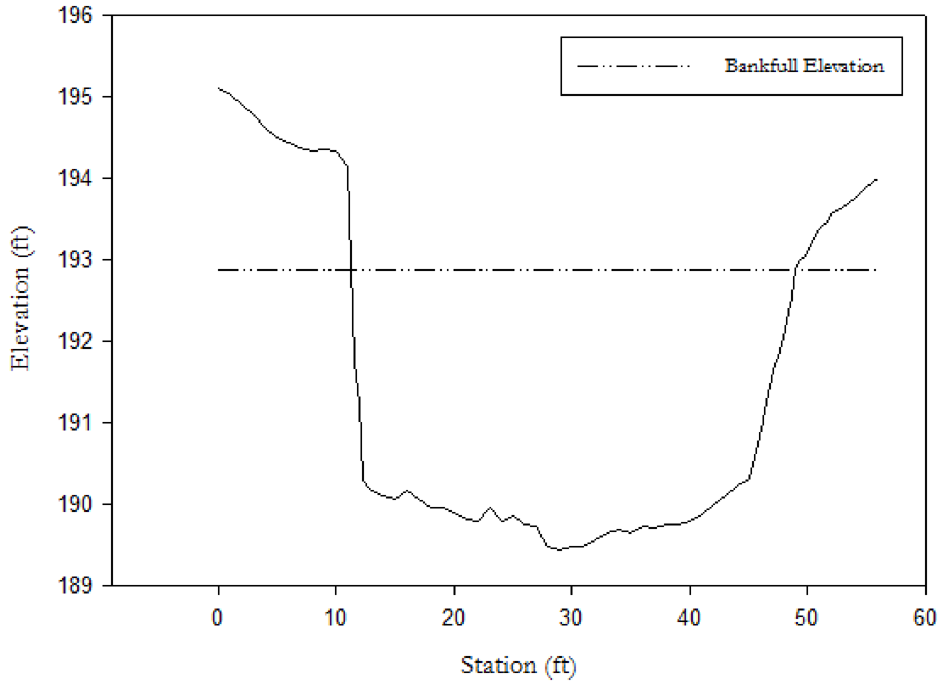

Figure A.7 Graph of Cross-section at: 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

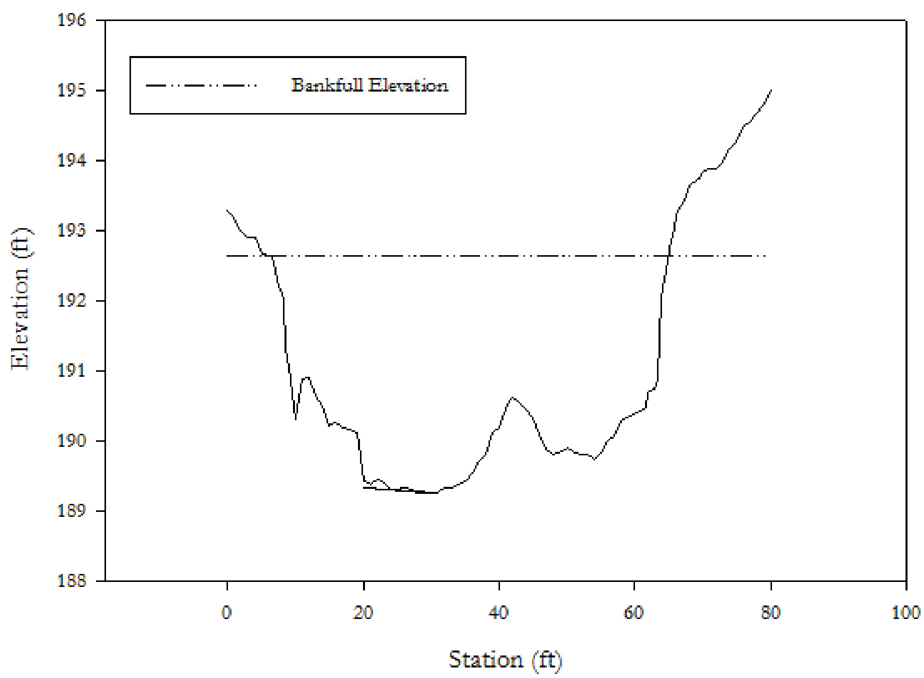

Figure A.8 Graph of Cross-section at: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

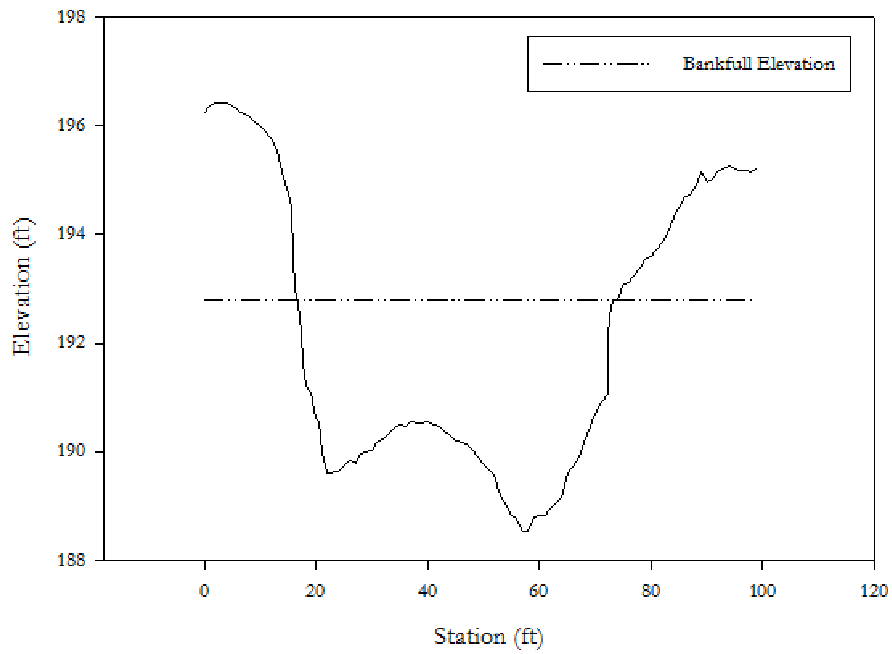

Figure A.9 Graph of Cross-section at: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

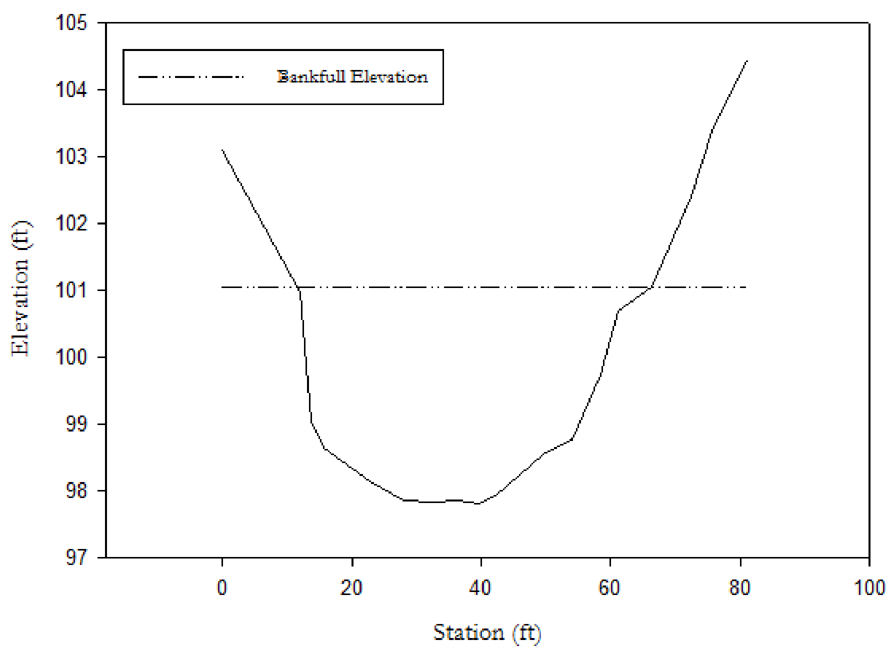

Figure A.10 Graph of Cross-section at: 03289000 South Elkhorn Creek at Fort Springs, KY.

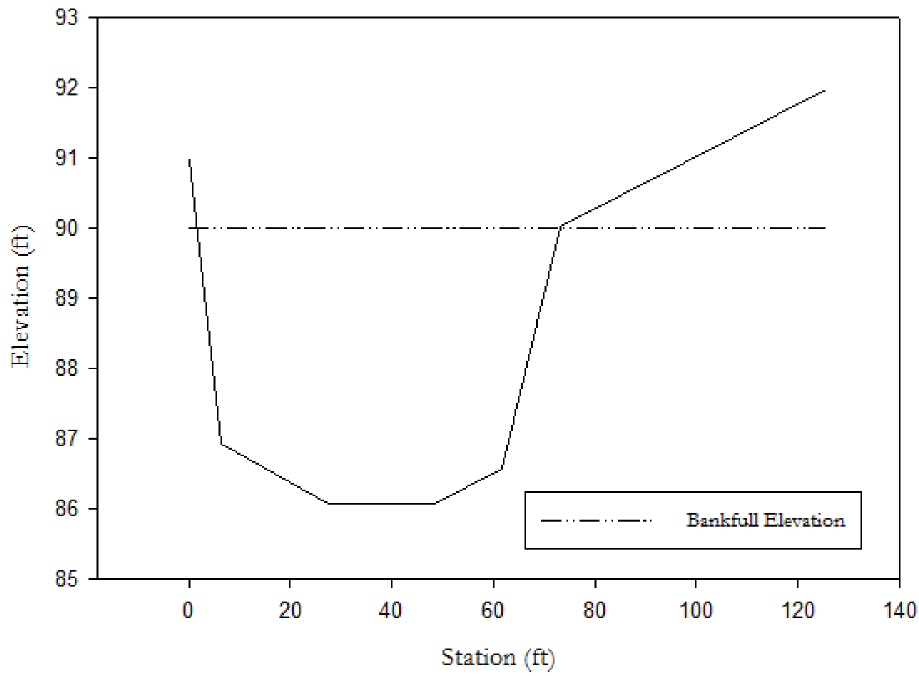

Figure A.11 Graph of Cross-section at: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

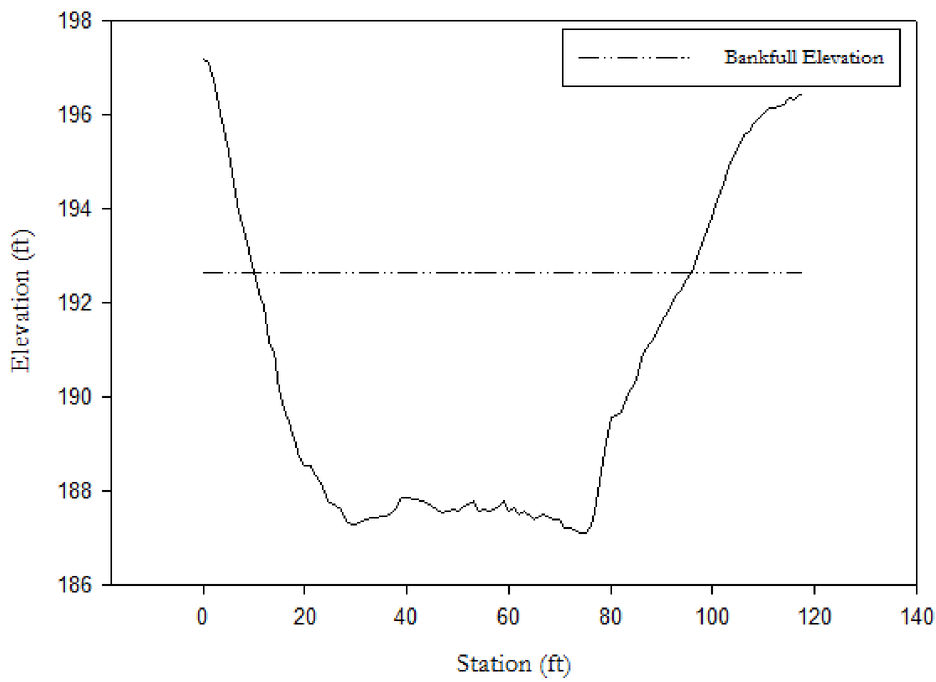

Figure A.12 Graph of Cross-section at: 03291000 Eagle Creek at Sadieville, KY.

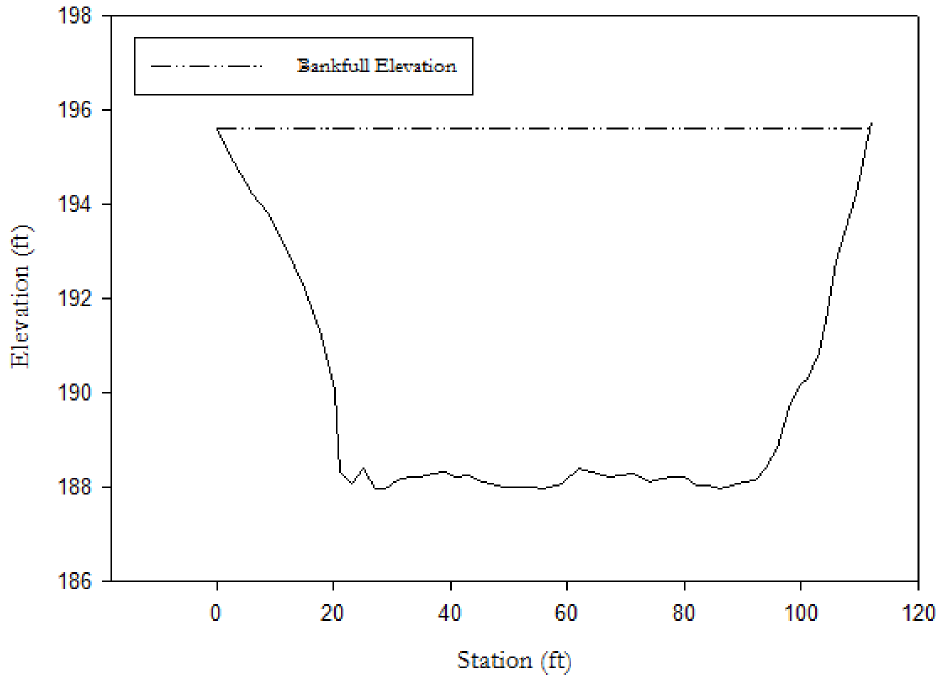

Figure A.13 Graph of Cross-section at: 03288000 North Elkhorn Creek near Georgetown, KY.

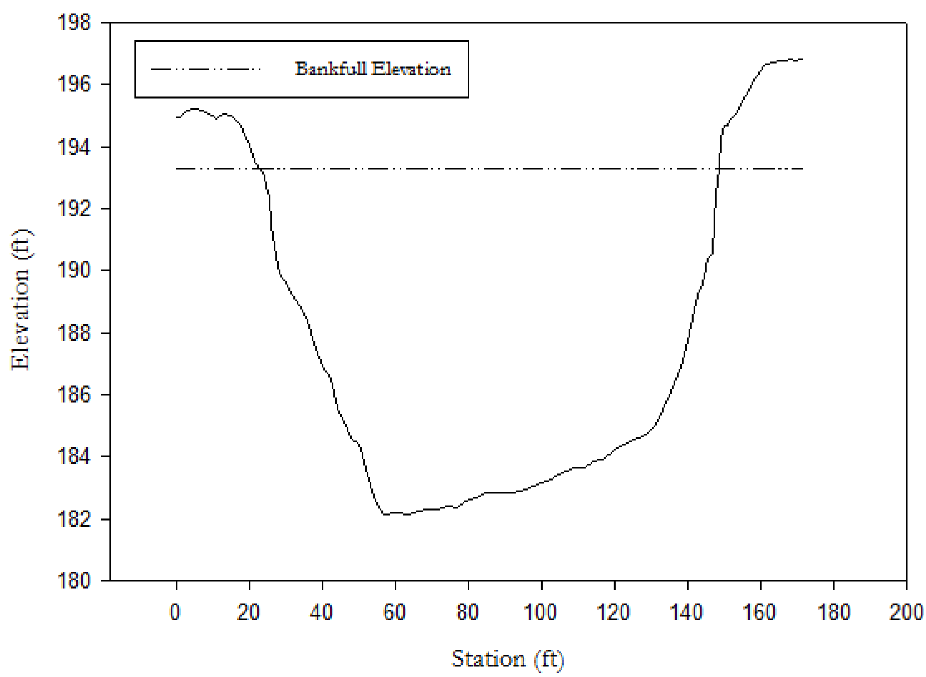

Figure A.14 Graph of Cross-section at: 03288100 North Elkhorn Creek at Georgetown, KY.

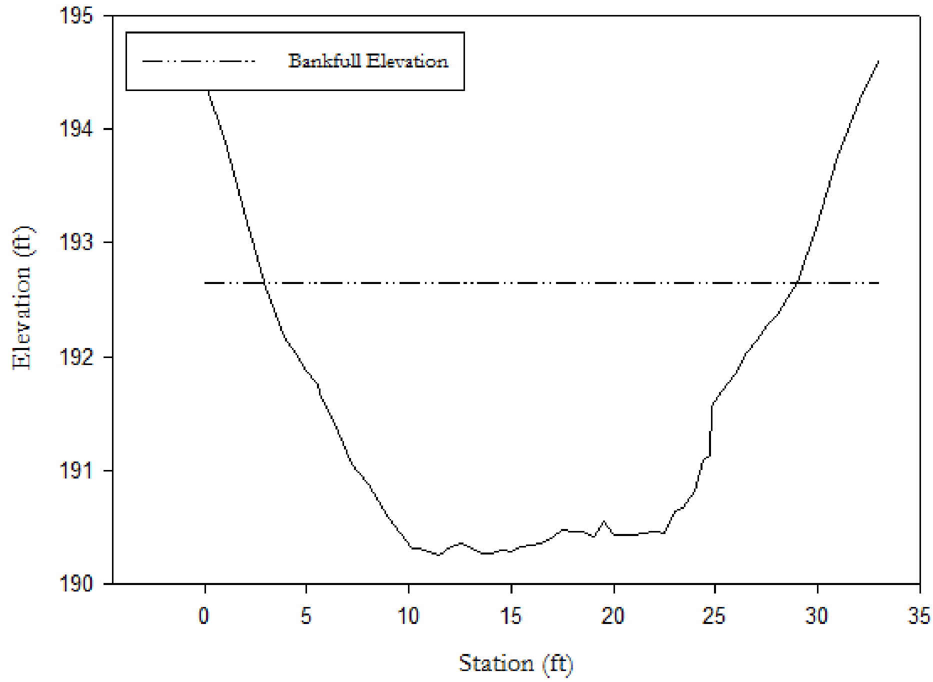

Figure A.15 Graph of Cross-section at: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

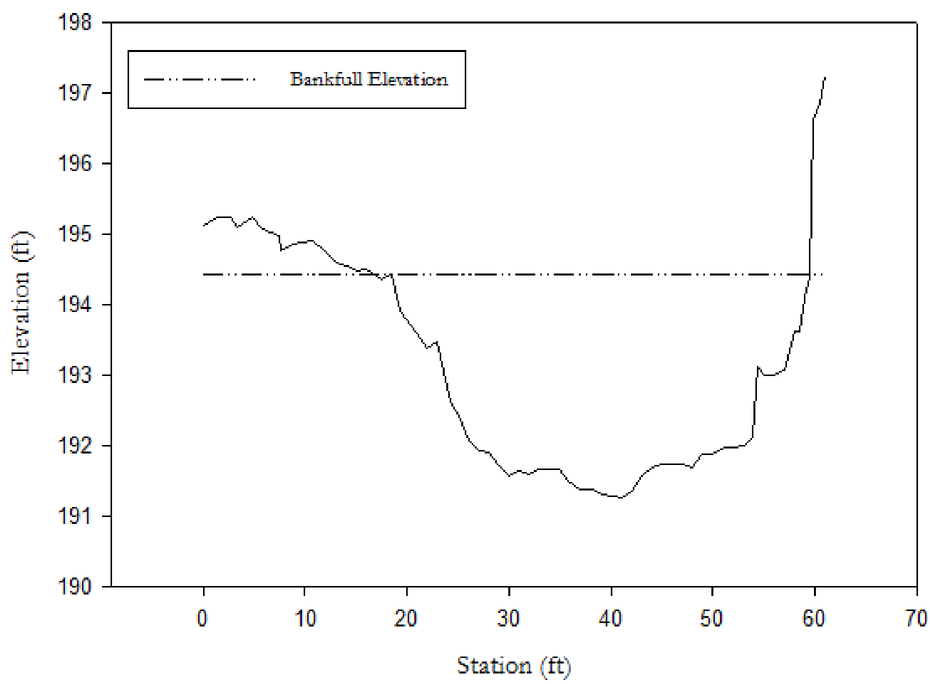

Figure A.16 Graph of Cross-section at: 03254400 North Fork Grassy Creek near Piner, KY.

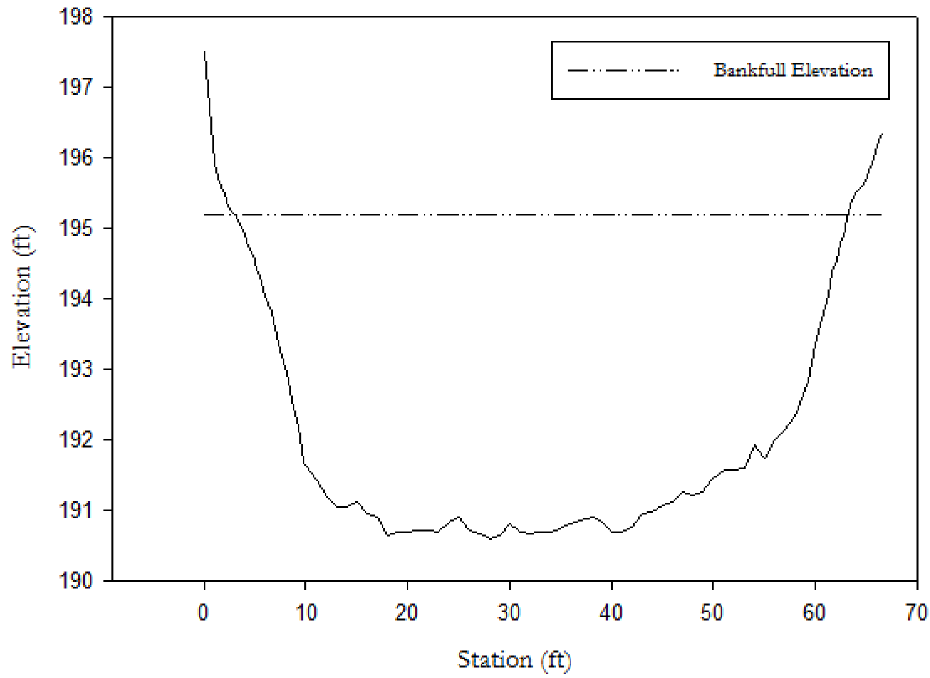

Figure A.17 Graph of Cross-section at: 03254480 Cruises Creek at Highway 17 near Piner, KY.

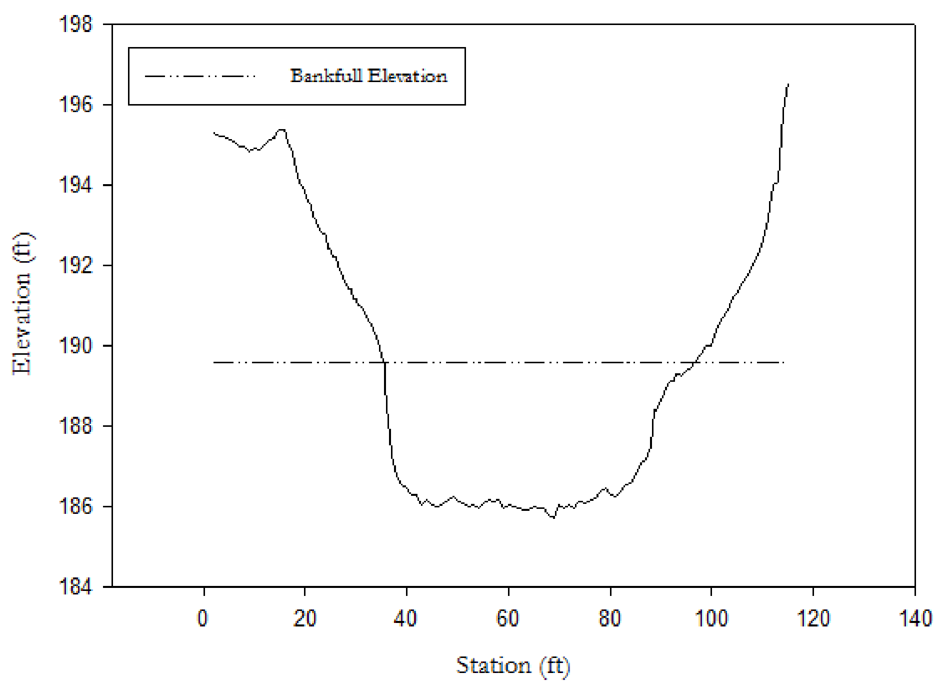

Figure A.18 Graph of Cross-section at: 03262001 Woolper Creek at Woolper Road near Burlington, KY.

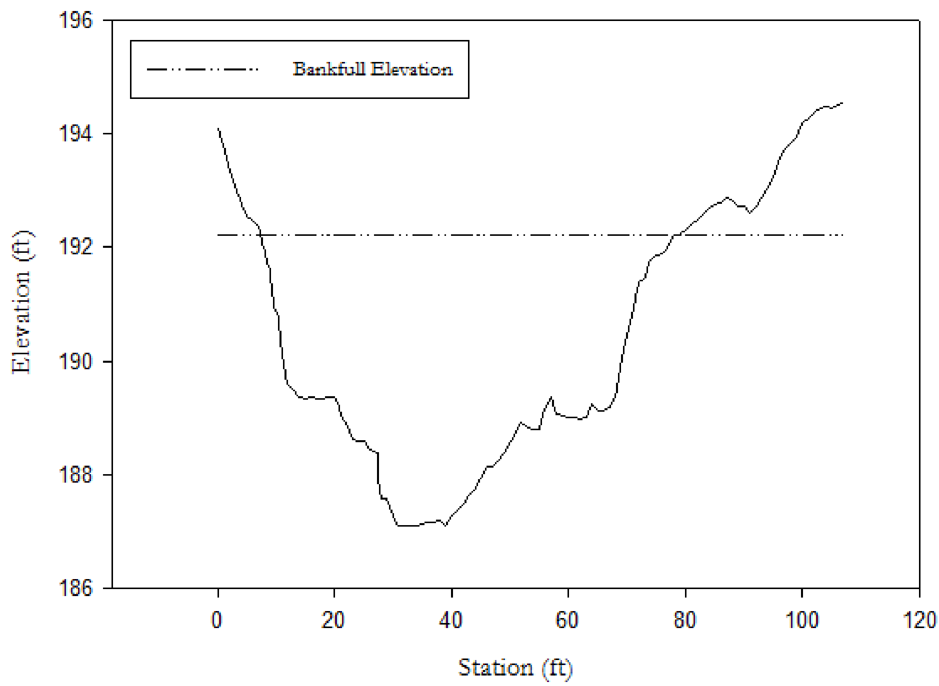

Figure A.19 Graph of Cross-section at: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

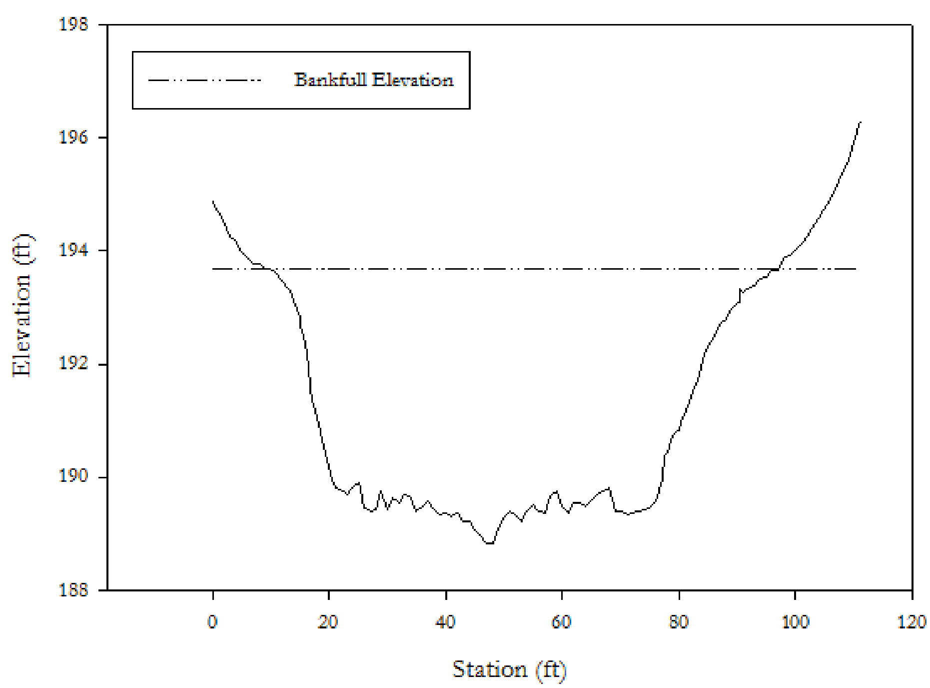

Figure A.20 Graph of Cross-section at: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

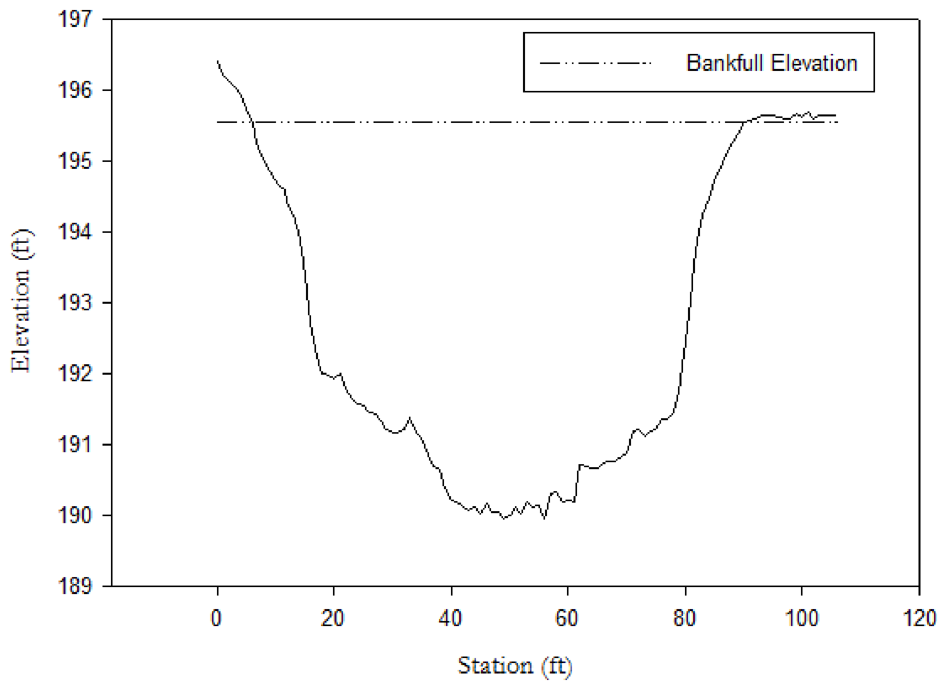

Figure A.21 Graph of Cross-section at: 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.

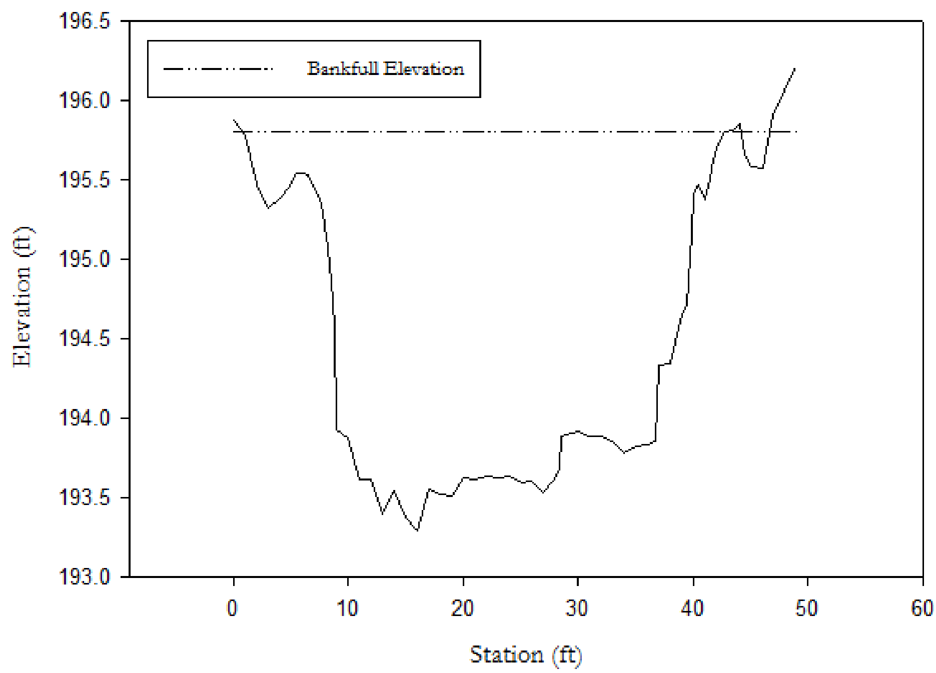

Figure A.22 Graph of Cross-section at: 03298135 Chenoweth Run at Ruckriegal Parkway, KY.

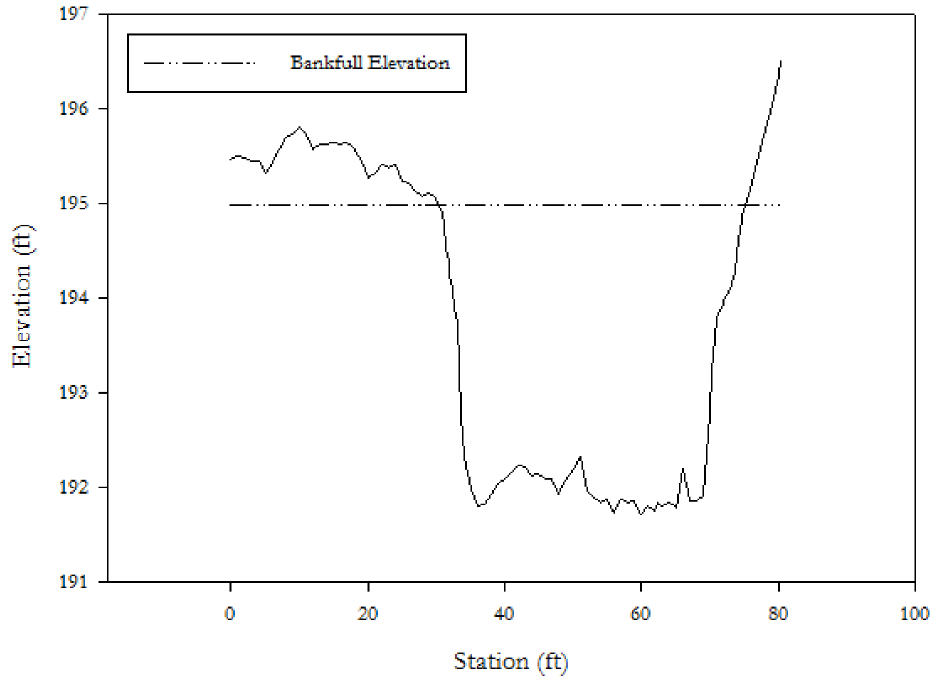

Figure A.23 Graph of Cross-section at: 03292480 Little Goose near Harrods Creek, KY.

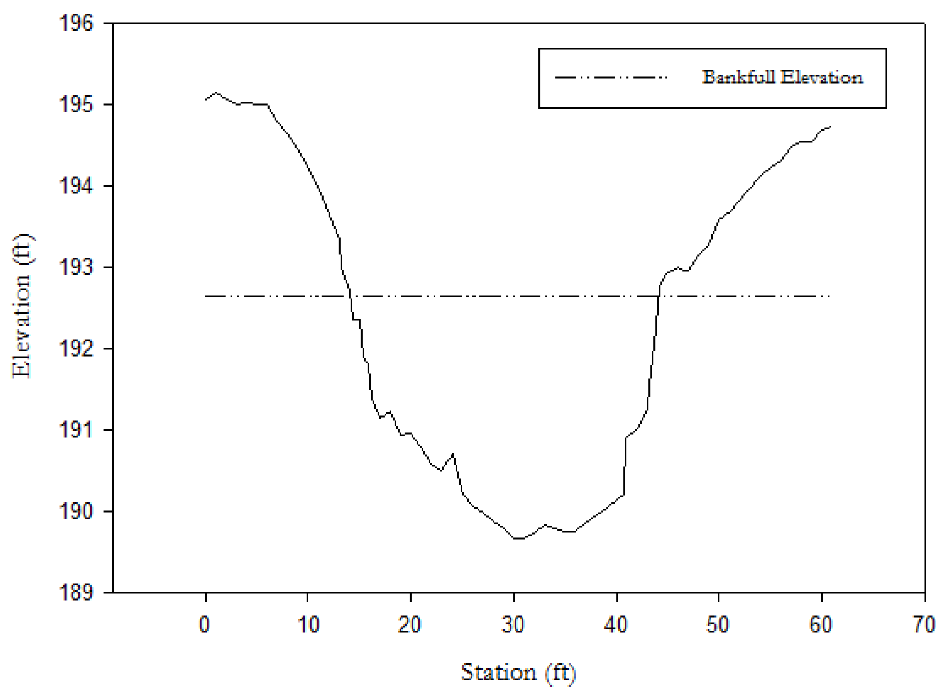

Figure A.24 Graph of Cross-section at: 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.

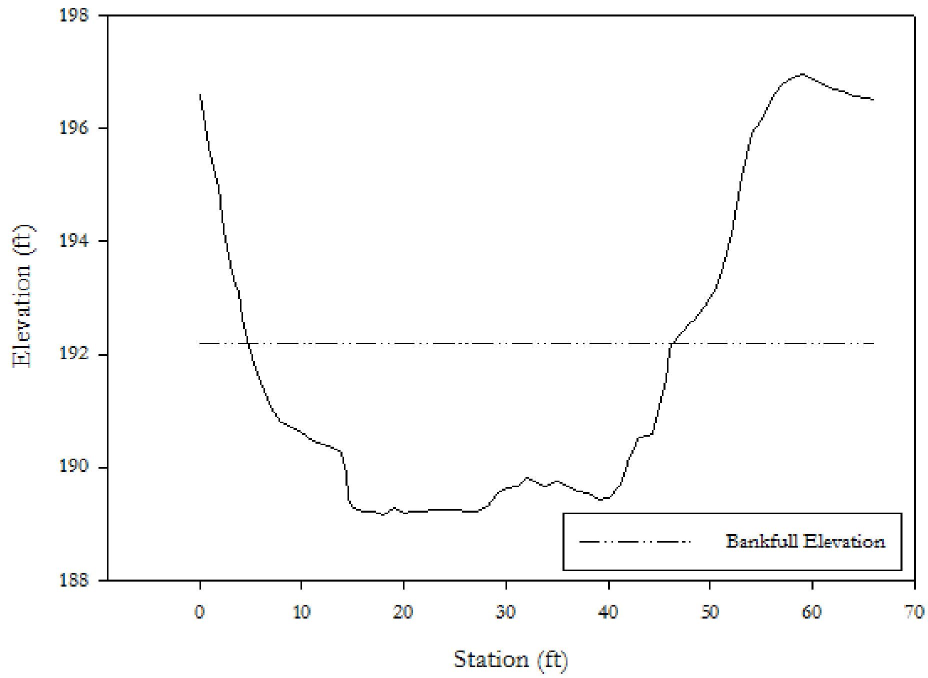

Figure A.25 Graph of Cross-section at: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

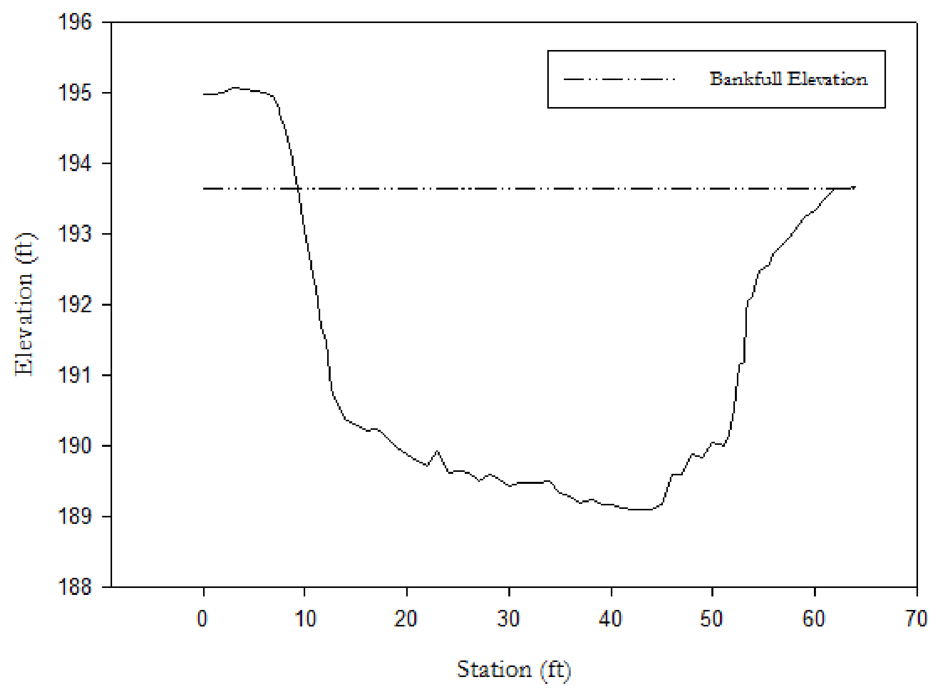

Figure A.26 Graph of Cross-section at: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

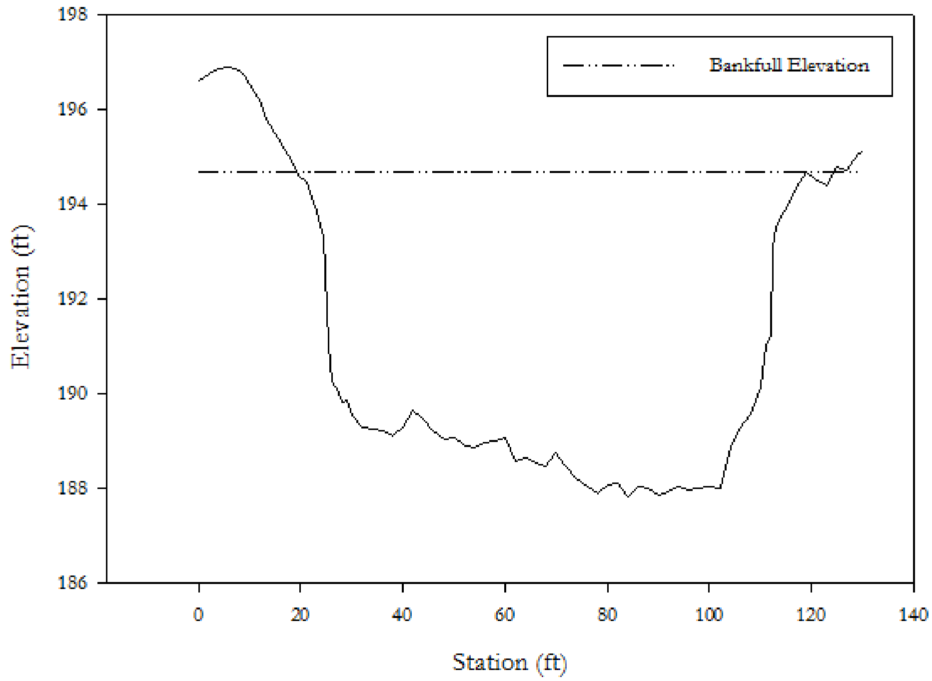

Figure A.27 Graph of Cross-section at: 03277130 Mud Lick at Highway 42 near Beaverlick, KY.

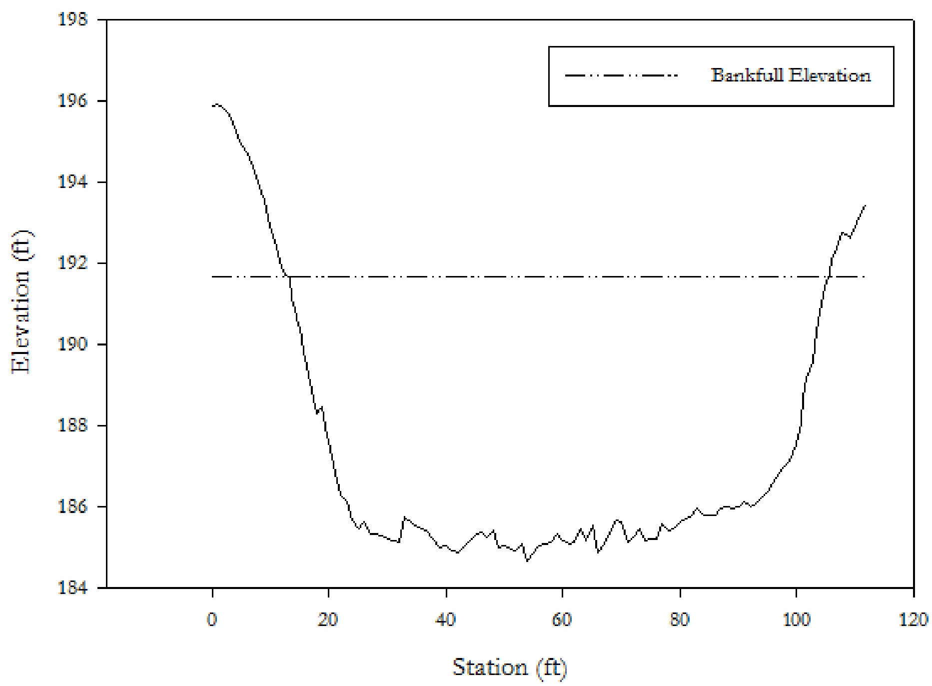

Figure A.28 Graph of Cross-section at: 03292470 Harrods Creek at Highway 329 near Goshen, KY.

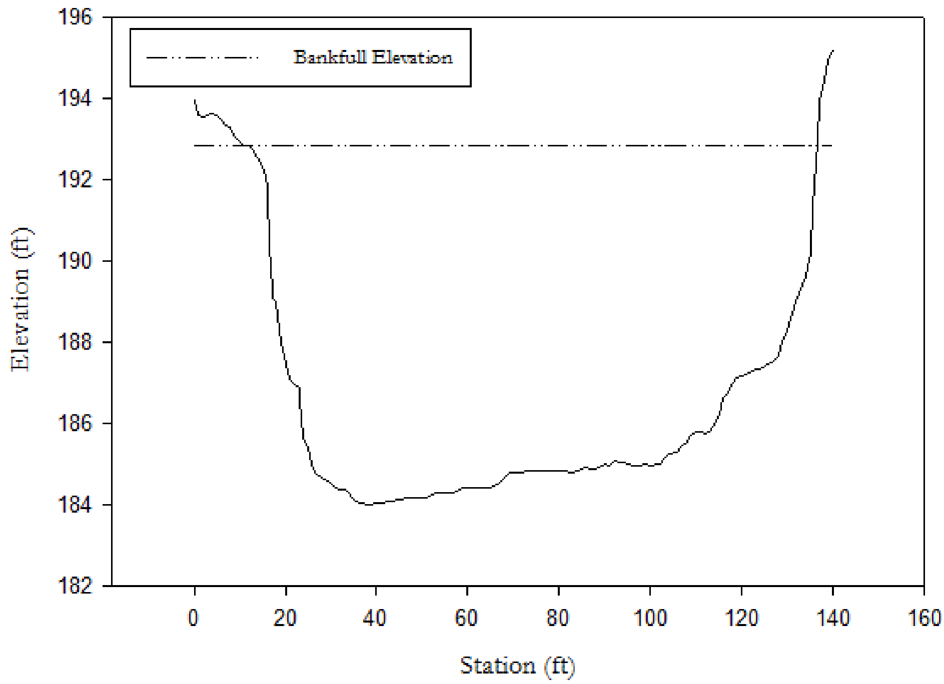

Figure A.29 Graph of Cross-section at: 03298000 Floyd's Fork at Fisherville, KY.


Figure A.30 Upstream View of 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.


Figure A.31 Downstream View of 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.

Figure A.32 Upstream View of 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

Figure A.33 Downstream View of 03284520 East Hickman Creek at Andover Village near Cadentown, KY.


Figure A.34 Upstream View of 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.


Figure A.35 Downstream View of 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

Figure A.36 Upstream View of 03288500 Cave Creek near Fort Springs, KY.

Figure A.37 Downstream View of 03288500 Cave Creek near Fort Springs, KY.

Figure A.38 Upstream View of 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

Figure A.39 Downstream View of 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.


Figure A.40 Upstream View of 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.


Figure A.41 Downstream View of 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

Figure A.42 Upstream View of 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

Figure A.43 Downstream View of 03284530 East Hickman Creek at Delong Road near East Hickman, KY.


Figure A.44 Downstream View of 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

Figure A.45 Upstream View of 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

Figure A.46 Upstream View of 03289000 South Elkhorn Creek at Fort Springs, KY.

Figure A.47 Downstream View of 03289000 South Elkhorn Creek at Fort Springs, KY.

Figure A.48 Upstream View of 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

Figure A.49 Downstream View of 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.


Figure A.50 Upstream View of 03291000 Eagle Creek at Sadieville, KY.


Figure A.51 Downstream View of 03291000 Eagle Creek at Sadieville, KY.

Figure A.52 Upstream View of 03288000 North Elkhorn Creek near Georgetown, KY.

Figure A.53 Downstream View of 03288000 North Elkhorn Creek near Georgetown, KY.


Figure A.54 Upstream View of 03288100 North Elkhorn Creek at Georgetown, KY.

Figure A.55 Upstream View of 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

Figure A.56 Downstream View of 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

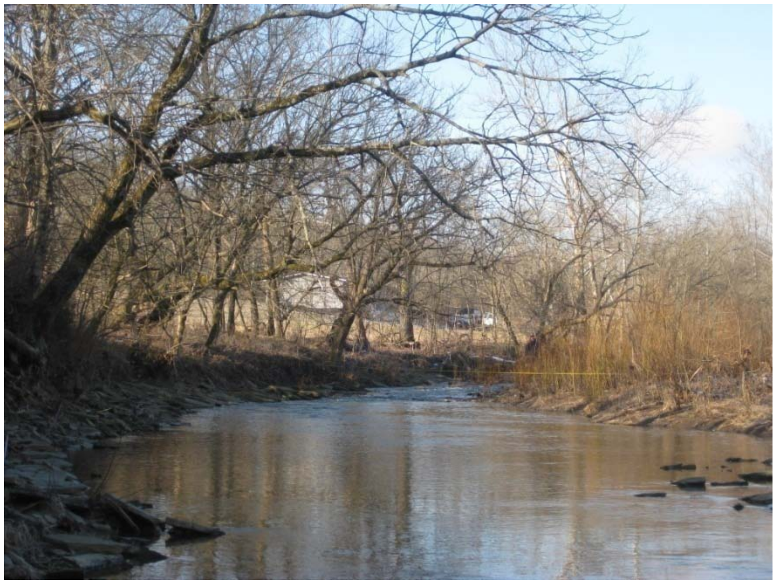
Figure A.57 Upstream View of 03254400 North Fork Grassy Creek near Piner, KY.


Figure A.58 Downstream View of 03254400 North Fork Grassy Creek near Piner, KY.

Figure A.59 Upstream View of 03254480 Cruises Creek at Highway 17 near Piner, KY.

Figure A.60 Downstream View of 03254480 Cruises Creek at Highway 17 near Piner, KY.

Figure A.61 Upstream View of 03262001 Woolper Creek at Woolper Road near Burlington, KY.

Figure A.62 Downstream View of 03262001 Woolper Creek at Woolper Road near Burlington, KY.

Figure A.63 Upstream View of 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

Figure A.64 Downstream View of 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

Figure A.65 Upstream View of 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

Figure A.66 Downstream View of 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

Figure A.67 Upstream View of 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.

Figure A.68 Downstream View of 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.


Figure A.69 Upstream View of 03298135 Chenoweth Run at Ruckriegal Parkway, KY.


Figure A.70 Downstream View of 03298135 Chenoweth Run at Ruckriegal Parkway, KY.

Figure A.71 Upstream View of 03292480 Little Goose near Harrods Creek, KY.

Figure A.72 Downstream View of 03292480 Little Goose near Harrods Creek, KY.

Figure A.73 Upstream View of 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.

Figure A.74 Downstream View of 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.


Figure A.75 Upstream View of 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.


Figure A.76 Downstream View of 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

Figure A.77 Upstream View of 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

Figure A.78 Downstream View of 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

Figure A.79 Upstream View of 03277130 Mud Lick at Highway 42 near Beaverlick, KY.

Figure A.80 Downstream View of 03277130 Mud Lick at Highway 42 near Beaverlick, KY.


Figure A.81 Upstream View of 03292470 Harrods Creek at Highway 329 near Goshen, KY.

Figure A.82 Upstream View of 03298000 Floyd's Fork at Fisherville, KY.

Figure A.83 Downstream View of 03298000 Floyd's Fork at Fisherville, KY.

Appendix B: Bed Material Summary

Table B.1 Representative Reach Particle Size Data: 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	1
2.0-4.0	45
4.0-5.7	12
5.7-8.0	13
8.0-11.3	8
11.3-16.0	13
16.0-22.6	5
22.6-32	2
32-45	1
45-64	0
64-90	0
90-128	0
128-180	0
180-256	0
256-362	0
362-512	0
512-1024	0
1024-2048	0
Bedrock	0

Table B.2 Representative Reach Particle Size Analysis: 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.

Classification (mm)	Size (mm)
D_{16}	2.6
D_{35}	3.5
D_{50}	4.5
D_{84}	13.1
D_{95}	19.9
D_{100}	45

Table B.3 Representative Reach Particle Size Data: 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	3
2.0-4.0	15
4.0-5.7	5
5.7-8.0	10
8.0-11.3	8
11.3-16.0	11
16.0-22.6	13
22.6-32	16
32-45	8
45-64	3
64-90	4
90-128	2
128-180	2
180-256	0
256-362	0
362-512	0
512-1024	0
1024-2048	0
Bedrock	0

Table B.4 Representative Reach Particle Size Analysis: 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

Classification (mm)	Size (mm)
D_{16}	3.7
D_{35}	8.8
D_{50}	15.2
D_{84}	36.9
D_{95}	83.5
D_{100}	180

Table B.5 Representative Reach Particle Size Data: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	10
2.0-4.0	14
4.0-5.7	37
5.7-8.0	12
8.0-11.3	38
11.3-16.0	19
16.0-22.6	12
22.6-32	10
32-45	12
45-64	18
64-90	41
90-128	34
128-180	23
180-256	13
256-362	4
362-512	0
512-1024	0
1024-2048	0
Bedrock	3

Table B.6 Representative Reach Particle Size Analysis: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

Classification (mm)	Size (mm)
D_{16}	5.1
D_{35}	10.8
D_{50}	30.1
D_{84}	122.4
D_{95}	209.2
D_{100}	Bedrock

Table B.7 Representative Reach Particle Size Data: 03288500 Cave Creek near Fort Springs, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	9
2.0-4.0	29
4.0-5.7	30
5.7-8.0	12
8.0-11.3	24
11.3-16.0	34
16.0-22.6	29
22.6-32	35
32-45	24
45-64	20
64-90	19
90-128	17
128-180	5
180-256	7
256-362	3
362-512	0
512-1024	1
1024-2048	0
Bedrock	2

Table B.8 Representative Reach Particle Size Analysis: 03288500 Cave Creek near Fort Springs, KY.

Classification (mm)	Size (mm)
D_{16}	4.6
D_{35}	11.4
D_{50}	18.7
D_{84}	72.2
D_{95}	159.1
D_{100}	Bedrock

Table B.9 Representative Reach Particle Size Data: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	4
2.0-4.0	20
4.0-5.7	27
5.7-8.0	8
8.0-11.3	22
11.3-16.0	17
16.0-22.6	21
22.6-32	27
32-45	25
45-64	28
64-90	38
90-128	29
128-180	11
180-256	5
256-362	6
362-512	0
512-1024	0
1024-2048	0
Bedrock	12

Table B.10 Representative Reach Particle Size Analysis: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

Classification (mm)	Size (mm)
D_{16}	5.5
D_{35}	18.2
D_{50}	34.1
D_{84}	109.7
D_{95}	309
D_{100}	Bedrock

Table B.11 Representative Reach Particle Size Data: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	6
2.0-4.0	9
4.0-5.7	12
5.7-8.0	11
8.0-11.3	14
11.3-16.0	24
16.0-22.6	20
22.6-32	22
32-45	15
45-64	23
64-90	44
90-128	52
128-180	25
180-256	15
256-362	5
362-512	1
512-1024	0
1024-2048	0
Bedrock	2

Table B.12 Representative Reach Particle Size Analysis: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

Classification (mm)	Size (mm)
$\mathbf{D_{16}}$	10.4
$\mathbf{D_{35}}$	26.5
$\mathbf{D_{50}}$	59.1
$\mathbf{D_{84}}$	128
$\mathbf{D_{95}}$	220.6
$\mathbf{D_{100}}$	Bedrock

Table B.13 Representative Reach Particle Size Data: 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	2
2.0-4.0	1
4.0-5.7	4
5.7-8.0	1
8.0-11.3	2
11.3-16.0	7
16.0-22.6	7
22.6-32	13
32-45	9
45-64	9
64-90	10
90-128	11
128-180	12
180-256	5
256-362	3
362-512	0
512-1024	0
1024-2048	0
Bedrock	4

Table B.14 Representative Reach Particle Size Analysis: 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

Classification (mm)	Size (mm)
D_{16}	15.3
D_{35}	30.6
D_{50}	53.4
D_{84}	162.7
D_{95}	326.7
D_{100}	Bedrock

Table B.15 Representative Reach Particle Size Data: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	8
2.0-4.0	11
4.0-5.7	22
5.7-8.0	6
8.0-11.3	12
11.3-16.0	10
16.0-22.6	7
22.6-32	15
32-45	12
45-64	22
64-90	37
90-128	53
128-180	38
180-256	13
256-362	3
362-512	1
512-1024	0
1024-2048	0
Bedrock	30

Table B.26 Representative Reach Particle Size Analysis: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

Classification (mm)	Size (mm)
D_{16}	8.3
D_{35}	46.7
D_{50}	81.6
D_{84}	178.6
D_{95}	Bedrock
D_{100}	Bedrock

Table B.37 Representative Reach Particle Size Data: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	1
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	6
32-45	23
45-64	22
64-90	23
90-128	16
128-180	5
180-256	4
256-362	0
362-512	0
512-1024	0
1024-2048	0
Bedrock	0

Table B.18 Representative Reach Particle Size Analysis: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

Classification (mm)	Size (mm)
D_{16}	37.1
D_{35}	49.3
D_{50}	62.3
D_{84}	111.4
D_{95}	169.6
D_{100}	256

Table B.49 Representative Reach Particle Size Data: 03289000 South Elkhorn Creek at Fort Springs, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	12
2.0-4.0	0
4.0-5.7	0
5.7-8.0	0
8.0-11.3	1
11.3-16.0	2
16.0-22.6	0
22.6-32	1
32-45	21
45-64	26
64-90	65
90-128	75
128-180	28
180-256	48
256-362	8
362-512	2
512-1024	0
1024-2048	0
Bedrock	11

Table B.20 Representative Reach Particle Size Analysis: 03289000 South Elkhorn Creek at Fort Springs, KY.

Classification (mm)	Size (mm)
D_{16}	47.5
D_{35}	78.5
D_{50}	98.9
D_{84}	211
D_{95}	329.7
D_{100}	Bedrock

Table B.21 Representative Reach Particle Size Data: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	0
4.0-5.7	0
5.7-8.0	0
8.0-11.3	6
11.3-16.0	8
16.0-22.6	7
22.6-32	17
32-45	45
45-64	38
64-90	51
90-128	44
128-180	34
180-256	10
256-362	5
362-512	0
512-1024	0
1024-2048	0
Bedrock	35

Table B.22 Representative Reach Particle Size Analysis: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

Classification (mm)	Size (mm)
D_{16}	34.9
D_{35}	56
D_{50}	78.8
D_{84}	195.3
D_{95}	Bedrock
D_{100}	Bedrock

Table B.23 Representative Reach Particle Size Data: 03291000 Eagle Creek at Sadieville, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	2
2.0-4.0	23
4.0-5.7	19
5.7-8.0	27
8.0-11.3	11
11.3-16.0	13
16.0-22.6	1
22.6-32	2
32-45	2
45-64	0
64-90	0
90-128	0
128-180	0
180-256	0
256-362	0
362-512	0
512-1024	0
1024-2048	0
Bedrock	0

Table B.24 Representative Reach Particle Size Analysis: 03291000 Eagle Creek at Sadieville, KY.

Classification (mm)	Size (mm)
D_{16}	3.2
D_{35}	4.9
D_{50}	6.2
D_{84}	12.0
D_{95}	16
D_{100}	45

Table B.55 Representative Reach Particle Size Data: 03288000 North Elkhorn Creek near Georgetown, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	9
2.0-4.0	2
4.0-5.7	3
5.7-8.0	2
8.0-11.3	6
11.3-16.0	8
16.0-22.6	9
22.6-32	24
32-45	40
45-64	51
64-90	57
90-128	48
128-180	23
180-256	7
256-362	4
362-512	0
512-1024	0
1024-2048	0
Bedrock	7

Table B.66 Representative Reach Particle Size Analysis: 03288000 North Elkhorn Creek near Georgetown, KY.

Classification (mm)	Size (mm)
D_{16}	26.4
D_{35}	46.3
D_{50}	63.3
D_{84}	125.1
D_{95}	253.7
D_{100}	Bedrock

Table B.77 Representative Reach Particle Size Data: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	0
4.0-5.7	1
5.7-8.0	4
8.0-11.3	2
11.3-16.0	4
16.0-22.6	8
22.6-32	2
32-45	15
45-64	17
64-90	20
90-128	21
128-180	4
180-256	2
256-362	0
362-512	0
512-1024	0
1024-2048	0
Bedrock	0

Table B.88 Representative Reach Particle Size Analysis: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

Classification (mm)	Size (mm)
D_{16}	20.1
D_{35}	44.1
D_{50}	60.7
D_{84}	109.9
D_{95}	141
D_{100}	256

Table B.29 Representative Reach Particle Size Data: 03254480 Cruises Creek at Highway 17 near Piner, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	1
4.0-5.7	1
5.7-8.0	1
8.0-11.3	4
11.3-16.0	5
16.0-22.6	7
22.6-32	7
32-45	11
45-64	17
64-90	20
90-128	7
128-180	14
180-256	3
256-362	1
362-512	1
512-1024	0
1024-2048	0
Bedrock	0

Table B.30 Representative Reach Particle Size Analysis: 03254480 Cruises Creek at Highway 17 near Piner, KY.

Classification (mm)	Size (mm)
D_{16}	19.8
D_{35}	42.6
D_{50}	59.5
D_{84}	139.1
D_{95}	180
D_{100}	512

Table B.31 Representative Reach Particle Size Data: 03262001 Woolper Creek at Woolper Road near Burlington, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	3
4.0-5.7	2
5.7-8.0	1
8.0-11.3	3
11.3-16.0	0
16.0-22.6	1
22.6-32	5
32-45	8
45-64	13
64-90	19
90-128	18
128-180	17
180-256	7
256-362	1
362-512	2
512-1024	0
1024-2048	0
Bedrock	0

Table B.32 Representative Reach Particle Size Analysis: 03262001 Woolper Creek at Woolper Road near Burlington, KY.

Classification (mm)	Size (mm)
D_{16}	1.7
D_{35}	25.5
D_{50}	45.5
D_{84}	104.9
D_{95}	155.1
D_{100}	362

Table B.33 Representative Reach Particle Size Data: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

Particle Size (mm)	Number of Particles
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	2
22.6-32	2
32-45	13
45-64	22
64-90	15
90-128	27
128-180	15
180-256	3
256-362	1
362-512	0
512-1024	0
1024-2048	0
Bedrock	0

Table B.34 Representative Reach Particle Size Analysis: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

Classification (mm)	Size (mm)
D_{16}	44
D_{35}	60.6
D_{50}	83.1
D_{84}	138.4
D_{95}	176.5
D_{100}	362

Table B.35 Representative Reach Particle Size Data: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	3
4.0-5.7	1
5.7-8.0	0
8.0-11.3	1
11.3-16.0	1
16.0-22.6	0
22.6-32	5
32-45	8
45-64	15
64-90	20
90-128	20
128-180	11
180-256	8
256-362	4
362-512	1
512-1024	1
1024-2048	0
Bedrock	1

Table B.36 Representative Reach Particle Size Analysis: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

Classification (mm)	Size (mm)
D_{16}	40.1
D_{35}	65.3
D_{50}	84.8
D_{84}	175.3
D_{95}	309
D_{100}	Bedrock

Table B.37 Representative Reach Particle Size Data: 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	8
2.0-4.0	0
4.0-5.7	2
5.7-8.0	4
8.0-11.3	3
11.3-16.0	0
16.0-22.6	3
22.6-32	1
32-45	1
45-64	7
64-90	7
90-128	12
128-180	28
180-256	15
256-362	4
362-512	3
512-1024	0
1024-2048	0
Bedrock	2

Table B.38 Representative Reach Particle Size Analysis: 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.

Classification (mm)	Size (mm)
$\mathbf{D_{16}}$	10.2
$\mathbf{D_{35}}$	86.3
$\mathbf{D_{50}}$	131.7
$\mathbf{D_{84}}$	220.5
$\mathbf{D_{95}}$	362
$\mathbf{D_{100}}$	Bedrock

Table B.39 Representative Reach Particle Size Data: 03298135 Chenoweth Run at Ruckriegal Parkway, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	3
2.0-4.0	2
4.0-5.7	2
5.7-8.0	2
8.0-11.3	6
11.3-16.0	6
16.0-22.6	4
22.6-32	12
32-45	13
45-64	18
64-90	12
90-128	8
128-180	5
180-256	3
256-362	0
362-512	0
512-1024	0
1024-2048	0
Bedrock	4

Table B.40 Representative Reach Particle Size Analysis: 03298135 Chenoweth Run at Ruckriegal Parkway, KY.

Classification (mm)	Size (mm)
D_{16}	12.1
D_{35}	30.4
D_{50}	45
D_{84}	109
D_{95}	230.7
D_{100}	Bedrock

Table B.41 Representative Reach Particle Size Data: 03292480 Little Goose near Harrods Creek, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	4
2.0-4.0	0
4.0-5.7	0
5.7-8.0	1
8.0-11.3	1
11.3-16.0	3
16.0-22.6	2
22.6-32	2
32-45	6
45-64	18
64-90	18
90-128	19
128-180	14
180-256	8
256-362	0
362-512	2
512-1024	2
1024-2048	0
Bedrock	0

Table B.42 Representative Reach Particle Size Analysis: 03292480 Little Goose near Harrods Creek, KY.

Classification (mm)	Size (mm)
D_{16}	38.5
D_{35}	61.9
D_{50}	82.8
D_{84}	165.1
D_{95}	246.5
D_{100}	1024

Table B.43 Representative Reach Particle Size Data: 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	0
4.0-5.7	1
5.7-8.0	0
8.0-11.3	4
11.3-16.0	6
16.0-22.6	6
22.6-32	7
32-45	14
45-64	20
64-90	18
90-128	11
128-180	10
180-256	1
256-362	1
362-512	1
512-1024	0
1024-2048	0
Bedrock	0

Table B.44 Representative Reach Particle Size Analysis: 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.

Classification (mm)	Size (mm)
D_{16}	21.5
D_{35}	42.2
D_{50}	56.4
D_{84}	117.6
D_{95}	169.6
D_{100}	512

Table B.45 Representative Reach Particle Size Data: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	0
2.0-4.0	2
4.0-5.7	1
5.7-8.0	0
8.0-11.3	3
11.3-16.0	2
16.0-22.6	3
22.6-32	13
32-45	23
45-64	21
64-90	15
90-128	6
128-180	4
180-256	1
256-362	1
362-512	2
512-1024	0
1024-2048	0
Bedrock	3

Table B.46 Representative Reach Particle Size Analysis: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

Classification (mm)	Size (mm)
D_{16}	26.2
D_{35}	38.2
D_{50}	47.7
D_{84}	96.3
D_{95}	362
D_{100}	Bedrock

Table B.47 Representative Reach Particle Size Data: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	5
2.0-4.0	3
4.0-5.7	1
5.7-8.0	7
8.0-11.3	5
11.3-16.0	1
16.0-22.6	8
22.6-32	13
32-45	12
45-64	10
64-90	17
90-128	10
128-180	3
180-256	1
256-362	0
362-512	1
512-1024	0
1024-2048	0
Bedrock	3

Table B.48 Representative Reach Particle Size Analysis: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

Classification (mm)	Size (mm)
D_{16}	8
D_{35}	26.2
D_{50}	39.6
D_{84}	97.6
D_{95}	180
D_{100}	Bedrock

Table B.49 Representative Reach Particle Size Data: 03277130 Mud Lick at Highway 42 near Beaverlick, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	10
2.0-4.0	4
4.0-5.7	3
5.7-8.0	0
8.0-11.3	0
11.3-16.0	3
16.0-22.6	0
22.6-32	4
32-45	4
45-64	9
64-90	23
90-128	15
128-180	13
180-256	4
256-362	3
362-512	3
512-1024	2
1024-2048	0
Bedrock	0

Table B.50 Representative Reach Particle Size Analysis: 03277130 Mud Lick at Highway 42 near Beaverlick, KY.

Classification (mm)	Size (mm)
D_{16}	5.13
D_{35}	59.8
D_{50}	78.7
D_{84}	164
D_{95}	362
D_{100}	1024

Table B.51 Representative Reach Particle Size Data: 03298000 Floyd's Fork at Fisherville, KY.

Particle Size (mm)	Number of Particles
1.0-2.0	1
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	2
32-45	2
45-64	20
64-90	28
90-128	17
128-180	19
180-256	7
256-362	3
362-512	0
512-1024	1
1024-2048	0
Bedrock	0

Table B.52 Representative Reach Particle Size Analysis: 03298000 Floyd's Fork at Fisherville, KY.

Classification (mm)	Size (mm)
D_{16}	55.5
D_{35}	73.3
D_{50}	87.2
D_{84}	166.3
D_{95}	245.1
D_{100}	1024

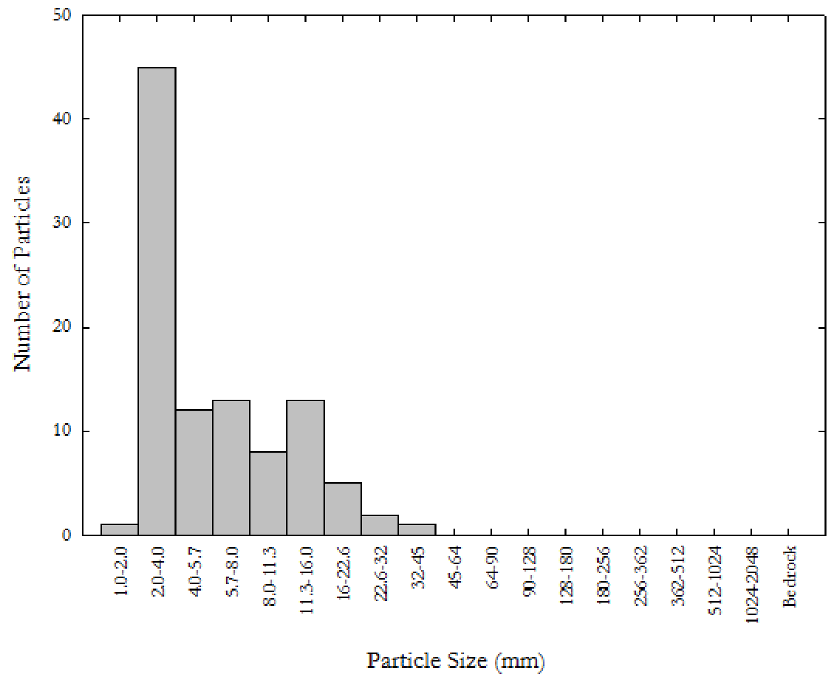

Figure B.1 Particle Distribution Bar Chart: 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.

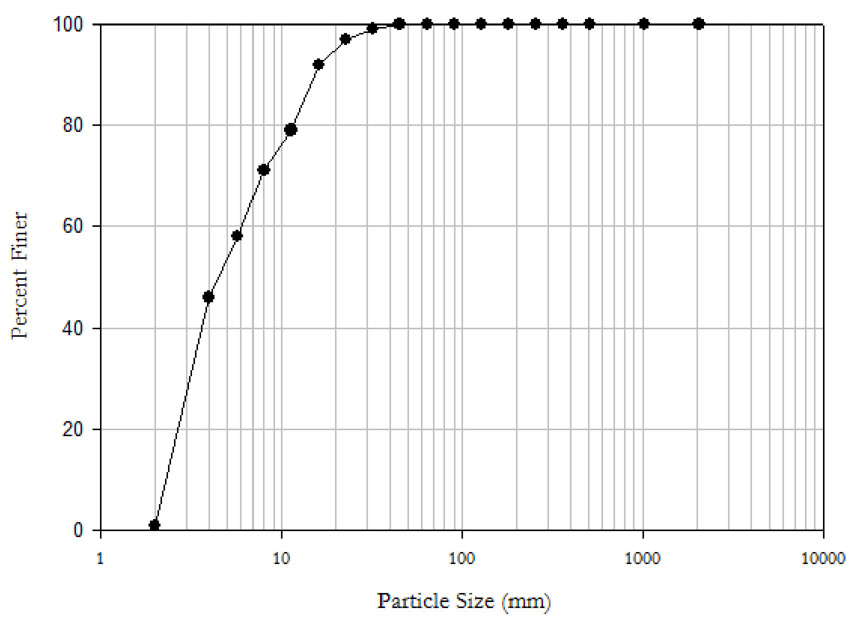

Figure B.2 Particle Distribution Percent Finer: 03284525 East Hickman Tributary at Chilesburg Rd near Lexington, KY.

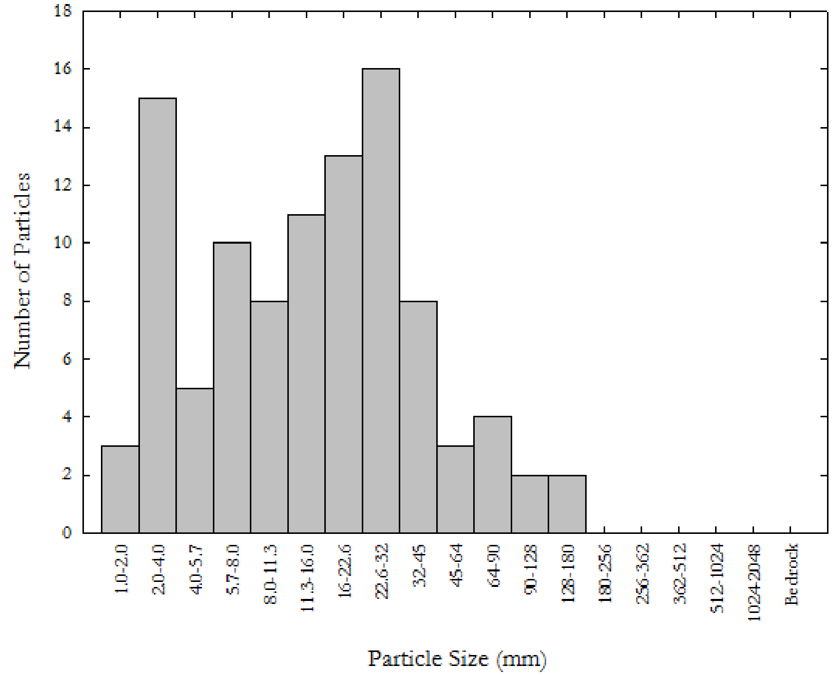

Figure B.3 Particle Distribution Bar Chart: 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

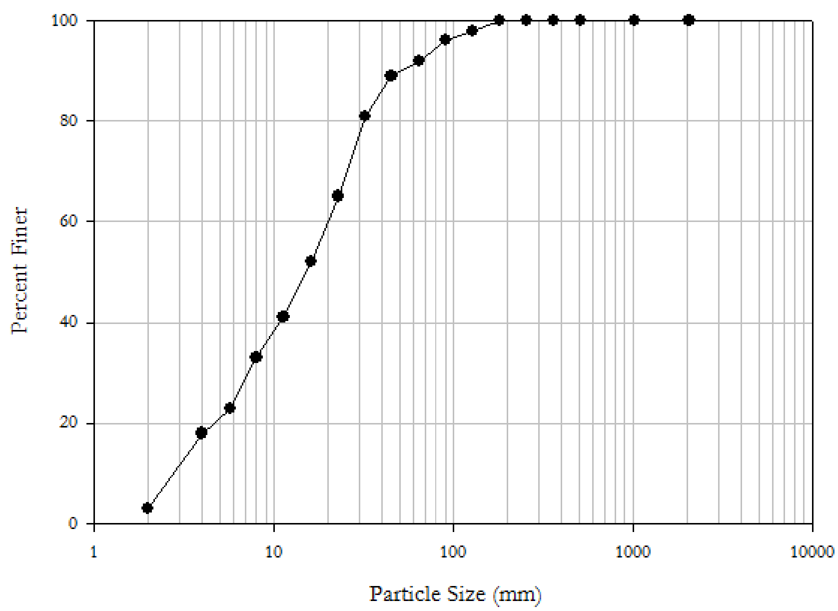

Figure B.4 Particle Distribution Percent Finer: 03284520 East Hickman Creek at Andover Village near Cadentown, KY.

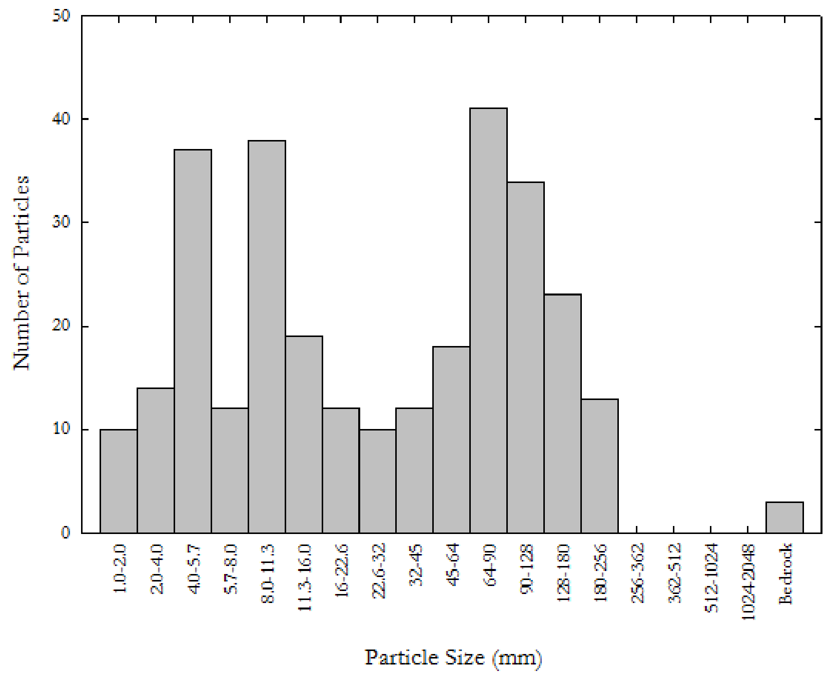

Figure B.5 Particle Distribution Bar Chart: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

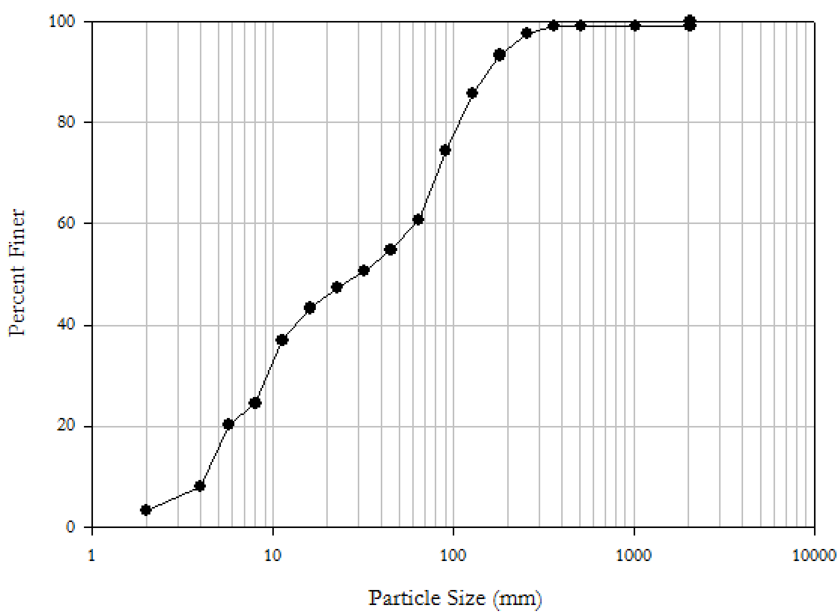

Figure B.6 Particle Distribution Percent Finer: 03287580 North Elkhorn Creek at Man O War Blvd near Cadentown, KY.

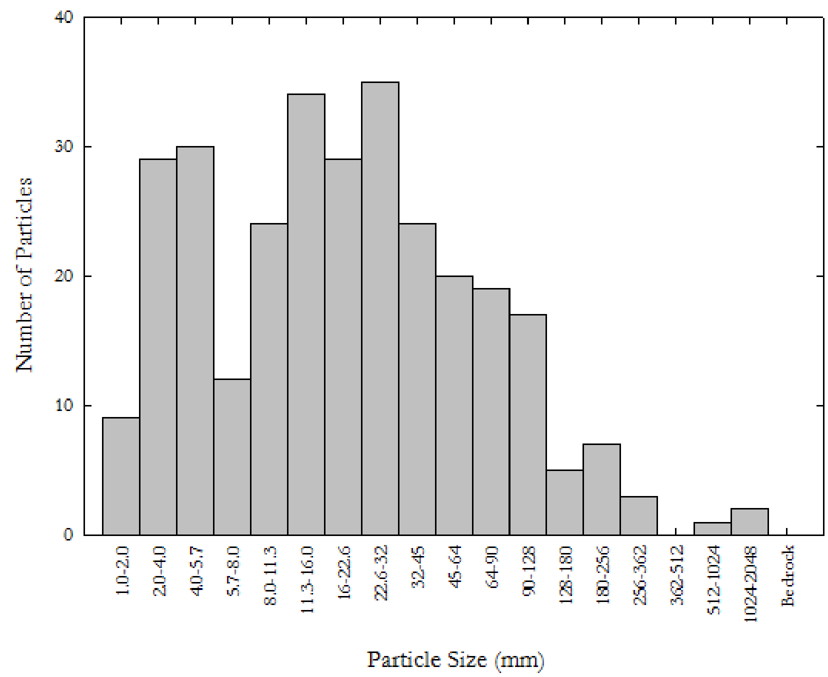

Figure B.7 Particle Distribution Bar Chart: 03288500 Cave Creek near Fort Springs, KY.

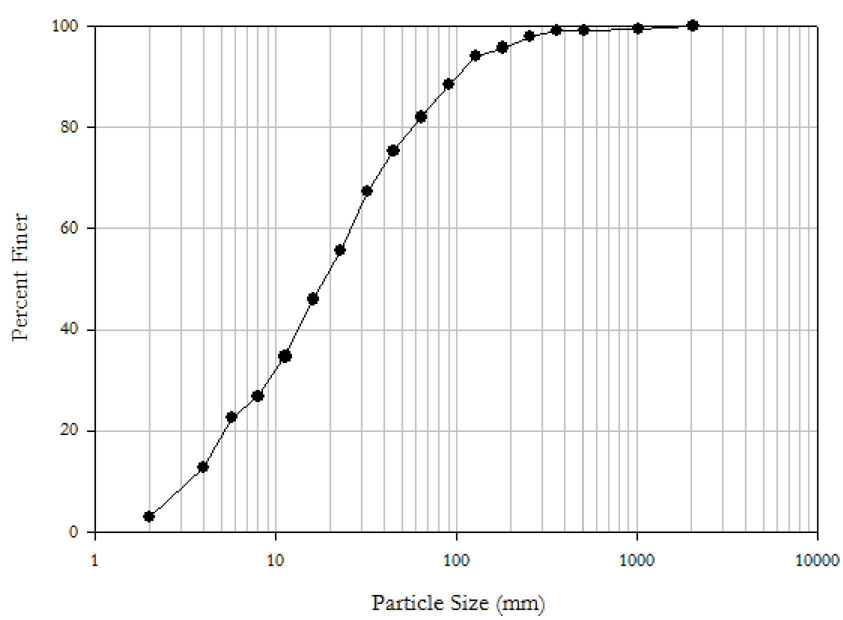

Figure B.8 Particle Distribution Percent Finer: 03288500 Cave Creek near Fort Springs, KY.

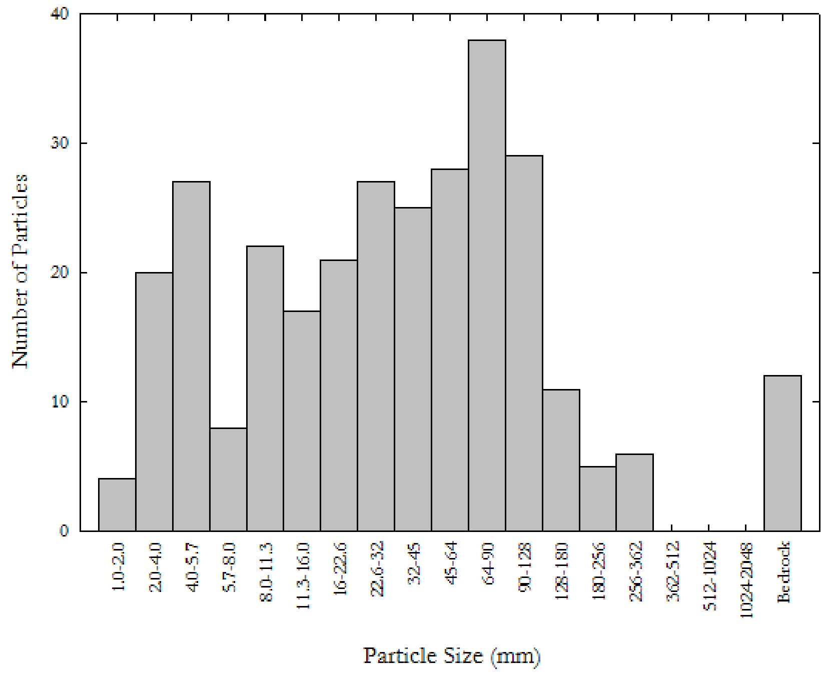

Figure B.9 Particle Distribution Bar Chart: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

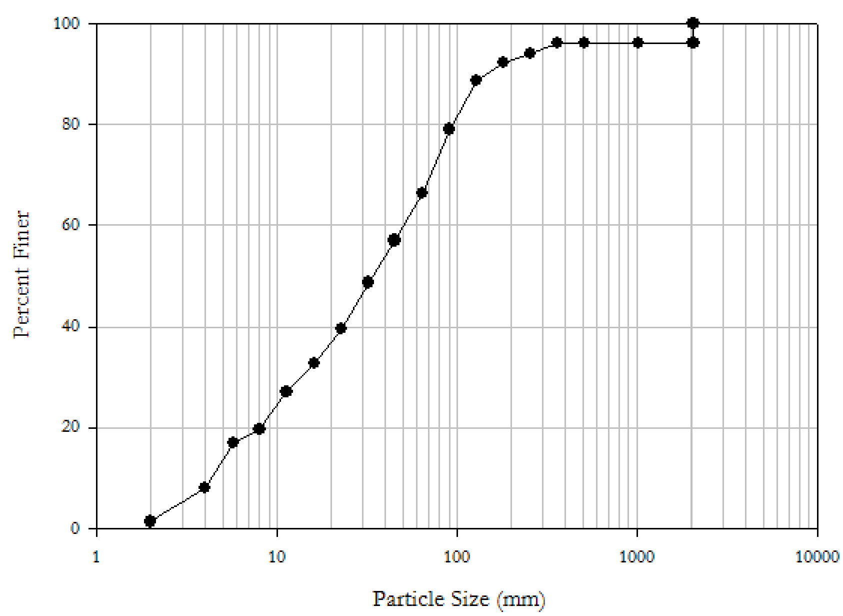

Figure B.10 Particle Distribution Percent Finer: 03287590 North Elkhorn Creek on Winchester Road near Lexington, KY.

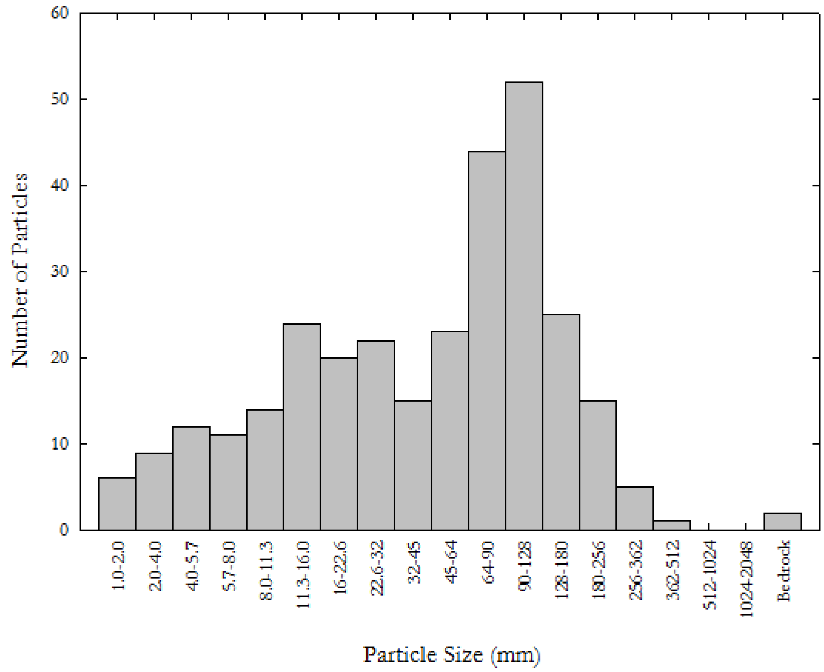

Figure B.11 Particle Distribution Bar Chart: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

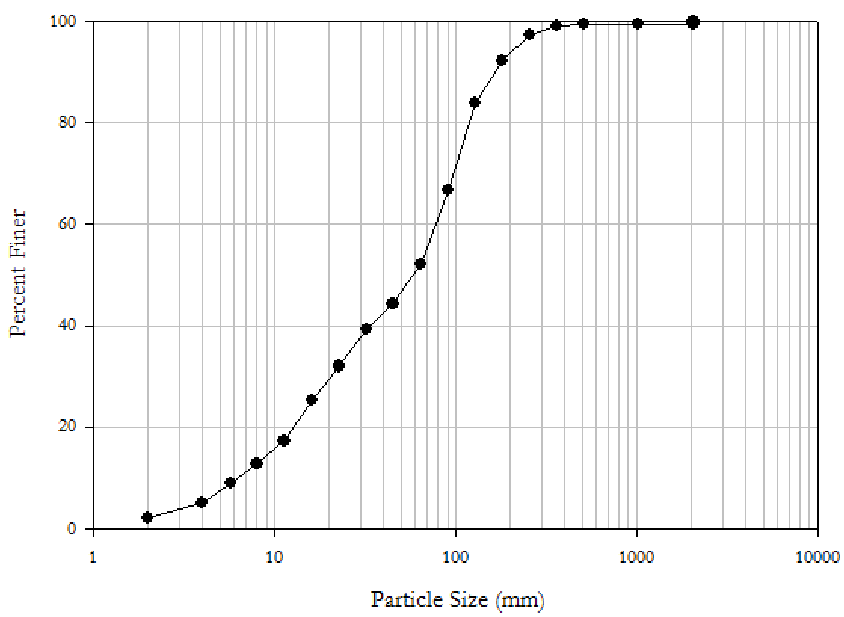

Figure B.12 Particle Distribution Percent Finer: 03289193 Wolf Run at Old Frankfort Pike, Lexington, KY.

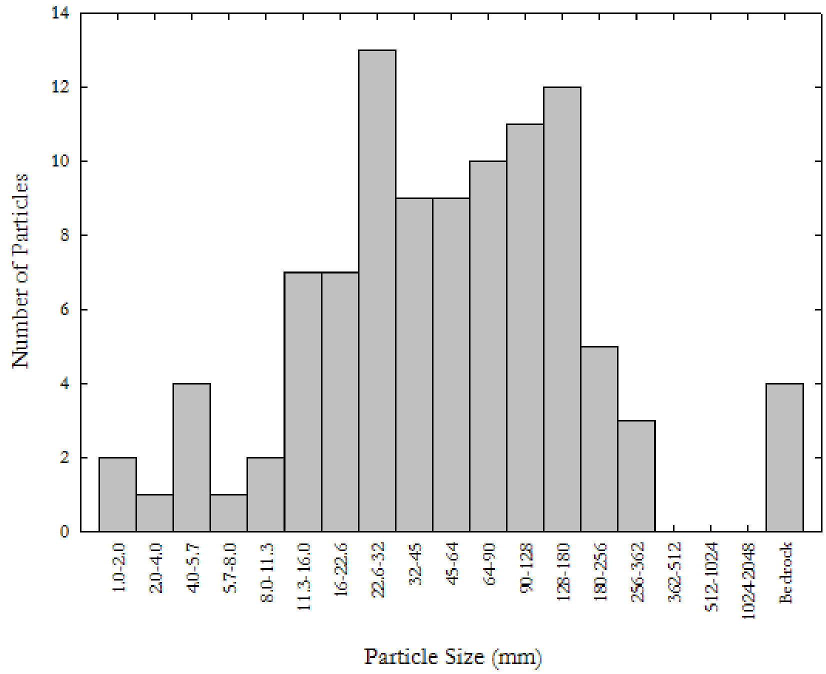

Figure B.13 Particle Distribution Bar Chart: 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

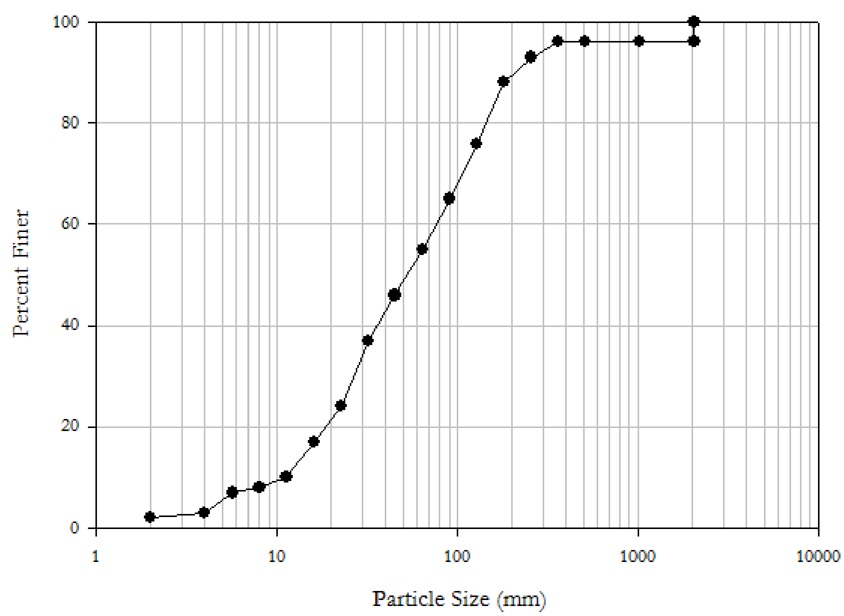

Figure B.14 Particle Distribution Percent Finer: 03284530 East Hickman Creek at Delong Road near East Hickman, KY.

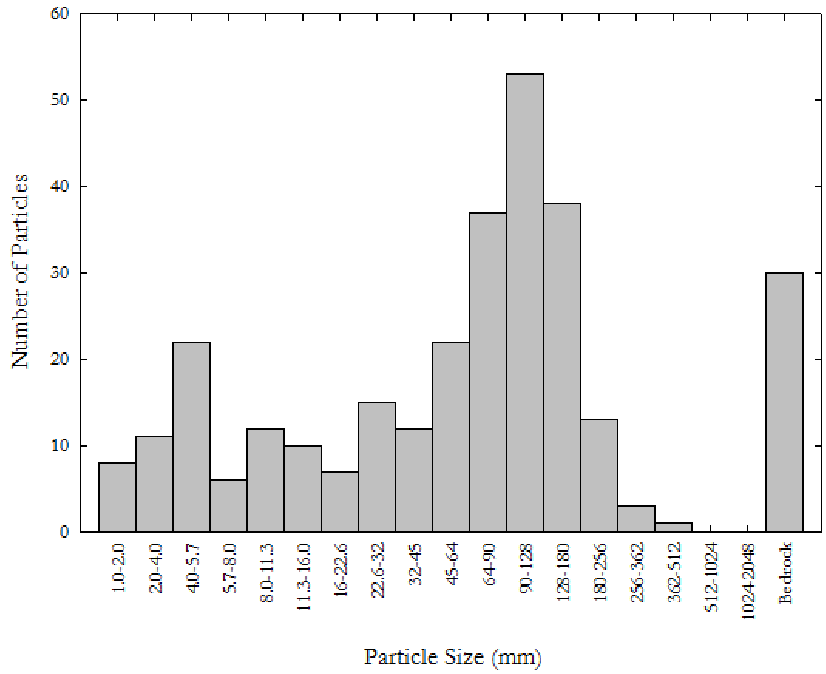

Figure B.15 Particle Distribution Bar Chart: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

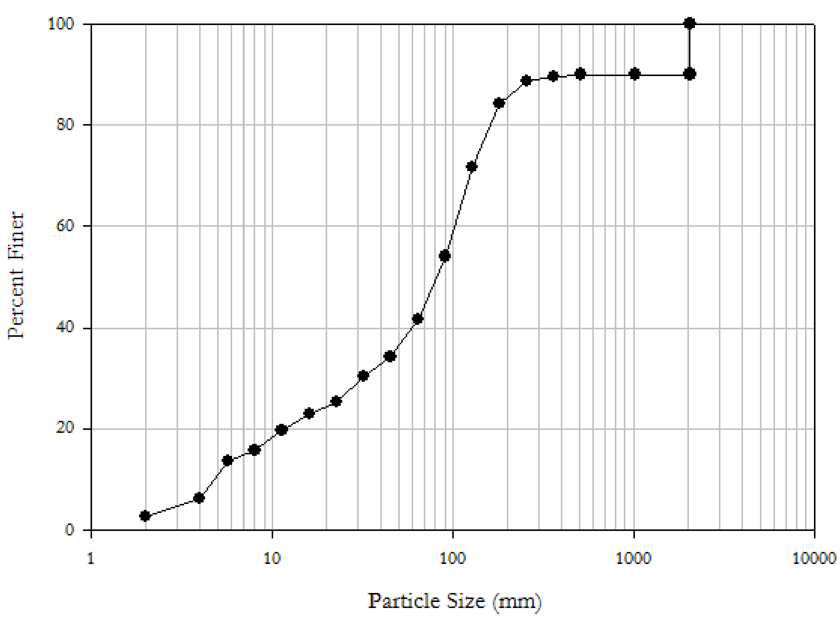

Figure B.16 Particle Distribution Percent Finer: 03284555 West Hickman Creek at Ash Grove Pike near East Hickman, KY.

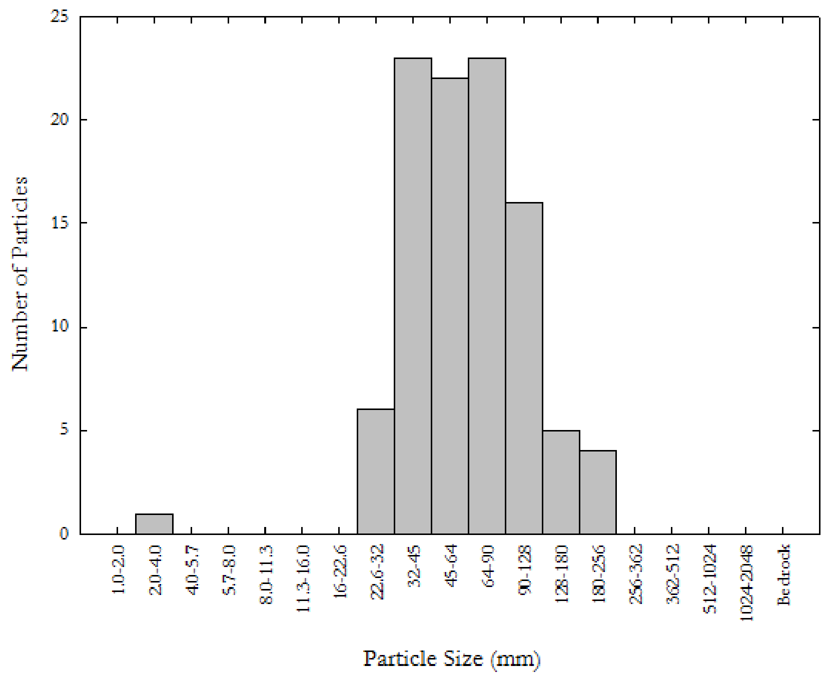

Figure B.17 Particle Distribution Bar Chart: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

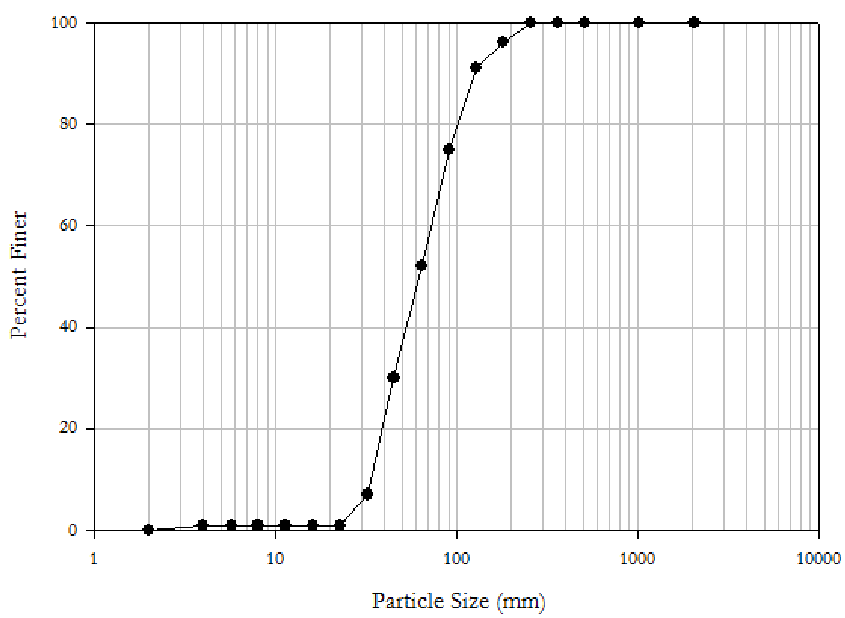

Figure B.18 Particle Distribution Percent Finer: 03287600 North Elkhorn at Bryan Station Road near Montrose, KY.

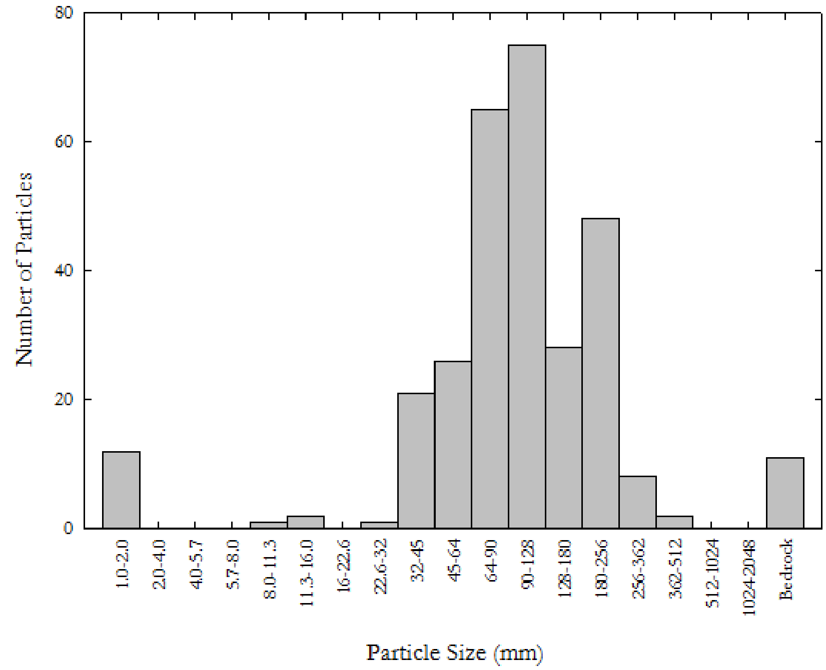

Figure B.19 Particle Distribution Bar Chart: 03289000 South Elkhorn Creek at Fort Springs, KY.

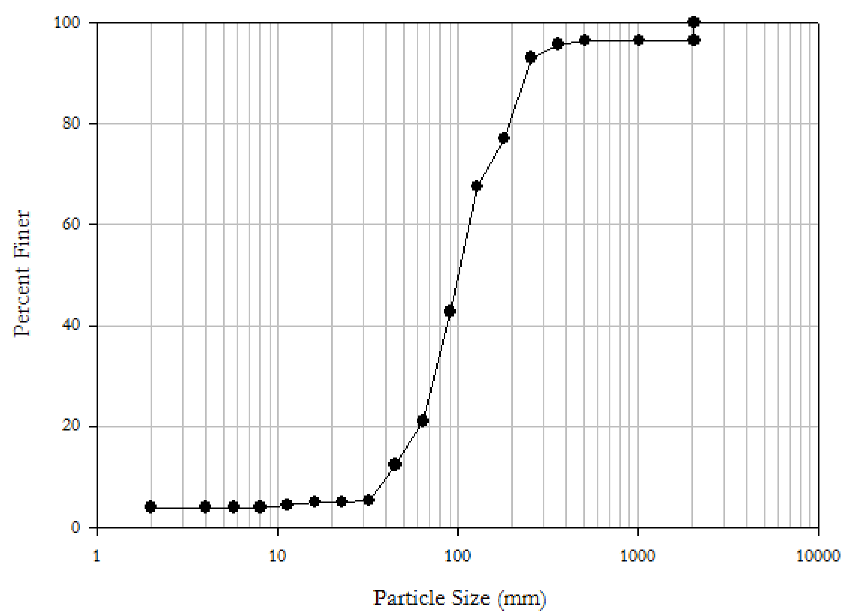

Figure B.20 Particle Distribution Percent Finer: 03289000 South Elkhorn Creek at Fort Springs, KY.

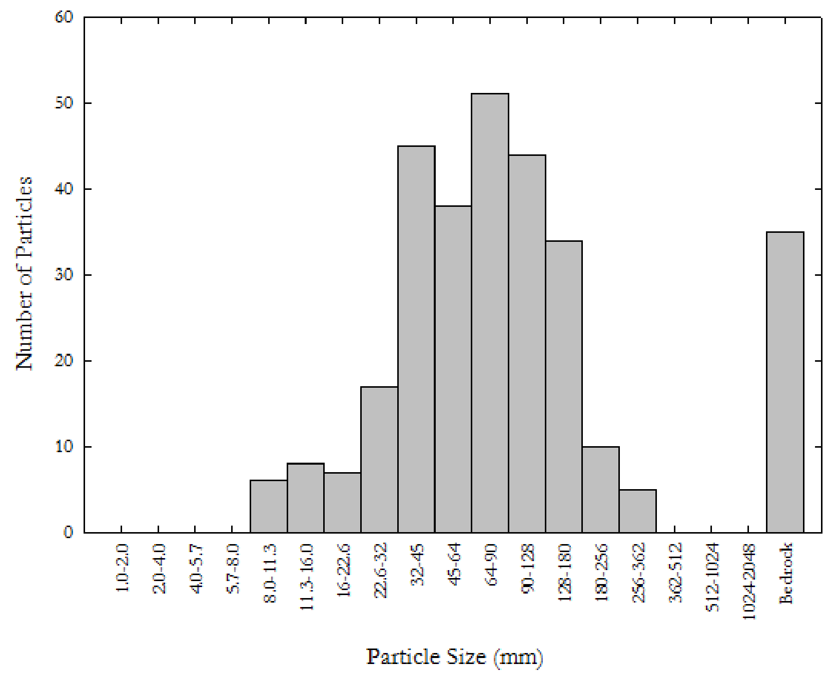

Figure B.**21** Particle Distribution Bar Chart: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

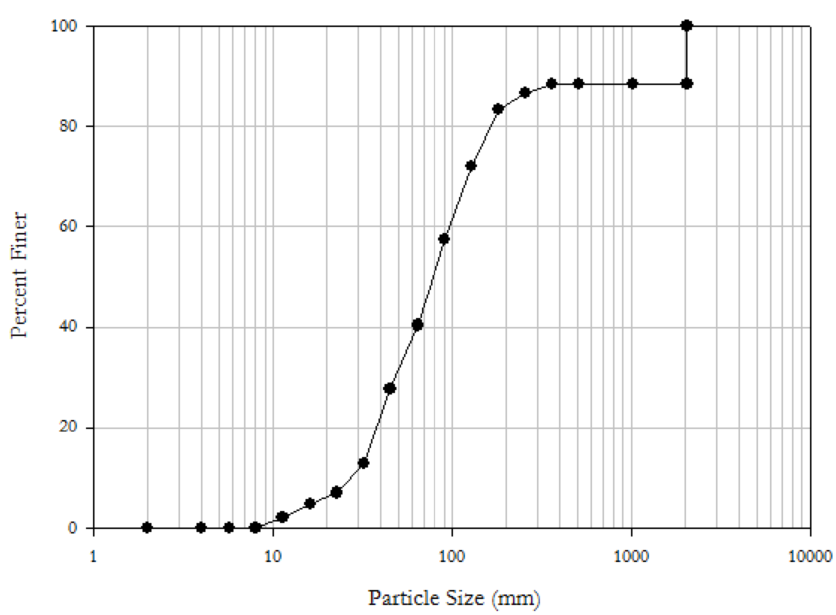

Figure B.22 Particle Distribution Percent Finer: 03289200 Town Branch at Yarnallton Rd at Yarnallton, KY.

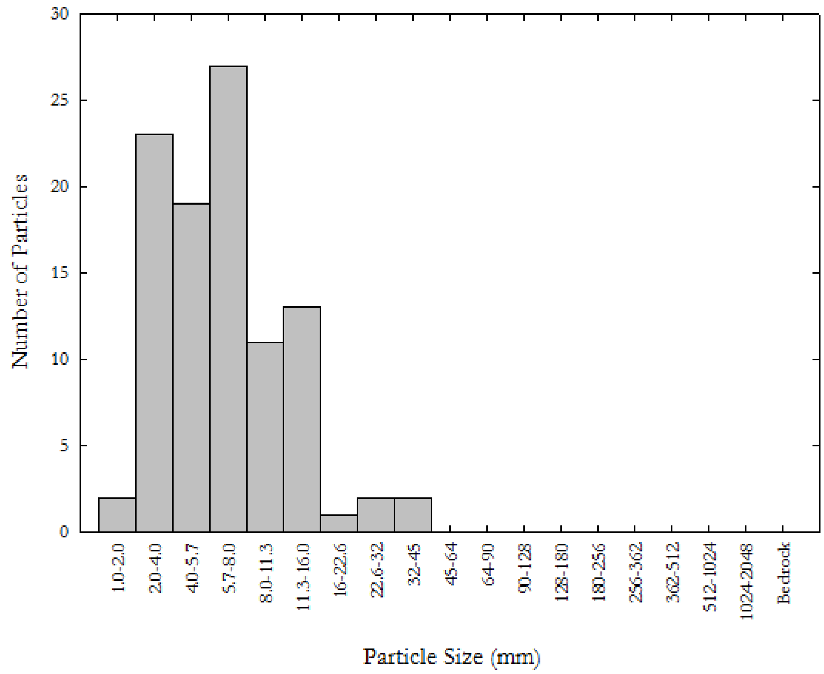

Figure B.23 Particle Distribution Bar Chart: 03291000 Eagle Creek at Sadieville, KY.

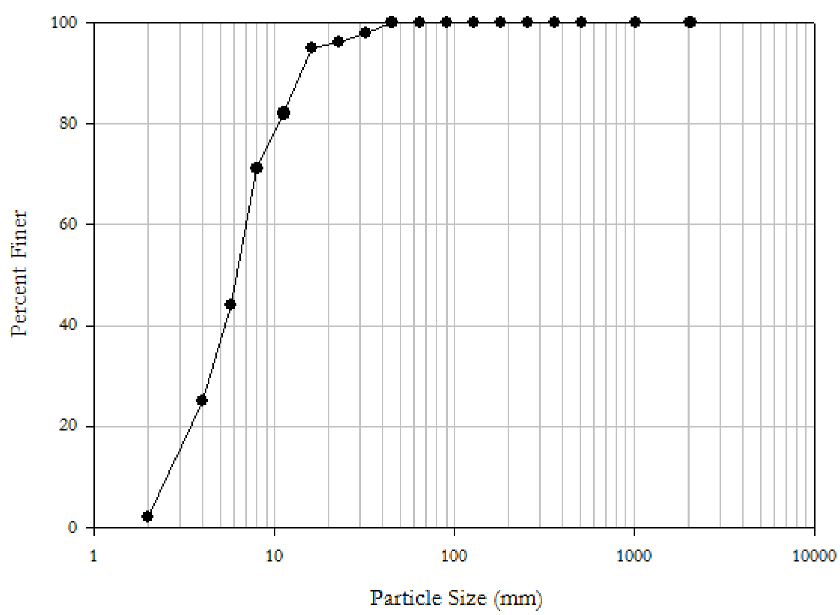

Figure B.24 Particle Distribution Percent Finer: 03291000 Eagle Creek at Sadieville, KY.

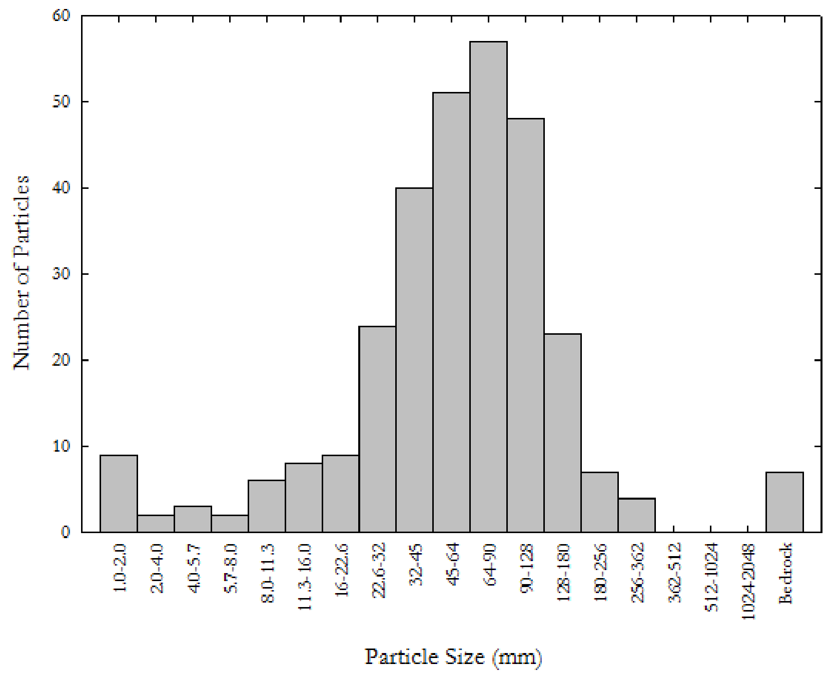

Figure B.25 Particle Distribution Bar Chart: 03288000 North Elkhorn Creek near Georgetown, KY.

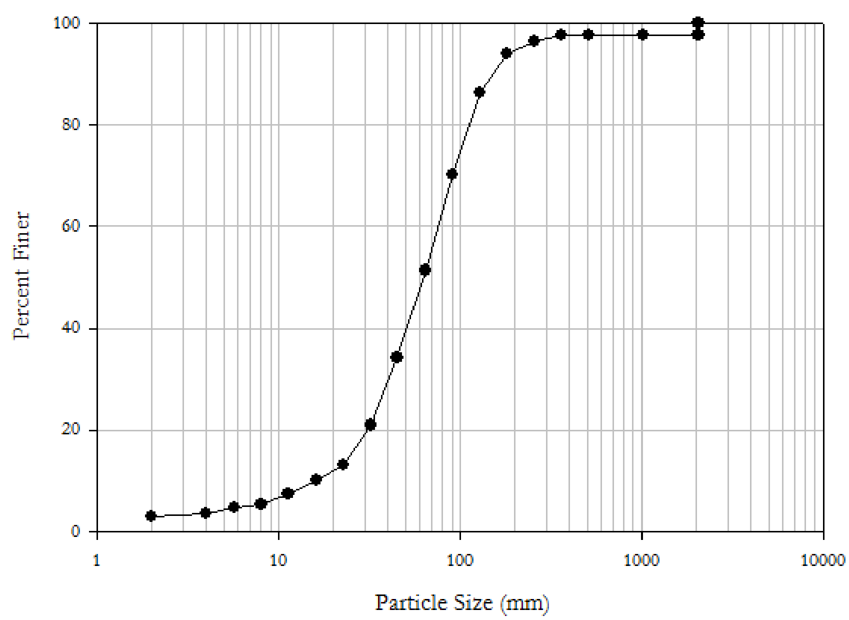

Figure B.**26** Particle Distribution Percent Finer: 03288000 North Elkhorn Creek near Georgetown, KY.

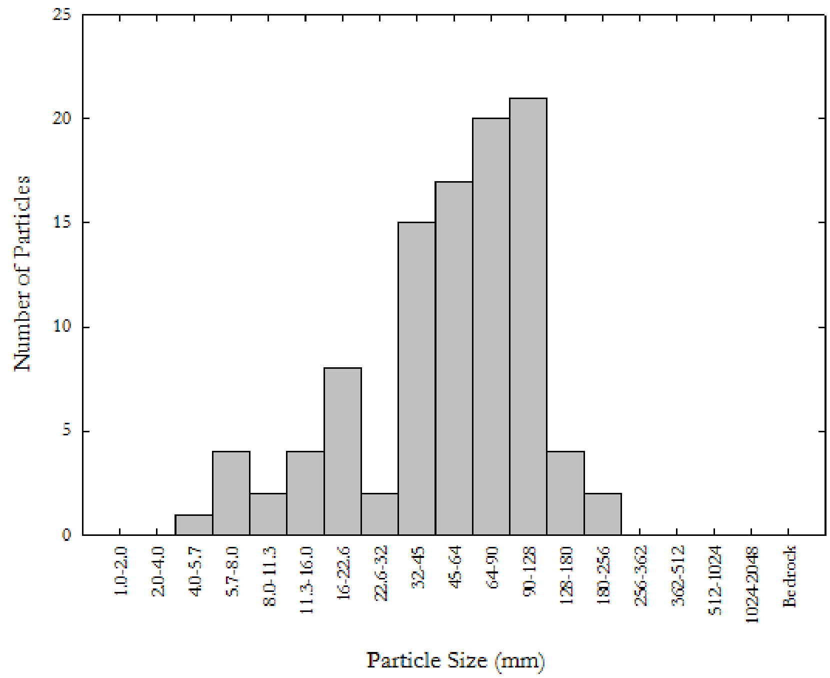

Figure B.27 Particle Distribution Bar Chart: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

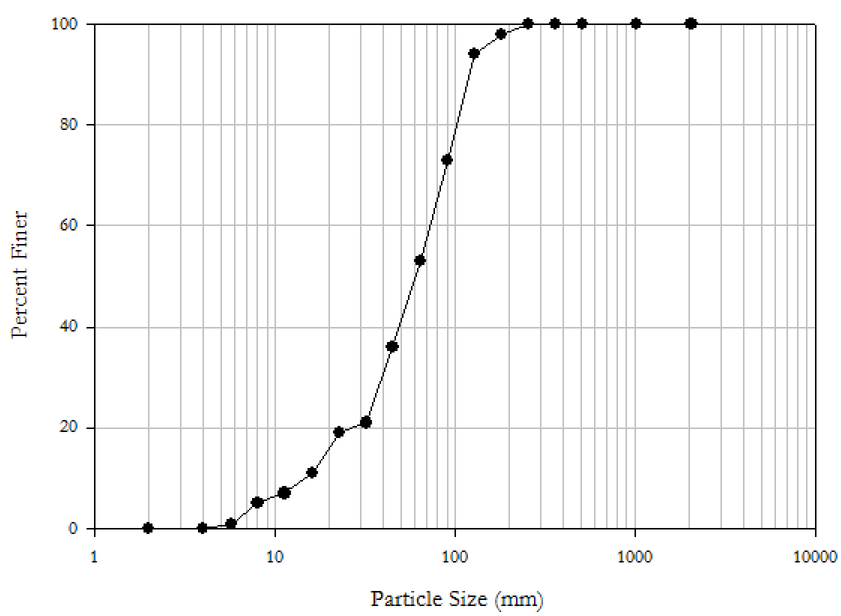

Figure B.28 Particle Distribution Percent Finer: 03238772 Fourmile Creek at Poplar Ridge near Alexandria, KY.

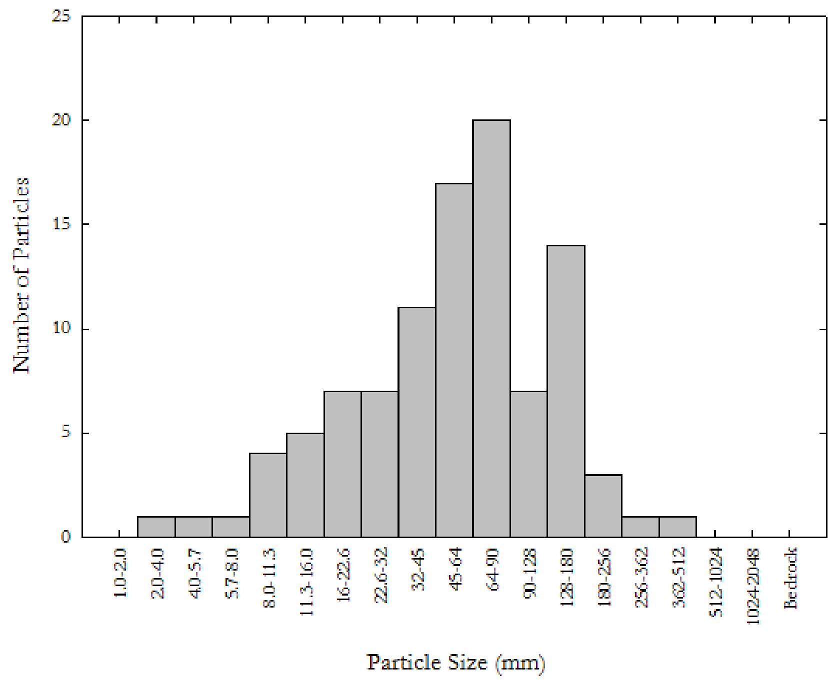

Figure B.29 Particle Distribution Bar Chart: 03254480 Cruises Creek at Highway 17 near Piner, KY.

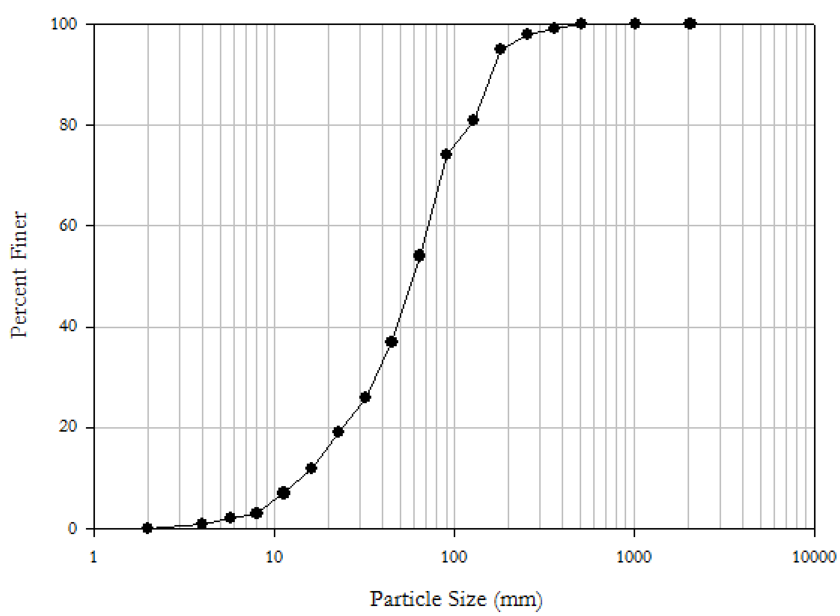

Figure B.**30** Particle Distribution Percent Finer: 03254480 Cruises Creek at Highway 17 near Piner, KY.

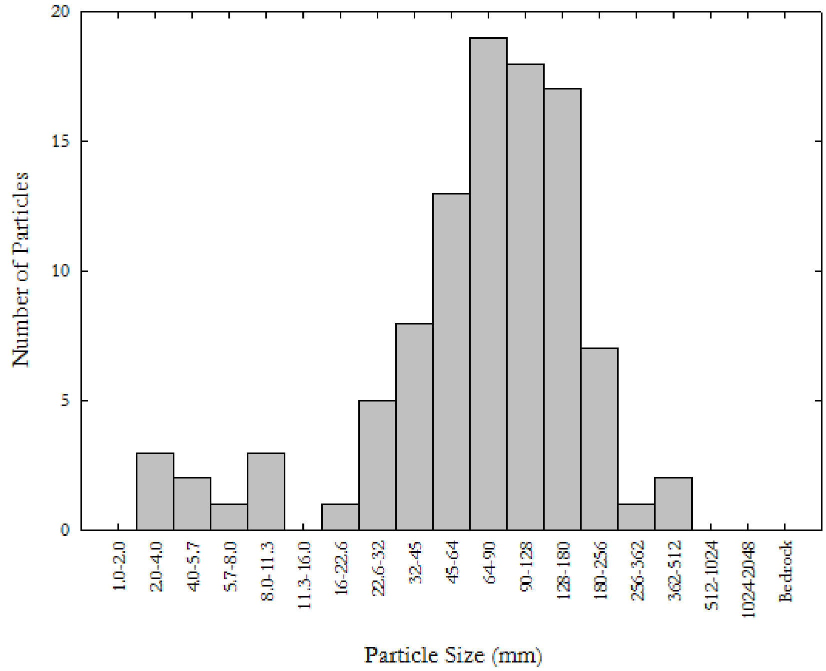

Figure B.**31** Particle Distribution Bar Chart: 03262001 Woolper Creek at Woolper Road near Burlington, KY.

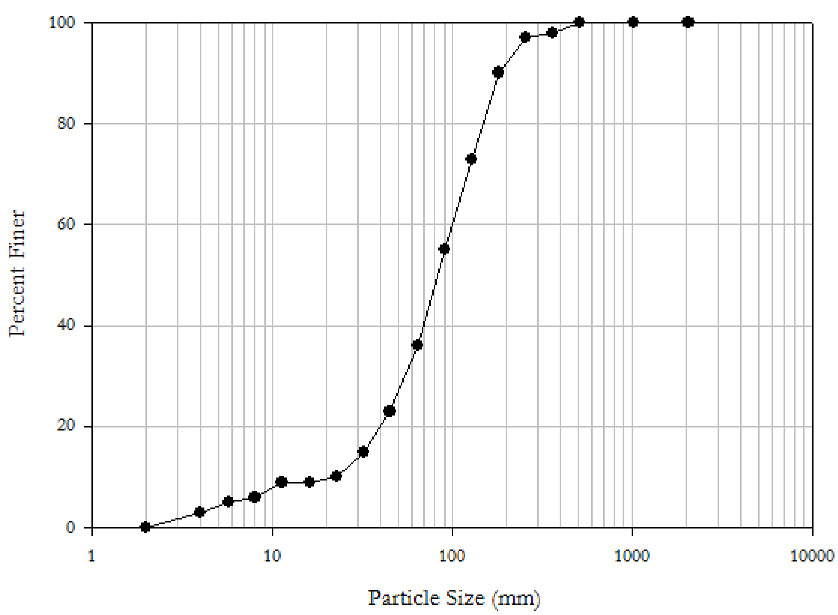

Figure B.**32** Particle Distribution Percent Finer: 03262001 Woolper Creek at Woolper Road near Burlington, KY.

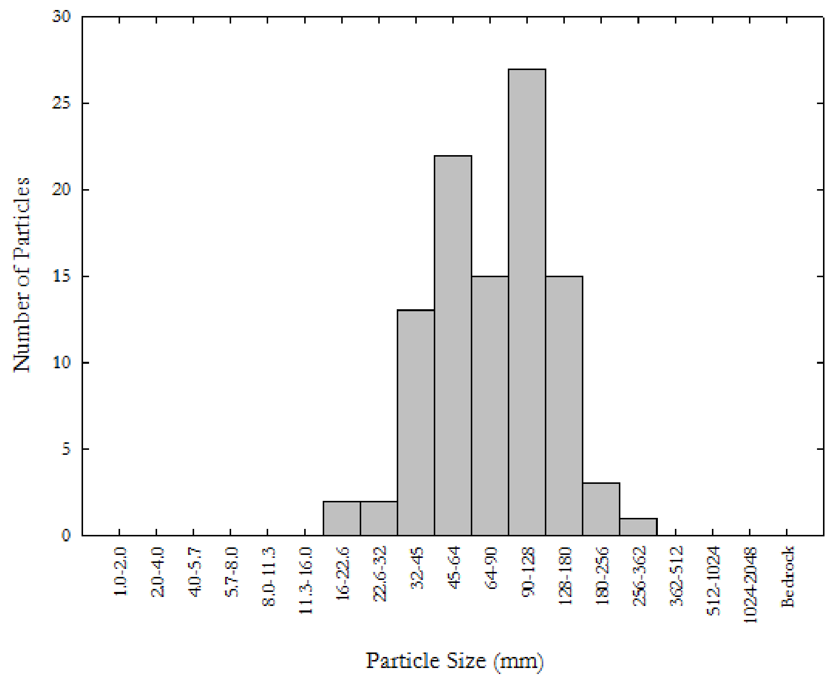

Figure B.33 Particle Distribution Bar Chart: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

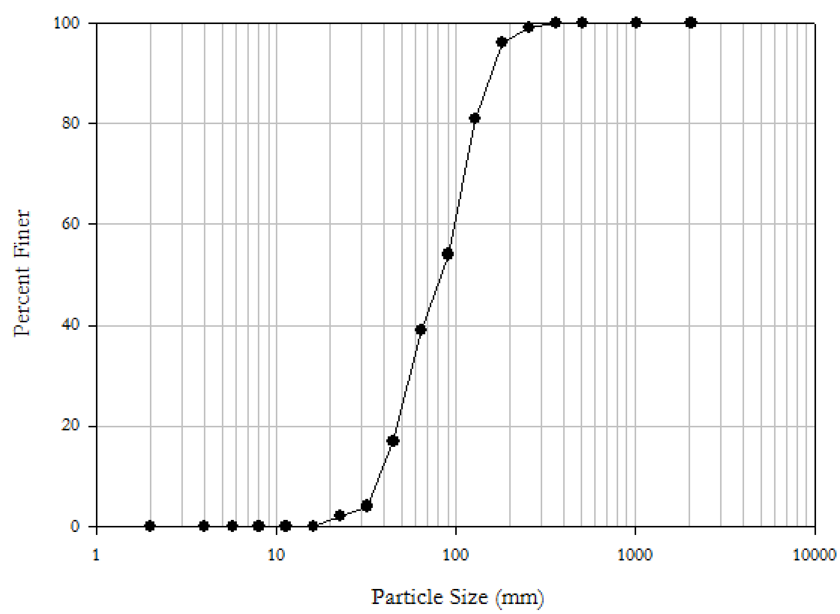

Figure B.34 Particle Distribution Percent Finer: 03254550 Banklick Creek at Highway 1829 near Erlanger, KY.

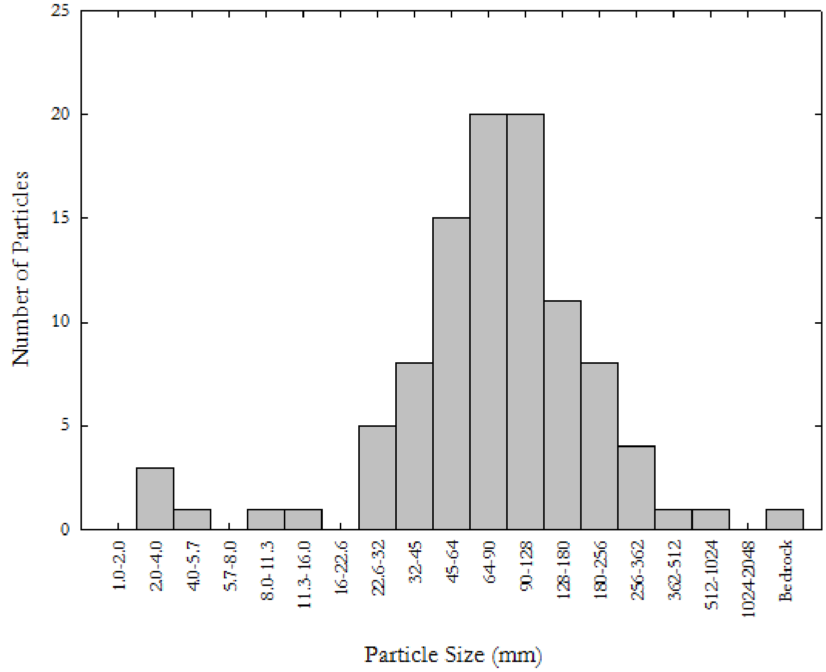

Figure B.35 Particle Distribution Bar Chart: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

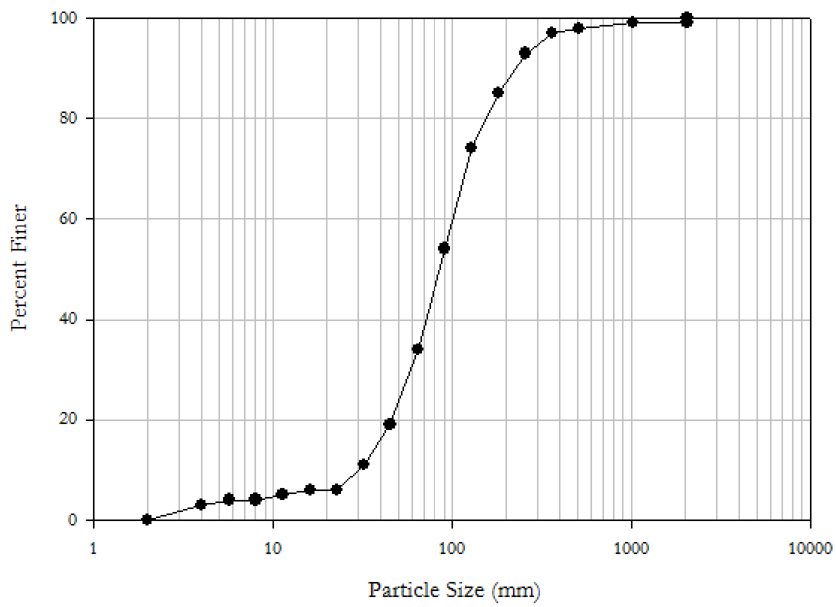

Figure B.36 Particle Distribution Percent Finer: 03277075 Gunpowder Creek at Camp Ernst Road near Union, KY.

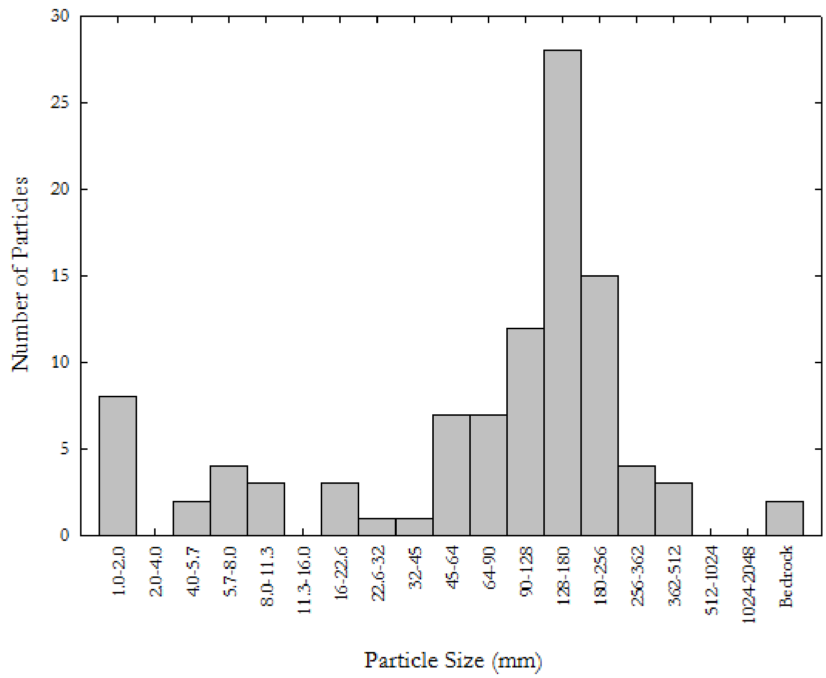

Figure B.37 Particle Distribution Bar Chart: 03238745 Twelvemile Creek at Highway 1997 near Alexandria, KY.

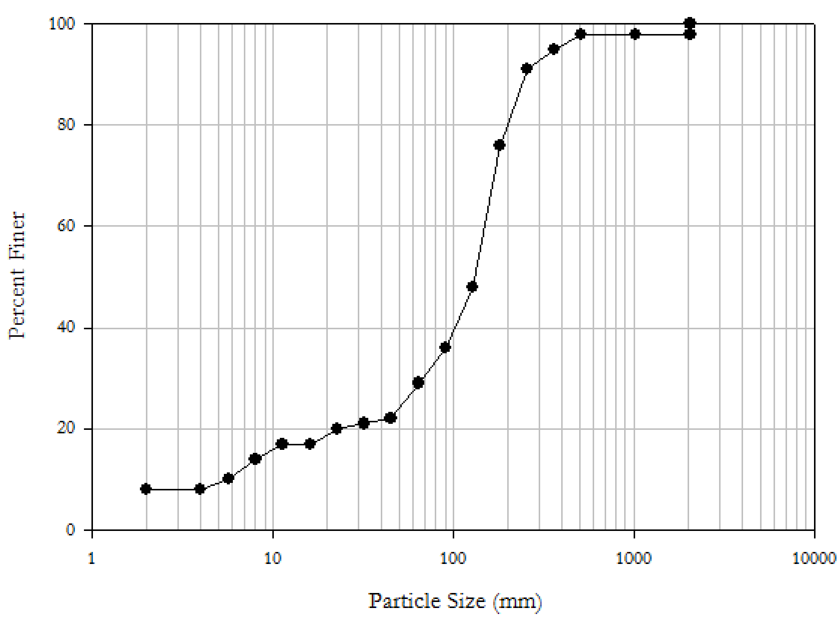

Figure B.38 Particle Distribution Percent Finer: 03292474 Goose Creek at Old Westport Road near St. Matthews, KY.

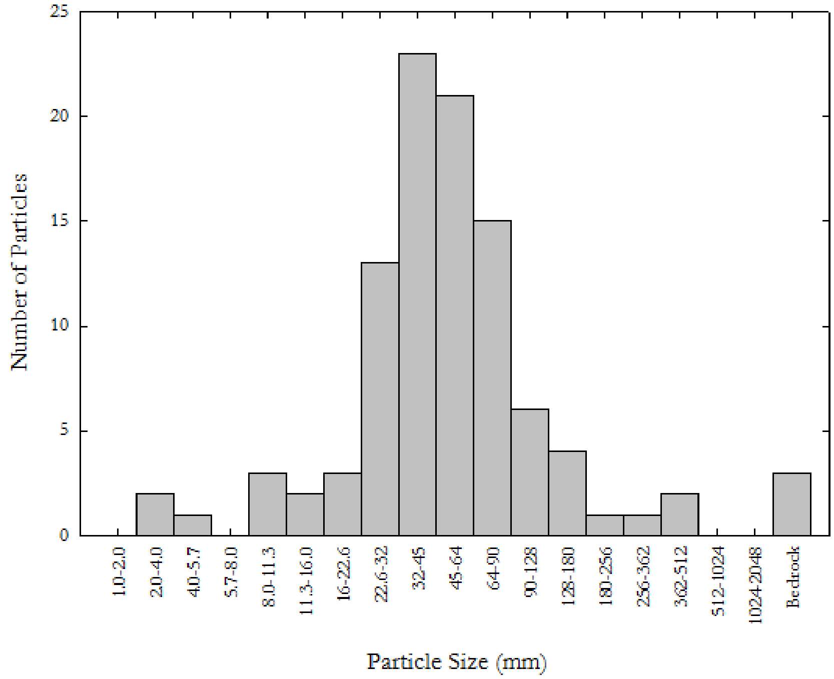

Figure B.39 Particle Distribution Bar Chart: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

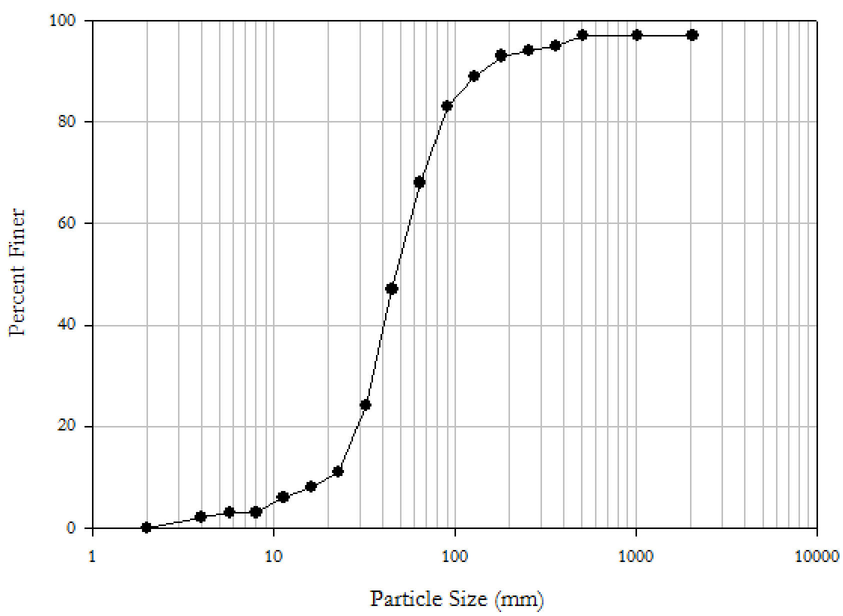

Figure B.40 Particle Distribution Percent Finer: 03297800 Cedar Creek at Highway 1442 near Sheperdsville, KY.

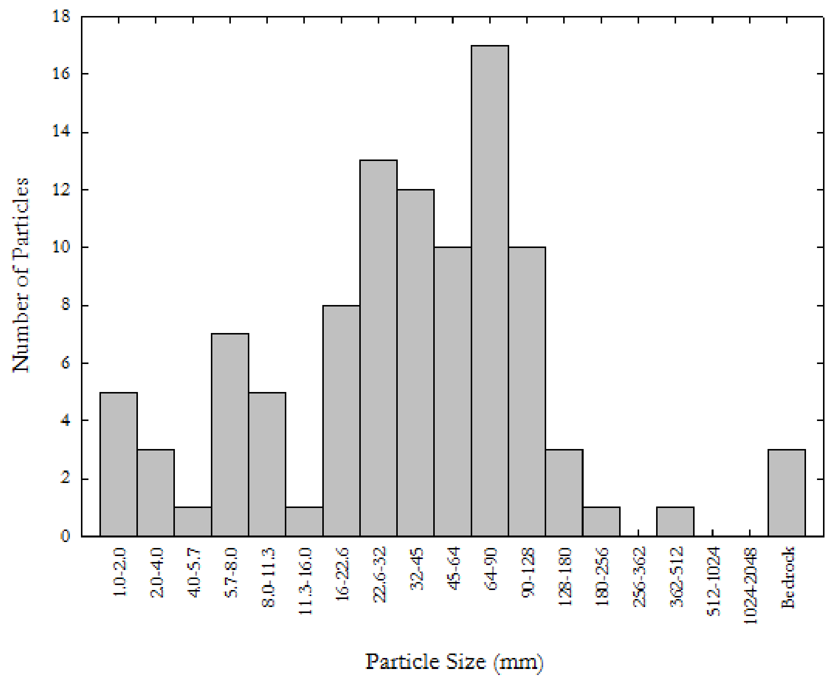

Figure B.41 Particle Distribution Bar Chart: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

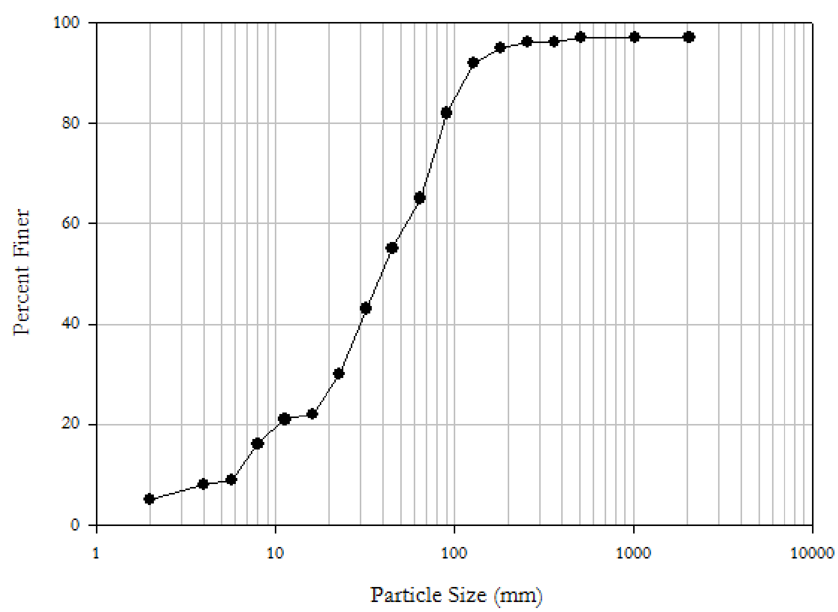

Figure B.42 Particle Distribution Percent Finer: 03293000 Middle Fork Beargrass Creek at Old Cannons Lane at Louisville, KY.

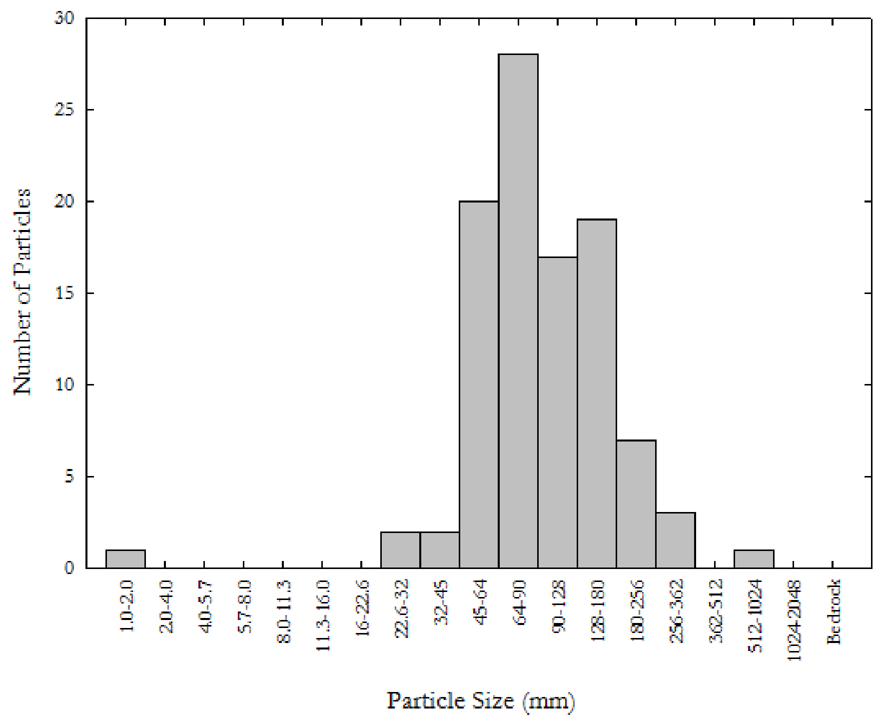

Figure B.**43** Particle Distribution Bar Chart: 03298000 Floyd's Fork at Fisherville, KY.

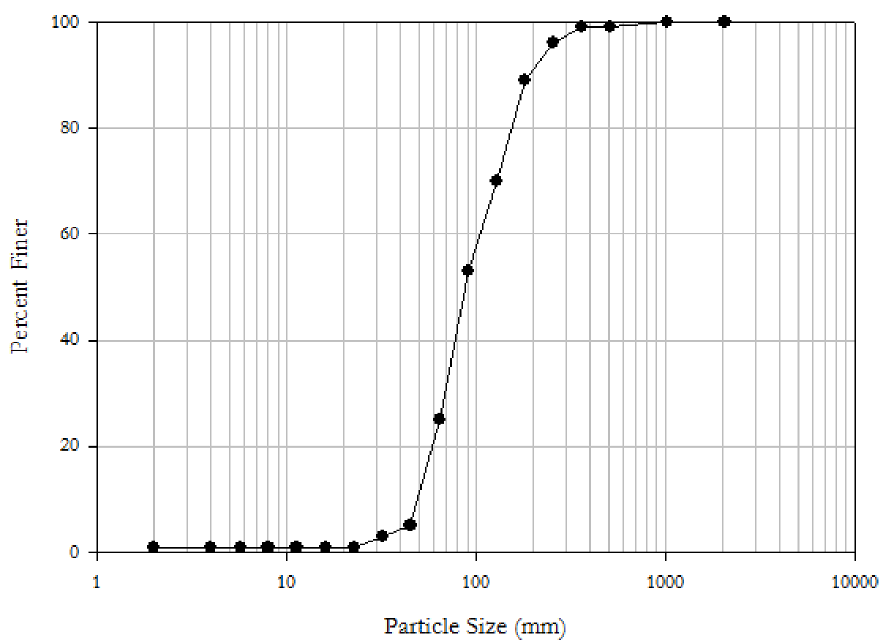

Figure B.44 Particle Distribution Percent Finer: 03298000 Floyd's Fork at Fisherville, KY.

References

Adams, R.K., Spotila, J.A., 2005. The Form and Function of Headwater Streams Based on Field and Modeling Investigations in the Southern Appalachian Mountains. Earth Surface Processes and Landforms 30, 1521-1546.

Allmendinger, N.E., Pizzuto, J.E., Potter, N., Johnson, T.E., Hession, W.C., 2005. The influence of riparian vegetation on stream width, eastern Pennsylvania, USA. Geological Society of America 117, 229-243.

Andrews, E.D., 1980. Effective and Bankfull Discharges of Streams in the Yampa River Basin, Colorado and Wyoming. Journal of Hydrology 46, 311-330.

Andrews, E.D., Nankervis, J.M., 1995. Effective Discharge and the Design of Channel Maintenance Flows for Gravel-bed Rivers. Natural and Anthropogenic Influences in Fluvial Geomorphology. American Geophysical Union, Geophysical Monograph, pp. 151-164.

Arcadis, SCDOT, 2004. Development of SC Rural Piedmont Regional Curves. NC SRI Southeastern Regional Conference on Stream Restoration Acadis Natural Resources Department, Winston-Salem, N.C.

Baer, E.M., 2008. Recurrence Interval. Science Resource Center at Carleton College.

Benson, M.A., Thomas, D.M., 1966. A definition of dominant discharge. Bulletin of the International Association of Scientific Hydrology 11, 76-80.

Bidelspach, D., 2008. Comparison and Use of Regional Curves in the Southeastern US. Stream Restoration in the Southeast: Advancing the Science and Practice, Asheville, N.C.

Biedenharn, D.S., Copeland, R.R., 2000. Effective Discharge Calculation. ERDC/CHL CHETN-VIII-4.

Booth, D., 1991. Urbanization and the Natural Drainage System-Impacts, Solution and Prognoses. Northwest Environmental Journal 7, 93-118.

Brath, A., Montanari, A., Moretti, G., 2006. Assessing the Effect on Flood Frequency of Land Use Change via Hydrological Simulation (with uncertainty). Journal of Hydrology 324, 141-153.

Castro, J.M., Jackson, P.L., 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA. Journal of the American Water Resources Association 37, 1249-1262.

Chaplin, J.J., 2005. Development of Regional Curves Relating Bankfull-Channel Geometry and Discharge to Drainage Area for Streams in Pennsylvania and Selected Areas of Maryland. U.S. Geological Survey Scientific Investigations Report 2005-5147.

Cianfrani, C.M., Hession, W.C., Rizzo, D.M., 2006. Watershed Imperviousness Impacts on Stream Channel Condition in Southeastern Pennsylvania. Journal of the American Water Resources Association.

Cinotto, P.J., 2003. Development of Regional Curves of Bankfull-Channel Geometry and Discharge for Streams in Non-Urban Piedmont Physiographic Province, Pennsylvania and Maryland. U. S. Geological Survey Water-Resources Investigations Report 03-4014.

Copeland, R.R., Biedenharn, D.S., Fischenich, J.C., 2000. Channel Forming Discharge. ERDC/CHL CHETN-VIII-5.

Crowder, D.W., Knapp, H.V., 2005. Effective discharge recurrence intervals of Illinois Streams. Geomorphology 64, 167-184.

DeWolfe, M.N., Hession, W.C., Watzin, M.C., 2004. Sediment and phosphorus loads from streambank erosion in Vermont, USA. Critical Transitions in Water and Environmental Resources Management. Sehick. G., D.F. Hayes, and D.K. Stevens. American Society of Civil Engineers, Reston, VA.

Doll, B.A., Dobbins, A.D., Spooner, J., Clinton, D.R., Bidelspach, D.A., 2003. Hydraulic Geometry Relationships for Rural North Carolina Coastal Plain Streams. N. C. Division of Water Quality for 319 Grant Project NOEW20011.

Doll, B.A., Wise-Frederick, D.E., Buckner, C.M., Wilderson, S.D., Harman, W.A., Smith, R.E., Spooner, J., 2002. Hydraulic Geometry Relationships for Urban Streams Throughout the Piedmont of North Carolina. Journal of the American Water Resources Association 38, 641-651.

Doyle, M.W., Shields, C.A., 2008. An alternative measure of discharge effectiveness. Earth Surface Processes and Landforms 33, 308-316.

Dunne, T., Leopold, L.B., 1978. Water in Environmental Planning. W. H. Freeman, Co., New York.

Dury, G.H., 1976. Discharge Prediction, Present and Former, from Channel dimensions. Journal of Hydrology 30, 219-245.

Emmett, W.W., 1975. The channels and waters of the upper Salmon River, Idaho. U.S. Geological Survey Professional Paper: 870A.

Emmett, W.W., Wolman, M.G., 2001. Effective Discharge and Gravel-Bed Rivers. Earth Surface Processes and Landforms 26, 1369-1380.

Ferguson, R.I., 1986. Hydraulics and Hydraulic Geometry. Progress in Physical Geography 10, 1-31.

Hammer, T.R., 1972. Stream Channel Enlargement Due to Urbanization. Water Resources Research 8, 1530-1540.

Hanley, T., 2006. Piedmont Geologic Province.

Harman, W.A., Wise, D.E., Walker, M.A., Morris, R., Cantrell, M.A., Clemmons, M., Jennings, G.D., Clinton, D., Patterson, J., 2000. Bankfull Regional Curves for North Carolina Mountain Streams. Water Resources in Extreme Environments AWRA TPS-00-1, 185-190.

Harman, W.H., Jennings, G.D., Patterson, J.M., Clinton, D.R., Slate, L.O., Jessum, A.G., Everhart, J.R., Smith, R.E., 1999. Bankfull Hydraulic Geometry Relationships for North Carolina Streams. AWRA Wildland Hydrology Symposium Proceedings. Olsen, D.S., Polyandry, J.P., pp. 401-408.

Harrelson, C.C., Rawlins, C., Potyondy, J., 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Techniques. USDA Forest Service Rocky Mountain Forest adn Range Experiment Station General Technical Report RM245, 67.

Hession, W.C., Pizzuto, J.E., Johnson, T.E., Horwitz, R.J., 2003. Influence of Bank Vegetation on Channel Morphology in Rural and Urban Watersheds. Geology 31, 147-150.

Hey, R.D., 2006. Fluvial geomorphological methodology for natural stable channel design. Journal of the American Water Resources Association 42, 357-374.

Hey, R.D., Thorne, C.R., 1986. Stable Channels with Mobile Gravel Beds. Journal of Hydraulic Engineering 112, 671-689.

Hodgkins, G.A., Martin, G.R., 2003. Estimating the magnitude of peak flows for streams in Kentucky for selected recurrence intervals. Water-Resources Investigations Report: 03-4180. USGS, Louisville, KY.

Hollis, G.E., 1975. The Effect of Urbanization of Floods of Different Recurrence Intervals. Water Resources Research 11, 431-435.

Hollis, G.E., Luckett, J.K., 1976. The Response of Natural River Channels to Urbanization: Two Case Studies from Southeast England. Journal of Hydrology 30, 351-363.

Huang, S., Cheng, S., Wen, J., Lee, J., 2008. Identifying Peak-Imperviousness-Recurrence Relationships on a Growing-Impervious Watershed, Taiwan Journal of Hydrology 362, 320-336.

Johnson, P.A., Fecko, B.J., 2008. Regional Channel Geometry Equations: A Statistical Comparison for Physiographic Provinces in the Eastern US. River Research and Applications 24, 823-834.

Julien, P.Y., Wargadalam, J., 1995. Alluvial channel geometry: theory and applications. Journal of Hydraulic Engineering ASCE 121.

Kauffman, J.B., Krueger, W.C., 1984. Livestock Impacts on Riparian Ecosystems adn Streamside Management Implications: a Review. Journal of Range Management 36.

Keaton, J.N., Messinger, T., Doheny, E.J., 2005. Development and Analysis of Regional Curves for Streams in the Non-Urban Valley and Ridge Physiographic Province, Maryland, Virginia, and West Virginia. U.S. Geological Survey Scientific Investigations Report: 2005-0576. p. 116.

KGS, 2007. The Bluegrass Region. Available at: http://www.uky.edu/KGS/geoky/regionbluegrass.htm. The Kentucky Geological Survey.

Knighton, A.D., 1977. Short-term changes in hydraulic geometry. River Channel Changes. Gregory, K.J. John Wiley & Sons, New York, pp. 101-119.

Knighton, A.D., 1998. Fluvial Forms and Processes. Edward Arnold, London.

Lakly, M.B., McArthur, J.V., 2000. Macroinvertebrate recovery of a post-thermal stream: habitat structure and biotic function. Ecological Engineering 15, S87-S100.

Lane, E.W., 1955. The importance of fluvial morphology in hydraulic engineering. Proceedings of the American Society of Civil Engineers 81, 1-17.

Lane, L.J., Foster, G.R., 1980. Modeling channel processes with changing land use. Proceedings, ASCE Symposium on Watershed Management 1, 200-214.

Lawlor, S.M., 2004. Determination of Channel-Morphology Characteristics, Bankfull Discharge, and Various Design-Peak Discharges in Western Montana. Scientific Investigations Report - U.S. Department of the Interior and U.S. Geological Survey 2004-5263.

Lawrence, C.L., 1987. Streamflow Characteristics at Hydrologic Bench-mark stations. U.S. Geological Survey Circular 941.

Lee, A.M., Julien, M., 2006. Downstream Hydraulic Geometry of Alluvial Channels. Journal of Hydraulic Engineering ASCE 132, 1347-1352.

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, Massachusetts.

Leopold, L.B., Maddock, T., 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. U.S. Geological Survey Professional Paper: 252

Leopold, L.B., Skibitzke, H.E., 1967. Observations on unmeasured rivers. Geografiska Annaler 49, 247-255.

Leopold, L.B., Wolman, M.G., Miller, J.P., 1964. Fluvial Processes in Geomorphology. Dover Publications, New York.

McCandless, T.L., 2003a. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Allegheny Plateau and the Valley and Ridge Hydrologic Regions. U. S. Fish and Wildlife Service Technical Report CBFO-S03-01.

McCandless, T.L., 2003b. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Coastal Plain Hydrologic Region. U. S. Fish and Wildlife Service Technical Report CBFO-S03-02.

McCandless, T.L., Everett, R.A., 2002. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Piedmont Hydrologic Region. U. S. Fish and Wildlife Service Technical Report CBFO-S02-01.

McCuen, R.H., 2004. Hydrologic Analysis and Design. Prentice-Hall, Upper Saddle River, N.J.

McDowell, R.C., 1986. The Geology of Kentucky - A Text to Accompany the Geologic Map of Kentucky. U. S. Geological Survey Professional Paper 1151-H. U.S. Geological Survey, United States Government Printing Office, Washington, D.C.

McInnis, M., McIver, J., 2001. Influence of Offstream Water and Salt on Stream Banks of Grazed Riparian Pastures. Journal of Range Management 54, 648-652.

McIver, J.D., McInnis, M.L., 2007. Cattle Grazing Effects on Macroinvertebrates in an Oregon Mountain Stream. Rangeland Ecology and Management 60.

Metcalf, C., Shaneyfelt, R., 2005. Alabama Riparian Reference Reach and Regional Curve Study. Alabama Department of Environmental Management, Alabama Coastal Nonpoint Pollution Control Program. U.S. Fish and Wildlife Service, Panama City, FL.

Metcalf, C.K., Wilderson, S.D., Harman, W.A., 2009. Bankfull Regional Curves for North and Northwest Florida Streams. Journal of the American Water Resources Association 45.

Miller, S.J., Davis, D., 2003. Identifying and optimizing regional relationships for bankfull discharge and hydraulic geometry at USGS stream gage sites in the Catskill Mountains, NY. New York City Department of Environmental Protection Technical Report.

Mulvihill, C.I., Baldigo, B.P., 2007a. Regionalized Equations for Bankfull-discharge and Channel Characteristics of Streams in New York State—Hydrologic Region 3 East of the Hudson River. U.S. Geological Survey Scientific Investigations Report 2007–5227, 15.

Mulvihill, C.I., Ernst, A.G., Baldigo, B.P., 2005. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York state: Hydrologic Region 6 in the Southern tier of New York. U. S. Geological Survey Scientific Investigations Report 2005-5100, 21.

Mulvihill, C.I., Filopowicz, A., Coleman, A., Baldigo, B.P., 2007b. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State—Hydrologic Regions 1 and 2 in the Adirondack Region of Northern New York. U. S. Geological Survey Scientific Investigations Report 2007-5189, 18.

Murgatroyd, A.L., Ternan, J.L., 1983. The Impact of Afforestation on Stream Bank Erosion and Channel Form. Earth Surface Processes and Landforms 8, 357-370.

Nixon, M.A., 1959. Study on the bank-full discharges of rivers in England and Wales. Proceedings of the Institute of Civil Engineers 12, 157-174.

NRC, 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, D.C.

Parola, A.C., Vesely, W.S., Croasdaile, M.A., Hansen, C., Swisher Jones, M., 2007. Geomorphic Characteristics of Streams in the Bluegrass Physiographic Region of Kentucky.

Perfect, E., Karathanasis, T., Haszler, G., 1998. MLRA 121: Kentucky Bluegrass. Southern Cooperative Series Bulletin 391.

Pickup G. and Warner, R.F., 1976. Effects of hydrologic regime on magnitude and frequency of dominant discharge. Journal of Hydrology 29, 51-75.

Pizzuto, J.E., Hession, W.C., McBride, M., 2000. Comparing Gravel-bed Rivers in Paired Urban and Rural Catchements of Southeastern Pennsylvania. Geology 28, 79-82.

Radecki-Pawlik, A., 2002. Bankfull Discharge in Mountain Streams: Theory and Practive. Earth Surface Processes and Landforms 27, 115-123.

Rosgen, D.L., 1994. A classification of natural rivers. Catena 22, 169-199.

Rosgen, D.L., 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Schueler, T.R., 1995. The Importance of Imperviousness. Watershed Protection Techniques 1, 100-111.

Schumm, S.A., 1960. The shape of alluvial channels in relation to sediment type. U. S. Geological Survey Professional Paper 352-B.

Sherwood, J.A., Huitger, C.A., 2005. Bankfull Characteristics of Ohio Streams and Their Relation to Peak Streamflows. U. S. Geological Survey Scientific Investigations Report 2005–5153.

Simon, A., Dickerson, W., Heins, A., 2004. Suspended-sediment transport rates at the 1.5-year recurrence interval for ecoregions of the United States: transport conditions at the bankfull and effective discharge? Geomorphology 58, 243-262.

Simon, A., Pollen, N., Langendoen, E., 2006. Influence of Two Woody Riparian Species on Critical Conditions for Streambank Stability: Upper Truckee River, California. Journal of the American Water Resources Association.

Singh, V.P., 2003. On the Theories of Hydraulic Geometry. International Journal of Sediment Transport 18, 196-218.

Smith, D.P., Turrini-Smith, L., 1999. Western Tennessee Fluvial Geomorphic Regional Curves. Water Management Division: United States Environmental Protection Agency.

Stall, J.B., Fok, Y.S., 1968. Hydraulic geometry of Illinois streams. Universitiy of Illinois Water Resouces Center Research Report No. 15.

Stall, J.B., Yang, C.T., 1970. Hydraulic geometry of 12 selected stream systems of the United States. Universitiy of Illinois Water Resouces Center Research Report No. 32.

Stephenson, G.R., Rychert, R.C., 1982. Bottom sediment: a reservoir of *Escherichia coli* in rangeland streams. Journal of Range Management 35, 119-123.

Sweeney, B.W., 1992. Streamside Forests and the Physical, Chemical, and Trophic Characteristics of Piedmont Streams in Eastern North America. Water Science Technology 26, 2653-2673.

Sweet, W.V., Geratz, J.W., 2003. Bankfull Hydraulic Geometry Relationships adn Recurrence Intervals for the North Carolina's Coastal PLain. Journal of the American Water Resources Association 39, 861-871.

USGS, 1982. Bulletin 17B, Guidelines for determining flood-flow frequency. Hydrology Subcommittee of the Interagency Advisory Committee on Water Data, Reston, VA.

USGS, 2003. USGS Valley and Ridge Province.

Van Donsel, D.J., Gelreich, E.E., 1971. Relationships of Salmonella to fecal coliforms in bottom sediments. Water Research 5, 1079-1087.

Van Eps, M.A., Formica, S.J., Morris, T.L., Beck, J.M., Cotter, A.S., 2004. Using a bank erosion hazard index (BEHI) to estimate annual sediment loads from streambank erosion in the West Fork White River Watershed. ASAE Specialty Conference: Self-Sustaining Solutions for Streams, Wetlands, and Watersheds. y, St. Paul Minnesota.

Villarini, G., Smith, J.A., Serinaldi, F., Bales, J., Bates, P.D., Krajewski, W.F., 2009. Flood Frequency Analysis for Nonstationary Annual Peak Records in an Urban Drainage Basin. Advances in Water Resources 32, 1255–1266.

Wenger, S., 1999. A review of the scientific literature on riparian buffer width, extent, and vegetation. Publication of the Office of Public Service and Outreach. Institute of Ecology, University of Georgia. Athens, Georgia.

Westergard, B.E., Mulvill, C.I., Ernst, A.G., Baldigo, B.P., 2004. Regionalized equations for bankfull-discharge and channel characteristics of streams in New York state Hydrologic province 5 in Central New York. U.S. Geological Survey Scientific Investigations Report: 2004-1259.

Williams, P.G., 1978. Bankfull Discharge of Rivers. Water Resources Research 14, 1141-1154.

Wolman, M.G., 1955. The natural channel of Brandywine Creek, Pennsylvania
U. S. Geological Survey Professional Paper 282.

Wolman, M.G., 1967. A Cycle of Sedimentaion and Erosion in Urban River Channels. Geografiska Annaler 49A, 385-395.

Wolman, M.G., Miller, J.P., 1960. Magnitude and Frequency of Geomorphic Processes. Journal of Geology 68, 57-74.

Wolman, M.G.a.L., L. B., 1957. River Flood Plains: Some observation on their formation. U. S. Geological Survey Professional Paper 282.

Woodyer, K.D., 1968. Bankfull frequency in rivers. Journal of Hydrology 6, 114-142.

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