EVALUATION AND APPLICATION OF THE BANK ASSESSMENT FOR NON-POINT SOURCE CONSEQUENCES OF SEDIMENT (BANCS) MODEL DEVELOPED TO PREDICT ANNUAL STREAMBANK EROSION RATES

by

KARI A. BIGHAM

B.S., Kansas State University, 2011

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Biological and Agricultural Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Approved by:

Major Professor
Dr. Trisha Moore

Abstract

Excess sediment is a leading cause of stream impairment in the United States, resulting in poor water quality, sedimentation of downstream waterbodies, and damage to aquatic ecosystems. Numerous case studies have found that accelerated bank erosion can be the main contributor of sediment in impaired streams. An empirically-derived "Bank Assessment for Non-Point Source Consequences of Sediment" (BANCS) model can be developed for a specific hydrophysiographic region to rapidly estimate sediment yield from streambank erosion, based on both physical and observational measurements of a streambank. This study aims to address model criticisms by (1) evaluating the model's repeatability and sensitivity and (2) examining the developmental process of a BANCS model by attempting to create an annual streambank erosion rate prediction curve for the Central Great Plains ecoregion.

To conduct the repeatability and sensitivity analysis of the BANCS model, ten stream professionals with experience utilizing the model individually evaluated the same six streambanks twice in the summer of 2015. To determine the model's repeatability, individual streambank evaluations, as well as groups of evaluations based on level of Rosgen course training, were compared utilizing Kendall's coefficient of concordance and a linear model with a randomized complete block design. Additionally, a one-at-a-time design approach was implemented to test sensitivity of model inputs. Statistical analysis of individual streambank evaluations suggests that the implementation of the BANCS model may not be repeatable. This may be due to highly sensitive model inputs, such as streambank height and near-bank stress method selection, and/or highly uncertain model inputs, such as bank material. Furthermore, it was found that higher level of training may improve model implementation precision.

In addition to the repeatability and sensitivity analysis, the BANCS model developmental process was examined through the creation of a provisional streambank erosion rate prediction curve for the Central Great Plains ecoregion. Streambank erosion data was collected sporadically from 2006 to 2016 from eighteen study banks within the sediment-impaired Little Arkansas River watershed of south-central Kansas. Model fit was observed to follow the same trends, but with greater dispersion, when compared to other created models throughout the United States and eastern India. This increase in variability could be due to (1) obtaining streambank erosion data sporadically over a 10-year period with variable streamflows, (2)

BEHI/NBS ratings obtained only once in recent years, masking the spatiotemporal variability of streambank erosion, (3) lack of observations, and (4) use of both bank profiles and bank pin measurements to calculate average retreat rates.

Based on the results of this study, a detailed model creation procedure was suggested that addresses several model limitations and criticisms. Recommendations provided in the methodology include (1) more accurate measurement of sensitive/uncertain BEHI/NBS parameters, (2) multiple assessments by trained professionals to obtain accurate and precise BEHI/NBS ratings, (3) the use of repeated bank profiles to calculate bank erosion rates, and (4) the development of flow-dependent curves based on annually assessed study banks. Subsequent studies should incorporate these findings to improve upon the suggested methodology and increase the predictive power of future BANCS models.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to thank my major professor, Dr. Trisha Moore, for her support, advice, and guidance throughout my Master's research. I am forever thankful that Dr. Moore accepted me as her first graduate student at Kansas State and allowed me to pursue a research project of my choice. Her flexibility and encouragement has made me a more confident and inquisitive researcher. I would also like to thank my committee members, Dr. Tim Keane and Dr. Jason Vogel. Dr. Keane's passion for streams influenced me as an undergraduate to follow in his footsteps. He has been a great teacher, mentor, and friend over the years and I look forward to learning from and working with him on many more projects in the future. Finally, I appreciate Dr. Vogel's ability to push me in becoming a better researcher and scientific communicator. This thesis would not have turned out like it did without his guidance.

I would also like to thank my undergraduate field assistants, Jacob Zortman, Saadia Cleve, and Matt Price. Thank you for putting up with me and doing basically anything I told you to do, like survey in the rain and snow, scale 35 foot near-vertical, silty banks, and carry ridiculously heavy equipment from site to site, all for the sake of science. I hope you found some the work to be enjoyable and insightful.

A big thank you goes to the watershed specialists, Rick Schlender and Ron Graber, for working with the landowners to identify sites to use in this study. Also, the statisticians that helped through all stages of my research, Dr. Leigh Murray, Dr. Christopher Vahl, Francis Ofri, and Jiena Gu. Thank you for patience and guidance. Also, I would like to thank my repeatability study participants and volunteer student helpers; you know who you are. I would not have had a project without you. I hope you find the results useful.

Thank you to all of my mentors I have had the honor of working with and learning from so far, such as Dr. Stacy Hutchinson, Dr. Phil Barnes, Brad Loveless, Mike Nolan, John Gravelle, Ed Radatz, Andy Broxterman, Phil Balch, Don Baker, Mark Boyd, Kevin Beck, Dr. Katie Burke, Dr. Dave Rosgen, and many more. You all have been an inspiration to me in some form or other.

Finally, I would like to thank my husband, Dan, for insisting that I pursue a career that I am passionate about and putting up with my "river farming," my family for inspiring me to work hard and do better, and my friends for always believing in me. You all are the best.

Chapter 1 - Executive Summary

Sediment is a leading impairment of streams in the United States (U.S. EPA, 2016). In order to properly identify problem areas, mitigate erosion, and reduce sediment in streams, estimates of sediment yield from all possible sources in a watershed must be obtained. Several case studies have identified streambank erosion as the main contributor of sediment in some impaired watersheds (Belmont et al., 2011; Bull, 1997; Kronvang et al., 1997; Mukundan, et al., 2010; Rondeau et al., 2000; Trimble, 1997; Wilson et al., 2008). An empirically-derived "Bank Assessment for Non-Point Source Consequences of Sediment" (BANCS) model is one approach that can be utilized to rapidly estimate erosion rates and sediment yield from streambanks, based on both measured and visual assessment of a streambank (Rosgen, 2009). The BANCS model consists of two parameters that are used to predict annual streambank erosion rates: (1) the Bank Erosion Hazard Index (BEHI) and (2) the Near Bank Stress (NBS) rating. These parameters incorporate the physical characteristics of a streambank that work to resist both the gravitational and hydraulic forces that are applied to a bank of interest. But, like many empirical models that attempt to explain and estimate the laws of nature, the BANCS model has been criticized. This work aims to address criticisms of the BANCS model by (1) conducting a repeatability analysis between users and identifying sensitive and uncertain parameters that have a large influence on final BEHI/NBS ratings and (2) examining the developmental process of a BANCS model by attempting to create an annual streambank erosion rate prediction curve for the Central Great Plains ecoregion based on streambank erosion data that was collected sporadically over a ten-year period.

To conduct the repeatability and sensitivity analysis of the BANCS model, ten stream professionals with experience utilizing the model assessed the same six streambanks twice in the summer of 2015. Kendall's coefficient of concordance and a linear model with a randomized complete block design (RCBD) were utilized to measure agreement between raters and groups of raters, with groups defined according to the level of Rosgen training obtained by the rater. Additionally, a one-at-a-time design approach was implemented to test sensitivity of model parameters. Based on the statistical analysis, it was found that individual raters did not always obtain repeatable results, which indicates that the model is subject to user bias. This may be due to sensitive model inputs, such as study bank height, root depth, bank angle, and NBS method selection or uncertain model inputs, such as bank material. Furthermore, results indicate that higher level of training may result in more precise BEHI ratings. Based on these findings, it was recommended that future BANCS models obtain (1) accurate measurements of identified sensitive and uncertain model inputs, (2) NBS ratings from as many NBS methods as reasonably possible, based on site conditions, and (3) at least two observations, preferable four, of BEHI/NBS ratings from trained stream professionals to finalize a precise BEHI/NBS rating for a study bank.

In addition to the repeatability and sensitivity analysis, the BANCS model developmental process was examined through the creation of a provisional streambank erosion rate prediction curve for the Central Great Plains ecoregion. Streambank erosion data was collected sporadically from 2006 to 2016 from eleven study banks and from 2015 to 2016 from seven study banks, all located within the sediment-impaired Little Arkansas River watershed of south-central Kansas. The results of the model had similar trends but greater dispersion when compared to other BANCS models that had been deemed successful (e.g. Kwan & Swanson, 2014; Rosgen, 2001; Van Eps et al., 2004). This may be due to (1) obtaining streambank erosion data sporadically over a 10-year period with variable streamflows, (2) BEHI/NBS ratings being obtained only once in recent years, masking the spatiotemporal variability of streambank erosion, (3) lack of observations, and (4) use of both bank profiles and bank pin measurements to obtain average retreat rates.

Based on the results of this study, a detailed procedure for BANCS model creation was provided that addresses several model limitations and criticisms and may improve future models' statistical fit and significance. Recommendations outlined in the procedure include (1) more accurate measurement of sensitive/uncertain BEHI/NBS parameters, (2) multiple assessments by trained stream professionals to obtain precise BEHI and NBS ratings, (3) the use of repeated bank profiles to calculate bank erosion rates, and (4) the development of flow-dependent curves based on annually assessed study banks. Subsequent studies should incorporate this procedure to enhance the creation methodology, improve the overall understanding of streambank erosion processes, and increase the predictive power of future BANCS models.

Chapter 2 provides a thorough background and literature review of streambank erosion processes, various quantification methods, the BANCS model methodology, limitations, criticisms, and modifications, and this thesis' research objectives. The repeatability and sensitivity analysis is detailed in Chapter 3, followed by the examination of the BANCS model development process through the creation of a provisional BANCS model for the Central Great Plains ecoregion in Chapter 4. Chapter 5 outlines a recommended BANCS model creation procedure, based on the results of this study and others. Finally, Chapter 6 summarizes the results of this work as well as future research needs.

Chapter 2 - Background and Literature Review

2.1 Streambank Erosion

Excess sediment is the second leading cause of stream impairment in the United States, as identified through Section 303(d) of the Clean Water Act (U.S. EPA, 2016). This pollutant may lead to:

- Poor water quality due to increased turbidity and transport of contaminated sediments (i.e. phosphorus, pesticides, heavy metals) causing increased water treatment costs,
- Damage to aquatic ecosystems caused by increased turbidity and aggradation and,
- Sedimentation/siltation of downstream waterbodies such as water-supply and flood control reservoirs.

Sediment is a non-point source pollutant. Possible sources include hillslope and riparian areas through sheetwash, rill and gully erosion, as well as stream channel erosion through streambank erosion and bed degradation. Several watershed case studies have found that accelerated stream degradation and bank erosion can be the main contributor of sediment in some watersheds (Belmont et al., 2011; Bull, 1997; Kronvang, Grant, & Laubel, 1997; Mukundan, Radcliffe, Ritchie, Risse, & McKinley, 2010; Rondeau, Cossa, Gagnon, & Bilodeau, 2000; Trimble, 1997; Wilson et al., 2008)

Streams are self-forming and self-maintaining dynamic landscape features that have two primary purposes: to provide drainage and to transport sediment (Dunne & Leopold, 1978). Stream dimension, pattern, and profile is established and maintained based upon the bankfull stage. As defined by Dunne & Leopold (1978), bankfull stage is the discharge where stream channel maintenance is most effective (i.e. creation of bars, moving of meanders, etc.) and has a reoccurrence interval, on average, of 1.5 years. On dynamically-stable streams that are neither aggrading nor degrading, bankfull stage is often easy to determine visually as there tends to be some kind of field indicator present, such as a low, connected floodplain where incipient flooding occurs, a break in slope and/or change in particle distribution, staining of rocks, etc. (Rosgen, 1996b).

It is natural for streambanks on stable streams to erode. In fact, bank erosion is an essential component of river ecosystems. It supplies sediment and large woody debris that is necessary for the development and diversification of aquatic and riparian habitat (Florsheim, Mount, & Chin, 2008). But, changes in regional climate and watershed land use, type, and/or management can create stream instability that results in both physical and biological degradation. Stream instability causes accelerated bank erosion and channel degradation and/or aggradation, as the stream works to change its dimension, pattern, and profile to reach a dynamic equilibrium under new flow and/or sediment regimes. This process is best depicted by Lane's (1955) qualitative relationship that sediment size and quantity is proportional to stream slope and discharge; a change in any of these causes a change in one or more of the others, leading to stream aggradation or degradation, until a balance is reached. Figure 2.1 below shows a schematic of Lane's relationship.

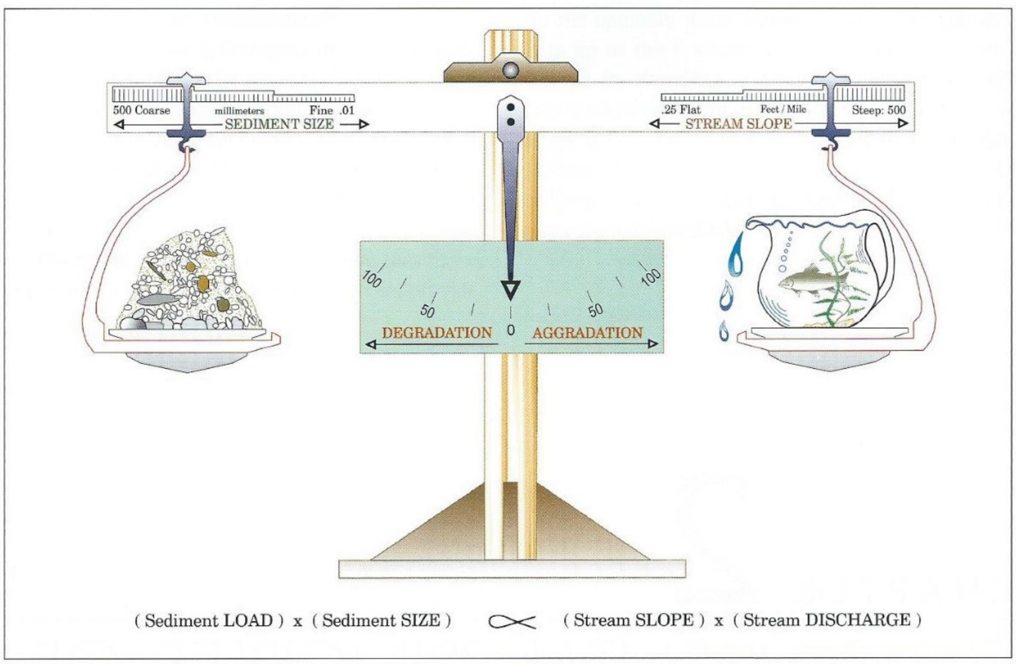


Figure 2.1 Illustration of Lane's Qualitative Relationship of Stream Stability (Rosgen, 1996b)

Both natural and anthropogenic influences can cause stream instability. Some examples of natural influences include changes in climate, vegetation, topography, and sediment source (Leopold, Wolman, & Miller, 1964). Examples of anthropogenic influences include in-channel dredging (Rondeau et al., 2000), channelization (Dunne & Leopold, 1978; Kronvang et al., 1997), construction of dams and embankments (Graf, 2006), human-induced climate change (Goudie, 2006), and conversion of land for urban and road development (Dunne & Leopold, 1978; Mukundan et al., 2010; Trimble, 1997) or for agricultural and silviculture purposes

(Belmont et al., 2011; Dunne & Leopold, 1978; Evans, Gibson, & Rossell, 2006; Fitzpatrick, Knox, & Whitman, 1999; Kronvang et al., 1997; Mukundan et al., 2010).

Streambank erosion varies on both spatial and temporal scales. On a spatial scale, streambank erosion is driven by its boundary conditions, which refer to the physical properties that characterize a streambank, as well as the gravitational and hydraulic forces that act on it. Boundary conditions vary on a macro-scale from stream-to-stream, on a meso-scale from meander-to-meander within a stream, and on a micro-scale from meter-by-meter along a given streambank (Parker, Simon, & Thorne, 2008). The physical properties of a streambank influence streambank erosion processes. Examples of these properties include geotechnical attributes such as soil texture, bulk density, cohesion, friction angle, unit weight, antecedent moisture content, and pore-water pressure (Simon, Curini, Darby, & Langendoen, 2000). Other physical properties include streambank height and angle, vegetation cover and root depth, and soil stratification (Gurnell, 1997; Hagerty, 1991; Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009; Simon & Hupp, 1987; Simon et al., 2000). These characteristics can provide insight into the erodibility of a given streambank.

The two driving forces that act on a streambank are gravitational and hydraulic forces. The gravitational force that acts on a streambank is dependent on the weight of the failure block and the angle of the failure plane (Simon et al., 2000). The shear strength of the bank resists the gravitational force acting on the bank. Shear strength depends on the soil cohesion, weight of the failure block, angle of its plane, pore-water pressure and the friction angle. Shear strength also depends on the presence of riparian vegetation roots (Pollen, 2007). If the gravitational force exceeds shear strength, failure is imminent (Simon et al., 2000). Bank erosion is also influenced by the hydraulic force being applied to a streambank at a particular location. The hydraulic force, often referred to as the applied shear stress, is dependent on the unit weight of water, the hydraulic radius of the cross section, and the slope of the hydraulic grade line. The highest applied shear stress often occurs near the toe of the bank, even during high flow events (Simon et al., 2000); therefore, the hydraulic force is resisted by the geotechnical properties that make up the toe of the streambank. This resistive force, which is called the critical shear stress, is dependent on sediment texture, particle density, bank angle, and soil friction angle (Simon et al., 2000). Once again, if the driving force (applied shear stress) exceeds the resistive force (critical shear stress), then fluvial entrainment and toe erosion is imminent.

Streambank erosion processes vary on a temporal scale, as well. Hydrologic and meteorologic changes through time are both processes that affect streambank erosion. For example, research has indicated that the greatest bank retreat rates do not occur during the largest storms or greatest flood events, but rather during long periods of rainfall events when the banks are the most saturated (Simon et al., 2000). Bull (1997) found similar results in that only a few of the total events in a given year may supply most of the sediment from bank erosion to the system and that erosion rates are highly dependent on the erosional processes that are occurring during a particular event. Finally, as Couper (2004) points out, once a streambank has retreated, the spatial features of that bank may no longer be the same, and therefore, may affect how that streambank erodes in the future.

Over the last hundred years, scientists have been developing ideas and models on how streams evolve over time following some kind of disturbance. The most popular of these channel evolution models have been from Schumm, Harvey, and Watson (1984) and Simon (1994). Schumm et al. (1984) state that a stream goes through five evolutionary stages. These stages are depicted in Figure 2.2 and are (1) pre-existing condition, (2) degradation following disturbance, (3) channel widening, (4) aggradation, and (5) equilibrium. Streambank erosion is most prominent during stages 2 and 3.

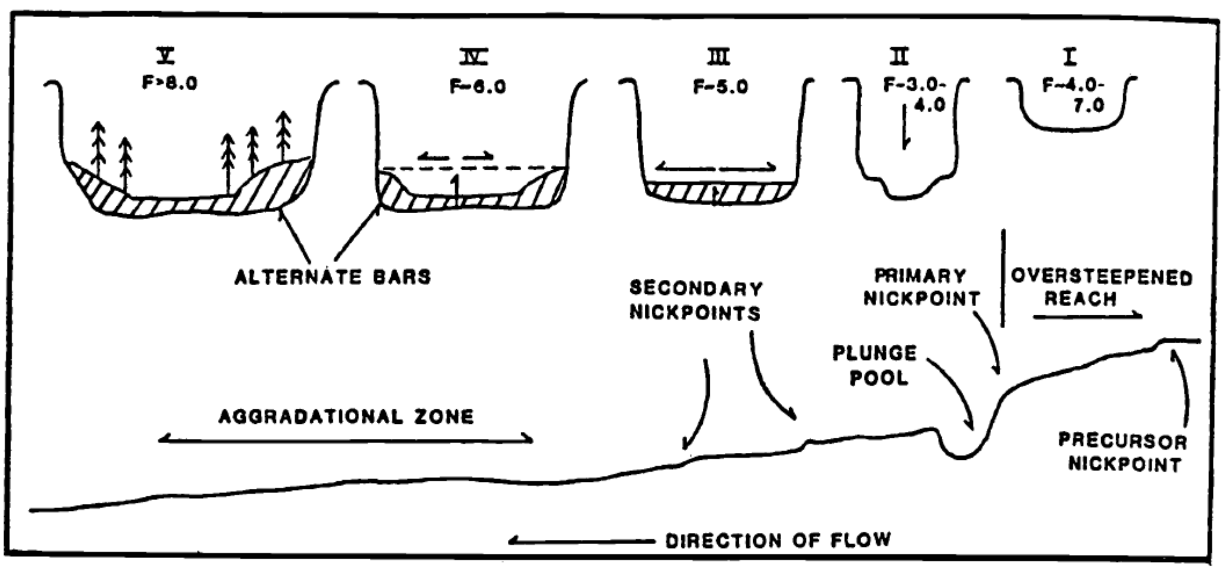


Figure 2.2 Five Stage Channel Evolution Model (Schumm et al., 1984)

Alternatively, Simon (1994) found that a stream may go through six stages of channel evolution. These stages are (1) pre-modified channel, (2) constructed channel or disturbance occurs, (3) degradation, (4) threshold, (5) aggradation, and (6) re-stabilization of the channel, as shown in Figure 2.3. The model contends that during stages 3 through 5, streambank erosion is accelerated. This evolution model is very similar to Schumm et al. (1984) but with an added stage (stage 2) depicting the disturbance, which in this case, was a modified channel. For either of these models, the amount of time it may take to move from one stage to the next can vary from days to even centuries, depending on site conditions. Channel evolution models can be very useful when attempting to determine whether streambank erosion in an impaired, unstable stream is a main contributor of sediment.

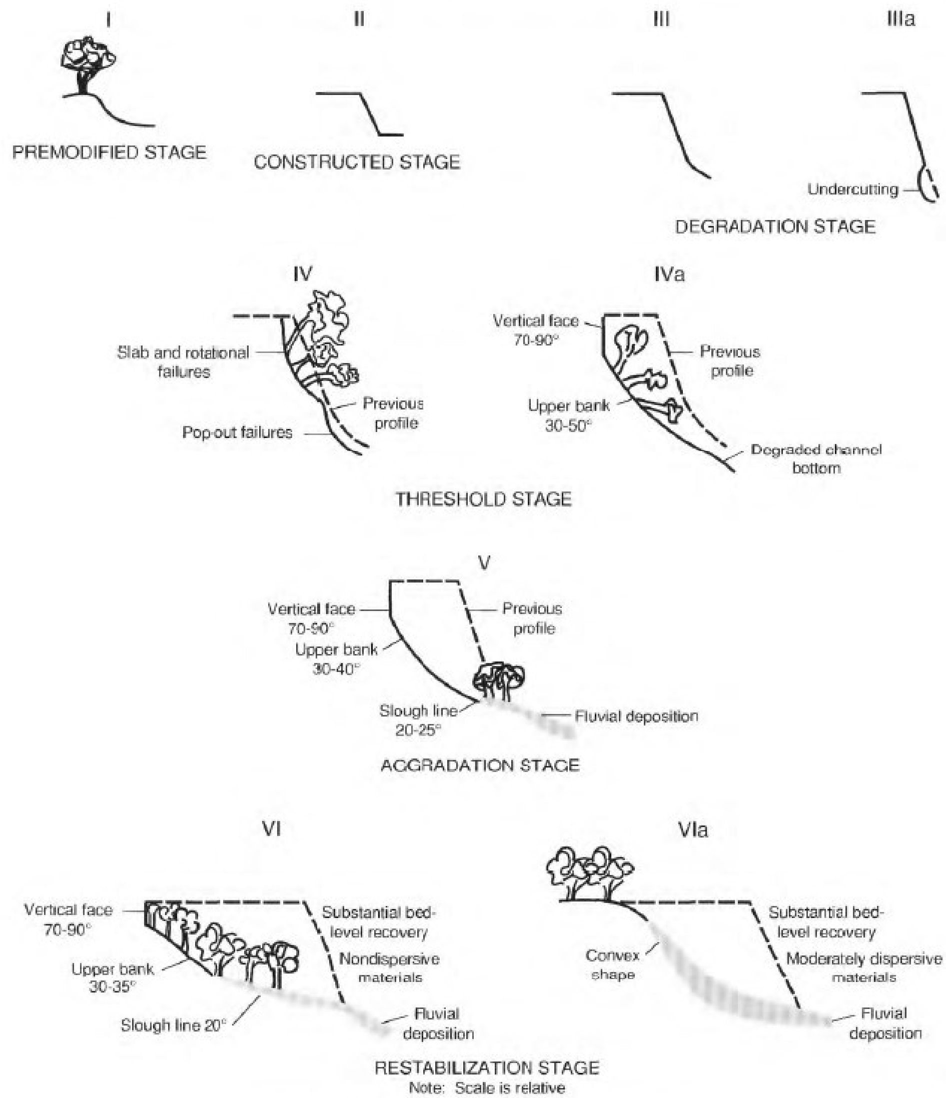


Figure 2.3 Six Stage Channel Evolution Model (Simon, 1994)

Because of changes in streambank boundary conditions and gravitational and hydraulic forces over time, either due to natural or anthropogenic influences, there is a wide array of streambank erosion processes. The three main processes of streambank failure are: mass failure, fluvial erosion, and subaerial weakening and weathering (Couper & Maddock, 2001). Each of these influences the other, but depending on the spatial and temporal scale, one process may dominate over the other. The following are common examples of these processes and are depicted in Figure 2.4:

a) Toe erosion caused by fluvial entrainment of non-cohesive bank materials, leading to mass failure due to gravity and lack of basal support, also known as cantilever failure (Bull, 1997; Casagli, Rinaldi, Gargini, & Curini, 1999; Thorne & Tovey, 1981)
b) Mass failure and headcut formation caused by seepage flow or piping created by pervious streambank layers or decaying plant material (Fox et al., 2007; Hagerty, 1991)
c) Tension crack formations along the edge of a streambank due to high tensile stress from the weight of the bank that can cause either a planar or rotational failure when the tensile strength is exceeded (Thorne & Tovey, 1981)
d) Mass wasting during the recessional limb of the stormflow hydrograph caused by bank saturation and loss of negative pore-water pressures (matric suction) in cohesive bank materials, also known as saturated rapid –drawdown condition (Casagli et al., 1999; Simon et al., 2000; Thorne & Tovey, 1981)
e) Freeze-thaw action or wetting and drying of the exposed surface of the bank which may loosen the soil, creating dry ravel that is easily transported via fluvial entrainment (Couper & Maddock, 2001; Lawler, 1993b)

Bank failures can also be further classified as either planar or rotational, depending on the shape of the bank failure surface. In general, planar failures tend to be more frequent and occur in the earlier stages of channel instability when bank heights tend to be lower. Rotational failures occur less often but can cause the most damage. These kinds of failures tend to occur on taller banks (Simon et al., 2000; Thorne & Tovey, 1981).

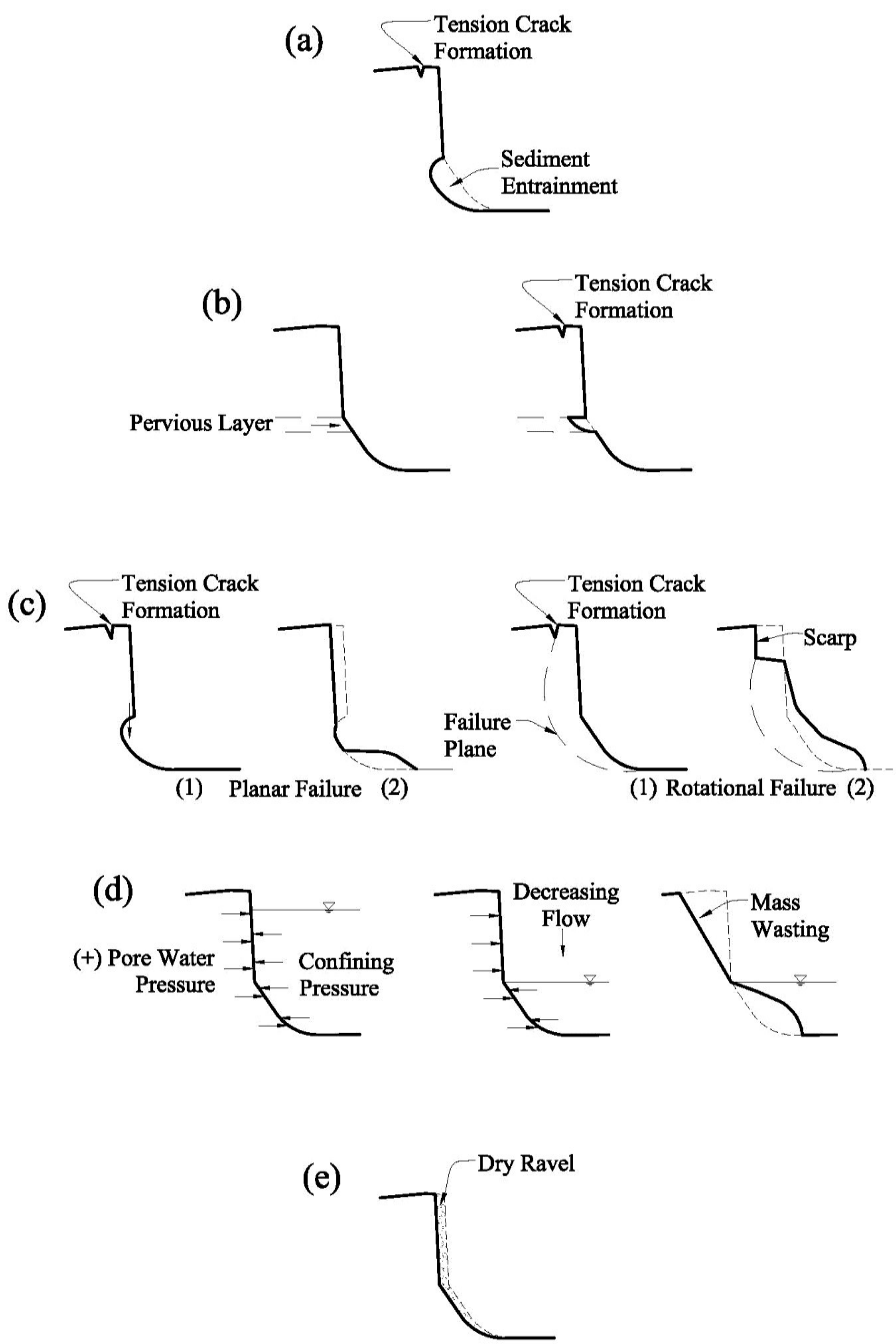


Figure 2.4 Streambank Erosion Processes: (a) Fluvial Entrainment, (b) Piping, (c) Planar or Rotational Failures, (d) Saturated Rapid-Drawdown Condition, and (e) Dry Ravel.

In streams that are impaired with excess sediment, it is critical to determine the sources so mitigation techniques can be implemented. Sediment source determination can be done by developing a watershed-scale sediment budget that identifies and quantifies sediment from all available sources including sheetwash, rill, gully, and channel erosion. The next section focuses on ways to identify and quantify sediment coming from channel erosion, and specifically streambank erosion.

2.2 Streambank Erosion Quantification Methods

In order to develop a sediment budget, a sediment yield in unit length, volume, or weight per time must be estimated from all of the potential sources of sediment. Because streambanks are typically not composed of homogenous materials and do not experience the same hydrologic events every year, it is very difficult to estimate and predict streambank erosion (Bull, 1997). Nevertheless, various methods have been developed to assist in the calculation of the sediment yield that originates from streambank erosion. Each method may yield different results, both in units as well as in values computed, therefore, it is recommended to use a combination of methods to more accurately develop a sediment yield. Examples of streambank erosion quantification methods include but are not limited to:

- Remote sensing, data acquisition, and geographic information system (GIS) analysis to (a) identify potential sources of high sediment yield (Evans et al., 2006; Rosgen, 2009), (b) estimate lateral retreat rates and/or volume of soil loss over time (Belmont et al., 2011; Sekely, Mulla, & Bauer, 2002; Trimble, 1997), and/or (c) analyze available water quality and quantity data to estimate sediment loads at a given point along the impaired stream (Belmont et al., 2011; Bull, 1997; Kronvang et al., 1997; Rondeau et al., 2000)
- Manually measuring streambank physical properties and erosion rates along the impaired stream of interest (Bull, 1997; Evans et al., 2006; Rosgen, 2009; Sekely, Mulla, & Bauer, 2002; Simon et al., 2000; Trimble, 1997)

Physical and empirical models have been developed that can be implemented to obtain a predicted or estimated sediment yield from streambank erosion using a combination of methods presented above (Rosgen, 2009; Simon et al., 2000). The “Bank Stability and Toe Erosion Model” (BSTEM) is a physically-based model that utilizes field measurement of streambank physical characteristics and storm hydrographs to predict micro- to meso-scale streambank erosion rates in unit area per storm event using the gravitational and hydraulic force balance (Simon et al., 2000). This approach can be quite costly and time consuming to obtain such high level of detail but precise prediction of bank erosion may be warranted in some instances. Alternatively, the "Bank Assessment for Non-Point Source Consequences of Sediment" (BANCS) model is an empirically-based model used to rapidly estimate average annual streambank erosion rates on a meso- to macro-scale. When the BANCS model is applied to a specific hydrophysiographic region, this model outputs an approximate sediment yield in unit length per year that can be easily converted to unit volume per year, and unit weight per year, provided some assumptions. The BANCS model applies the previously mentioned bank erosion quantification methods of (1) manually measuring streambank physical properties and erosion rates and (2) remote sensing, data acquisition and GIS analysis to identify vulnerable streambanks, determine site conditions (i.e. soils, vegetation, etc.), and estimate geomorphic characteristics. The BANCS model does not directly take into account hydrologic events and/or the climatic history of a given stream, but Rosgen (2015) states that there is a need to develop curves for different flow events. The BANCS model is developed solely on empirical relationships of the following measurable variables:

- Streambank physical properties, which include bank height, vegetation, slope, and bank material texture and stratification and
- Near-bank stress applied to the streambank in interest.

The BANCS model is process-integrated, as all of the variables utilized are critical components to the gravitational and hydraulic force balance (Rosgen, 2009). The BANCS model will be the focus of this thesis.

2.3 Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model

The BANCS model was developed as part of an overall watershed assessment tool that is used to comprehensively investigate sediment sources. Developed by Rosgen (2006), the Watershed Assessment for River Stability & Sediment Supply (WARSSS) method is a step-by-step, geomorphology-based procedure that examines land-use and its effect on channels found within a given watershed as well as its sediment supply, transport, and fate. Since the method is based on a variety of geomorphic processes and variables, users should be able to quantitatively measure these variables, providing a consistent and comparative analysis with low subjective bias. The geomorphic processes that influence erosion, aggradation and channel stability and are examined in the WARSSS methodology include hillslope, hydrologic, and channel processes.

The method has three phases in the watershed assessment. These phases include:

1. Reconnaissance Level Assessment (RLA)
2. Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC)
3. Prediction Level Assessment (PLA)

Each successive phase evaluates the entire watershed with increasing detail. The RLA is a sweeping assessment of the watershed using GIS tools to assist in delineating low- from moderate- and high-risk stream reaches and landscapes. This allows users to eliminate the low-risk features from further assessment. The next phase, the RRISSC, increases the detail of assessment by determining the erosional risk, based upon fluvial processes, land use, and aggradation/degradation relations, of those landscapes and stream reaches identified from the RLA. If the risk is low, no mitigation is necessary. Moderate-risk areas will most likely require mitigation and management changes that should be monitored following adjustment. The high-risk areas will be further assessed in the final step, the PLA. In this step, high-risk areas are evaluated by investigating hillslope, hydrologic and channel processes for a given area, allowing the user to determine the cause of impairment. Once the cause is determined, it can be alleviated through mitigation. Following mitigation, it is recommended that these sites are monitored over time to guarantee success (Rosgen, 2009).

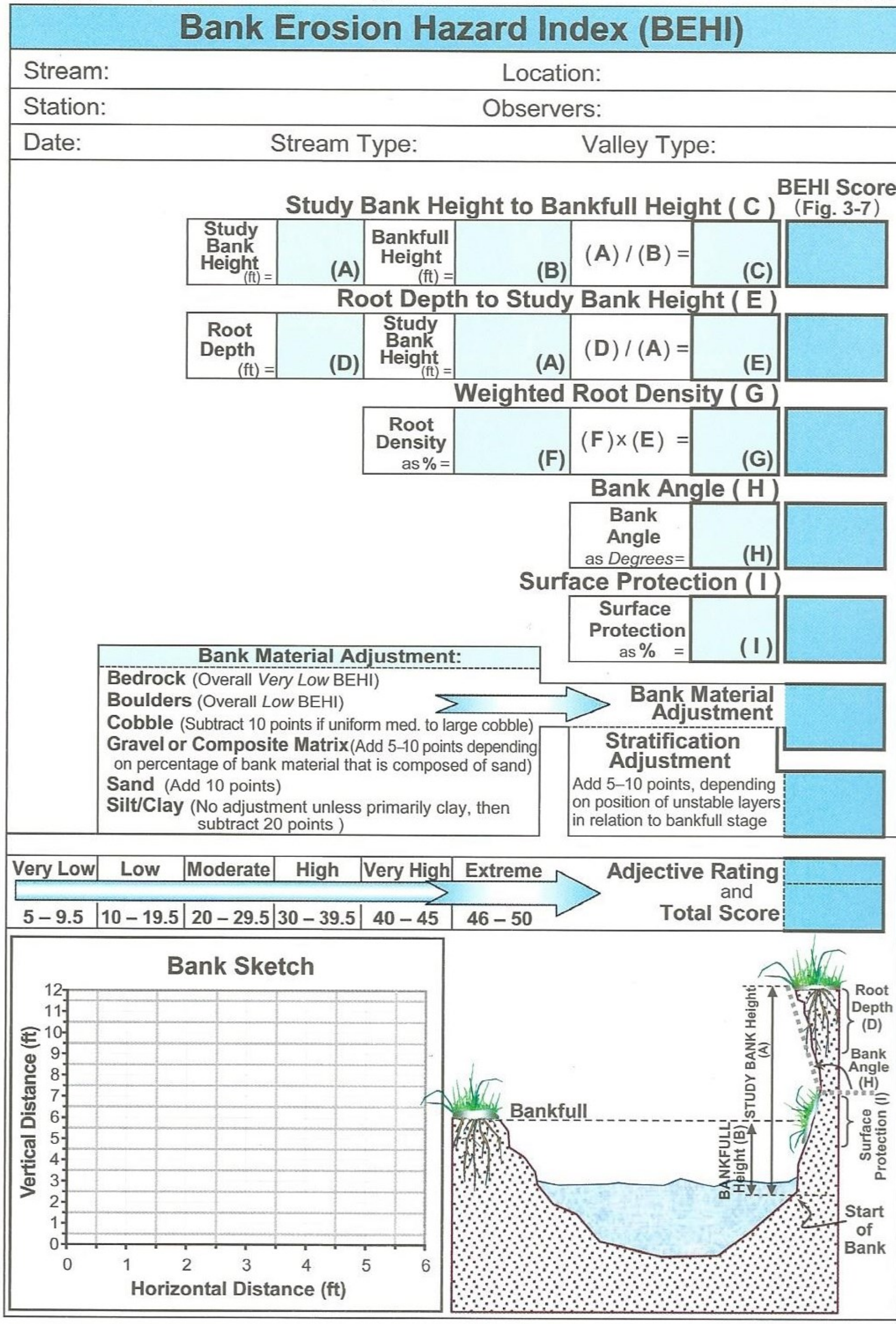
The BANCS model, upon which this thesis focuses, is part of the channel processes analysis of the PLA. Rosgen (2001) presents this model as a practical alternative to estimate annual streambank erosion rates within a given hydrophysiographic region rather than using more cumbersome, physically-based models. The BANCS model contains two parameters, (1) the Bank Erosion Hazard Index (BEHI) and (2) the Near-Bank Stress (NBS) rating, to predict annual streambank erosion rates, based upon regionally measured bank erosion rates. The terms “BANCS model” and “streambank erosion rate prediction curve” are used interchangeably throughout this thesis. The BANCS model methodology will be described in detail in the next sections.

2.3.1 Bank Erosion Hazard Index (BEHI) Rating Methodology

The BEHI provides an adjective rating of bank erodibility based on visual and measured assessment of a streambank of interest. Seven variables comprise the BEHI method to develop an overall BEHI rating. These variables are:

1) Study Bank Height-to-Bankfull Height Ratio
2) Root Depth-to-Study Bank Height Ratio
3) Weighted Root Density
4) Bank Angle
5) Surface Protection
6) Bank Material
7) Stratification of Bank Material

These seven variables are then inputted into the BEHI worksheet, shown in Figure 2.5, and converted into a BEHI score/rating using Figure 2.6. The empirical relationships between streambank variables and ratings presented in Figure 2.6 are based on the conversion of field observation to erosion potential (Rosgen, 2001). Individual ratings of the seven variables vary from Very Low (0-2 points) to Extreme (9-10 points). These scores are then summed to determine the overall BEHI rating for a specific streambank. Overall BEHI ratings range from Very Low (0-9.5 total points) to Extreme (46-50 total points). More detail is provided in the next sections for assessing each of the seven BEHI variables (Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009).



Bank Erosion Hazard Index (BEHI)

Stream: Location:

Station: Observers:

Date: Stream Type: Valley Type:

BEHI Score (Fig. 3-7)

Study Bank Height to Bankfull Height (C)

Study Bank Height (ft) = (A) | Bankfull Height (ft) = (B) | (A) / (B) = (C)

Root Depth to Study Bank Height (E)

Root Depth (ft) = (D) | Study Bank Height (ft) = (A) | (D) / (A) = (E)

Weighted Root Density (G)

Root Density as % = (F) | (F) x (E) = (G)

Bank Angle (H)

Bank Angle as *Degrees* = (H)

Surface Protection (I)

Surface Protection as % = (I)

Bank Material Adjustment:

Bedrock (Overall *Very Low* BEHI)
Boulders (Overall *Low* BEHI)
Cobble (Subtract 10 points if uniform med. to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (No adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment

Stratification Adjustment

Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score

Bank Sketch

Figure 2.5 Bank Erosion Hazard Index (BEHI) Worksheet (Rosgen, 2014)

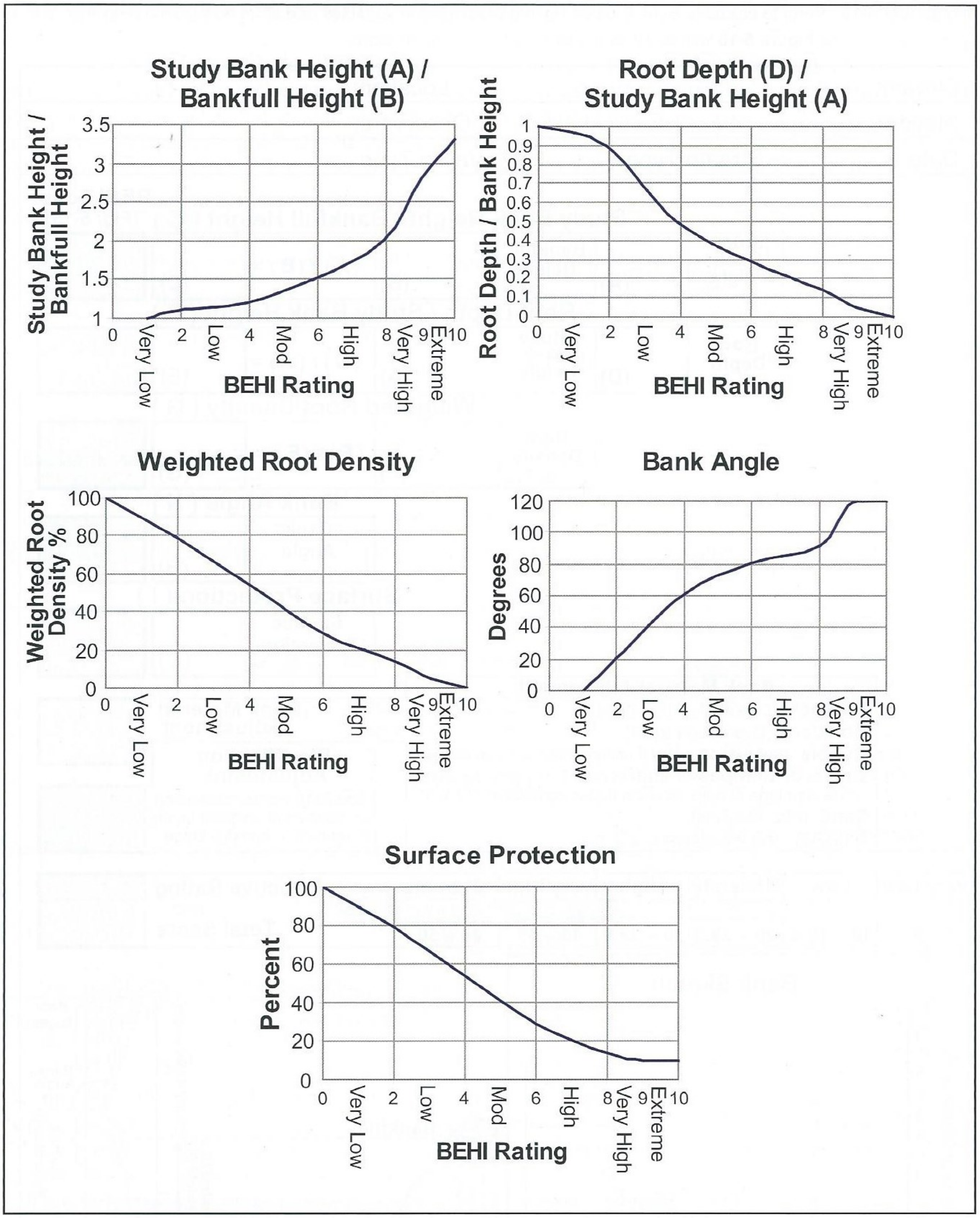


Figure 2.6 Relationships between Bank Erosion Hazard Index (BEHI) Variables and Ratings (Rosgen, 2009)

2.3.1.1 Study Bank Height-to-Bankfull Height Ratio

Study bank height and bankfull height are measured from the toe of the bank to the top of the bank of interest or to a bankfull indicator, respectively (see Figure 2.7). Study bank height is then divided by the bankfull height to adjust for scale, such that this measure can be applied to varying sizes of streams. As study bank height becomes greater than bankfull height, the risk of erosion as well as the amount of sediment potentially available to erode increases (Rosgen, 2009; Simon, 1989).

Figure 2.7 Study Bank Height-to-Bankfull Height Ratio Example – Middle Little Arkansas River Study Bank #3

2.3.1.2 Root Depth-to-Study Bank Height Ratio

The prevailing rooting depth, as shown in Figure 2.8, is measured and then divided by the study bank height, determined in the previous measurement. The deeper the roots, the greater the resistive force of the bank to erosion, as portrayed in the ratio-to-BEHI rating conversion (see Figure 2.6). If the roots do not extend to the toe of the bank, then the bank may become undercut which may lead to cantilever failure of the bank (Rosgen, 2009; Simon & Collison, 2002).

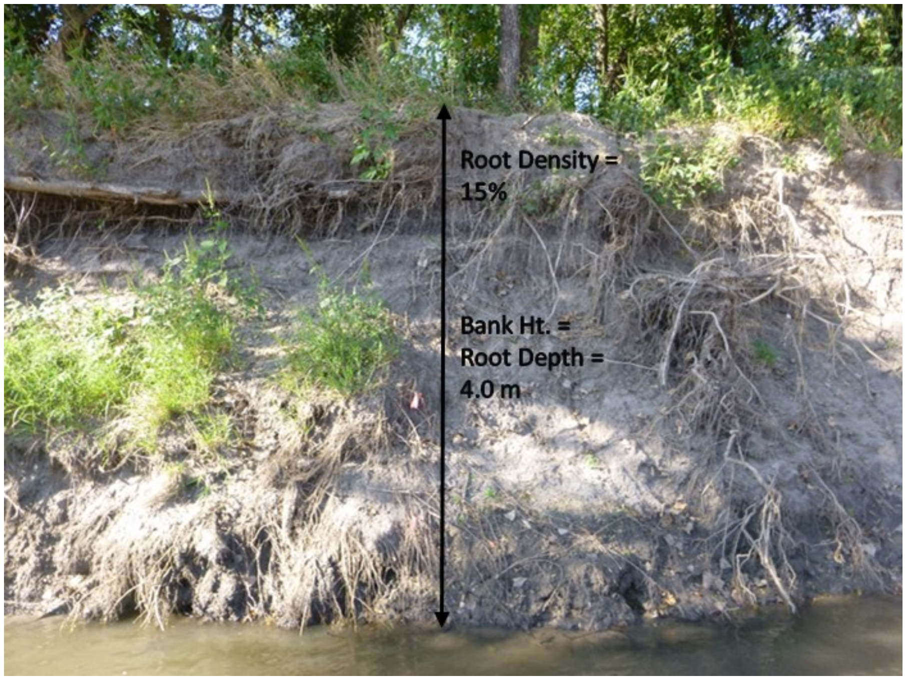


Figure 2.8 Root Depth-to-Study Bank Height Ratio and Root Density Example – Lower Little Arkansas River Study Bank #3

2.3.1.3 Weighted Root Density

Weighted root density is an ocular estimate of the amount of roots per unit volume of soil (see Figure 2.8). This estimate is taken only in the area of the bank where there are roots. This value is then multiplied by the root depth-to-study bank height ratio to get a weighted root density value for the entire height of the bank. The greater the weighted root density, the greater the soil strength (Simon & Collison, 2002), and the more resistive the bank is to erosion, as portrayed in the weighted root density-to-BEHI rating conversion (Rosgen, 2009).

2.3.1.4 Bank Angle

Bank angle is measured to determine the bank's susceptibility to erosion. Ninety degrees is a vertical bank, less than ninety degrees is a bank that is laid back, and greater than ninety degrees is a bank that is most likely undercut and highly susceptible to bank failure (Simon et al., 2000). Figure 2.9 below shows an example of bank angle (Rosgen, 2009).

Figure 2.9 Bank Angle Example – Lower West Emma Creek Study Bank # 1

2.3.1.5 Surface Protection

Surface protection is an ocular estimate of the percentage of bank surface area protected by some form of vegetation such as sod mats and/or woody debris (see Figure 2.10). The greater the streambank area protected by vegetation, the lower the potential for erosion (Rosgen, 2009; Simon & Hupp, 1987).

2.3.1.6 Bank Material

Bank material is determined either through an ocular or texture-by-feel estimate. Rosgen (2001; 2009) denotes six different types of bank materials: bedrock, boulders, cobble, gravel or composite matrix, sand, and silt/clay. Depending on what material the bank is composed of determines whether or not to give the bank a Very Low/Low overall BEHI rating (bedrock and boulders only) or if the field practitioner should add or subtract points from the overall BEHI score. Points may be added to the score if the material in the bank is considered to be highly erodible, such as gravel or composite matrix and sand. Points may be subtracted from the score if the bank material is highly resistive to erosion such as medium to large cobble and banks with high amounts of clay (Parker et al., 2008; Rosgen, 2009; Rosgen, 2014; Simon et al., 2000). As suggested by the RIVERMorph software, created by Stantec Consulting Services (2013) to easily analyze Rosgen stream geomorphology methodology, if the clay content is greater than 50% clay content, then subtract 10 points. If bank material is predominately clay, then subtract 20 points. See Figure 2.5 for point assignments and Figure 2.11 for an example.

Figure 2.10 Surface Protection Example – Lower Little Arkansas River Study Bank #2

2.3.1.7 Stratification of Bank Material

Banks with different layers of bank material are considered stratified. This overall BEHI score adjustment allows the field practitioner to determine whether the layers in the bank are susceptible to erosion, either via surface erosion or piping. Piping may occur in layers of pervious materials such as sand or small gravel (Fox et al., 2007; Hagerty, 1991; Rosgen, 2009; Thorne & Tovey, 1981). If these kinds of layers are evident, five to ten points may be added to the overall BEHI score (Rosgen, 2009). Figure 2.11 shows an example of bank stratification.

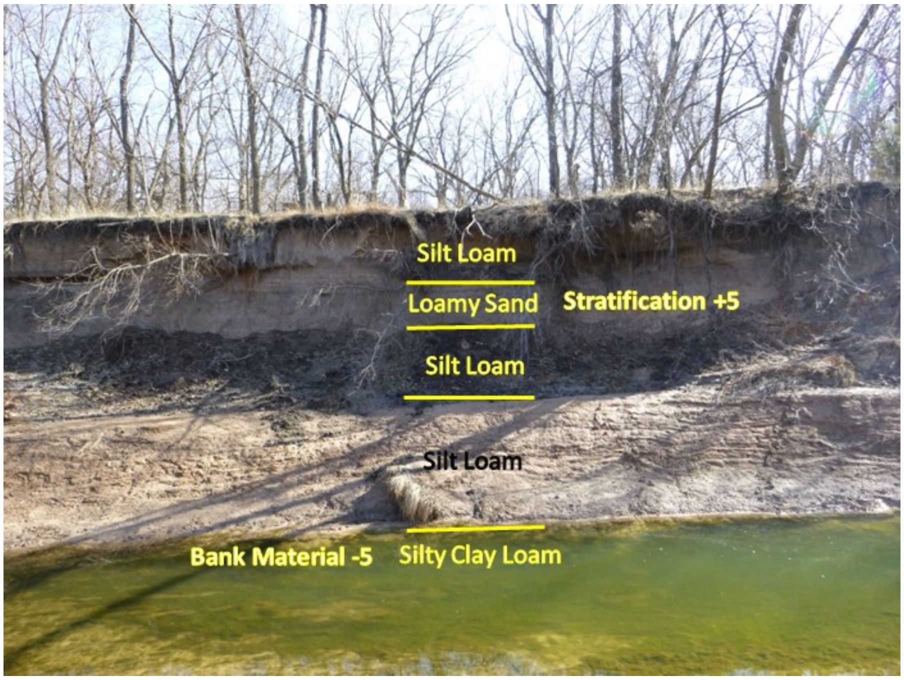


Figure 2.11 Bank Material and Stratification Example – Middle Little Arkansas River Study Bank #1

2.3.2 Near-Bank Stress (NBS) Rating Methodology

The NBS rating provides an adjective rating of the amount of fluvial force (or applied shear stress) induced by the outer one-third of the channel flow adjacent to the eroding bank of interest (Rosgen, 2009). Fluvial forces are the result of the local energy slope and the channel pattern and dimensions (Rosgen, 1996b; Simon et al., 2000). NBS ratings range from Very Low to Extreme. There are seven methods that can be used to determine the NBS rating. They are as follows:

1) Presence of Transverse/Central Bars or Channel Pattern Changes
2) Radius of Curvature-to-Bankfull Width ratio
3) Pool Slope-to-Average Water Surface Slope ratio
4) Pool Slope-to-Riffle Slope ratio
5) Near-bank Maximum Depth-to-Bankfull Mean Depth ratio
6) Near-bank Shear Stress-to-Bankfull Shear Stress ratio
7) Velocity Isovels

Estimating Near-Bank Stress (NBS)

Stream:	Location:	
Station:	Stream Type:	Valley Type:
Observers:		Date:

Methods for Estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar, or split channel/central bar creating NBS.....	Level I	Reconaissance
(2) Radius of curvature to bankfull width (R_c / W_{bkf})........................	Level II	General Prediction
(3) Pool slope to average water surface slope (S_p / S)........................	Level II	General Prediction
(4) Pool slope to riffle slope (S_p / S_{rif})........................	Level II	General Prediction
(5) Near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})...............	Level III	Detailed Prediction
(6) Near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})...............	Level III	Detailed Prediction
(7) Velocity profiles / Isovels / Velocity gradient........................	Level IV	Validation

Level I

(1) Transverse or central bars - short or discontinuous..........................NBS = *High / Very High*
Extensive deposition (continuous, cross-channel)..........................NBS = *Extreme*
Chute cutoffs, down-valley meander migration, converging flow..........................NBS = *Extreme*

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec/ ft)	Near-Bank Stress (NBS)

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) Ratings	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) Rating

Figure 2.12 Near-Bank Stress (NBS) Rating Worksheet (Rosgen, 2014)

These seven methods are ordered based on the amount of time and resources needed to conduct the method. Method 1 (Presence of Transverse/Central Bars or Channel Pattern Changes) is the one of the most cost-effective and rapid of the methods to conduct while method 7 (Velocity Isovels) is the most costly and time-consuming. The field practitioner selects one or several of these methods that best represent the site conditions and then uses the highest (not the average) of these ratings as the dominant near-bank stress (Rosgen, 2009). Rosgen (2009) cautions users by stating: "The [order of methods] are not necessarily synonymous with reliability of prediction (pg. 5-68)." In other words, just because method 7 requires greater level of detail, does not mean that this is the only method that could be used to determine the dominant NBS rating. Figure 2.12 shows the NBS rating worksheet. The next sections will provide more detail on each of the seven methods presented.

2.3.2.1 Method 1: Presence of Transverse/Central Bars or Channel Pattern Changes

This method requires the field practitioner to look for any kind of excess deposition, such as central or transverse bars, that may be directing flow and creating a high shear stress in the near-bank region of the streambank in interest. If this is the case, a NBS rating of High to Extreme may be given. Additionally, the user can give the streambank an Extreme NBS rating if it appears that the meander is migrating downstream, based on aerial imagery assessment (Rosgen, 2009).

2.3.2.2 Method 2: Radius of Curvature-to-Bankfull Width ratio

In this method, the radius of curvature of the meander bend containing the streambank of interest is measured. This is then divided by the bankfull width of the channel, as measured at a representative riffle within the reach. The radius of curvature can be obtained in the field or utilizing an aerial photograph. Figure 2.13 shows how to measure a meander's radius of curvature. The greater this ratio, the lower the expected near bank stress is on the streambank in interest (Rosgen, 2009). Rating cut-offs are presented at the bottom of the NBS rating worksheet in Figure 2.12. This method requires a cross-sectional survey at the midpoint of a representative riffle within the reach to determine bankfull width based on visual bankfull indicators and calibration using streamflow or regional curve data.

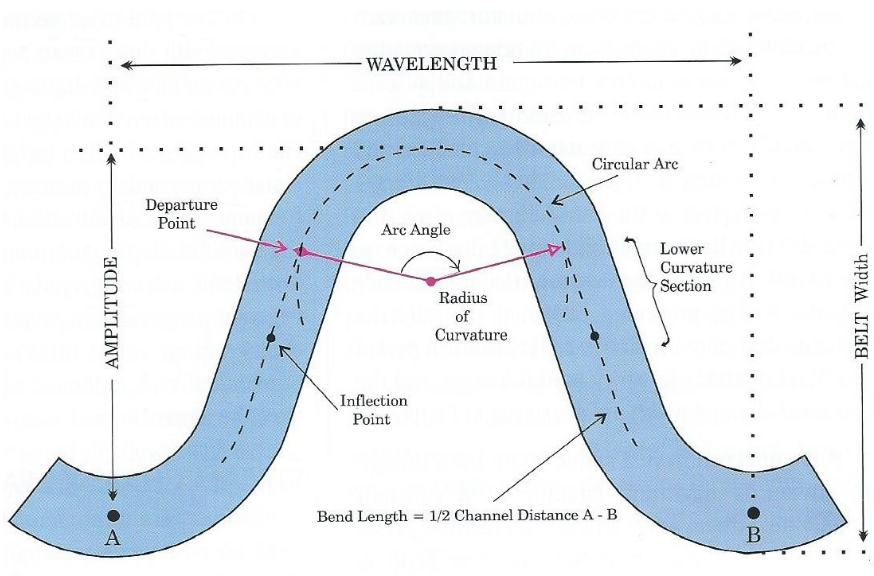


Figure 2.13 Radius of Curvature and Meander Geometry (Rosgen, 1996b)

2.3.2.3 Method 3: Pool Slope-to-Average Water Surface Slope ratio

This method can be used to determine NBS rating if the eroding streambank of interest is located along a pool. Pool slope is measured as the slope of the water surface from the end of a run to the start of glide along the pool of interest. The average water surface slope is measured from head-of-riffle to head-of-riffle of the given stream reach within which the streambank of interest is located. Alternatively, the average bankfull slope could also be used, as the average water surface slope and average bankfull slope should be equal. Average water surface slope, bankfull slope, and individual facet slopes for various features (i.e. pools, riffles) are depicted in Figure 2.14. The pool slope is then divided by the average slope of the stream to obtain a ratio value. The greater the ratio, the greater the near-bank stress on the eroding streambank (Rosgen, 2009). Rating cut-offs are presented at the bottom of the NBS rating worksheet in Figure 2.12. This method requires a longitudinal survey of a reach at least twenty bankfull widths long or two full meander wavelengths (Rosgen, 1996b).

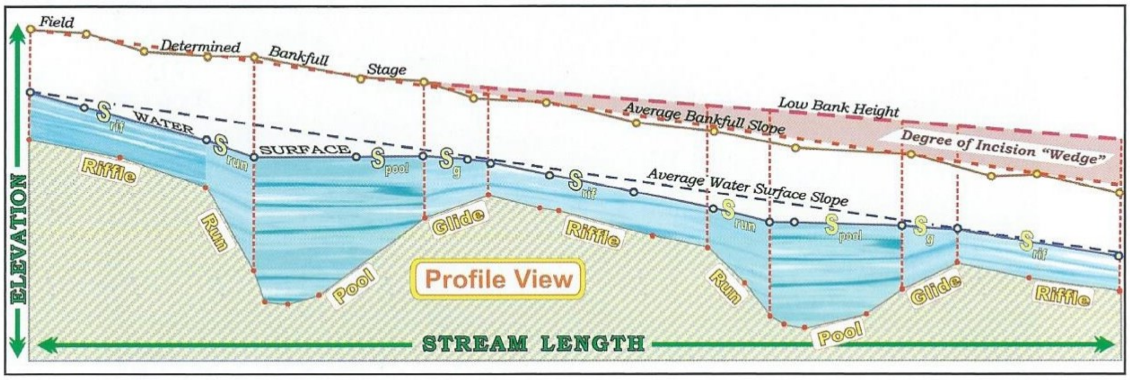


Figure 2.14 Slope Measurements (Rosgen, 2009)

2.3.2.4 Method 4: Pool Slope-to-Riffle Slope ratio

Once again, this method can be utilized to determine NBS rating if the eroding streambank of interest is located along a pool. If so, the pool slope is measured, as described for method 3, along the water surface from end of run to start of glide. The riffle slope must be measured along the riffle upstream of the pool. This slope is measured along the water surface from the head of riffle to start of run. These slope measurements are depicted in Figure 2.14. The pool slope is then divided by the riffle slope to obtain a ratio value. When pool slope is greater than the slope of the upstream riffle, also known as a slope reversal, streambank erosion increases. Therefore, as this ratio increases, so does the near bank stress along the streambank of interest (Rosgen, 2009). Rating cut-offs are presented at the bottom of the NBS rating worksheet in Figure 2.12. Similar to method 3, this method requires a longitudinal survey of a reach at least twenty bankfull widths long or two full meander wavelengths (Rosgen, 1996b).

2.3.2.5 Method 5: Near-bank Maximum Depth-to-Bankfull Mean Depth ratio

This method requires the field practitioner to survey a cross section at the eroding streambank of interest to obtain maximum depth and mean depth at bankfull stage (Rosgen, 2014). Bankfull mean depth is calculated by dividing the bankfull cross-sectional area by the bankfull width. Near-bank maximum bankfull depth is then divided by the bankfull mean depth to obtain a ratio value. As the ratio of the maximum bankfull depth to the average bankfull depth increases, the near bank stress rating also increases (Rosgen, 2009). Rating cut-offs are presented at the bottom of the NBS rating worksheet in Figure 2.12. It should be noted that in the WARSSS textbook (Rosgen, 2009), the description of this method states: "This method calculates the ratio of the near-bank maximum bankfull depth at a study site to mean depth from a *riffle* cross-section (p 5-74)." This description is corrected in Rosgen (2014) and is in fact, the bankfull mean depth at the eroding streambank of interest.

2.3.2.6 Method 6: Near-bank Shear Stress-to-Bankfull Shear Stress ratio

Shear stress (τ) in steady, uniform flow conditions is calculated using the following equation:

$$\tau = \gamma RS \qquad \text{(Eq. 1)}$$

Where γ = specific weight of the fluid, R = hydraulic radius = cross-sectional area/wetted perimeter, and S = average water surface slope. This same equation is what is used to calculate applied shear stress, the driving force in the hydraulic force balance described in Section 2.1. For this application, Rosgen (2009) assumes that the channel is a wide channel and therefore R is roughly equal to the depth of the channel (d), simplifying equation 1 to:

$$\tau = \gamma dS \qquad \text{(Eq. 2)}$$

Therefore, the equations to calculate near-bank shear stress (τ_{nb}) and bankfull shear stress (τ_{bkf}) are as follows:

$$\tau_{nb} = \gamma d_{nb} S_{nb} \qquad \text{(Eq. 3)}$$

$$\tau_{bkf} = \gamma d_{bkf} S \qquad \text{(Eq. 4)}$$

Where d_{nb} = the near-bank maximum depth in line with the streambank of interest, d_{bkf} = mean bankfull depth also in line with the streambank of interest, and S_{nb} = near-bank water surface slope. S_{nb} is equal to the facet slope of the bed feature adjacent to the streambank of interest. In most cases, S_{nb} is just the pool slope. The near-bank shear stress is then divided by the bankfull shear stress to obtain a ratio value. The greater the near-bank shear stress is compared to the bankfull shear stress, the greater the erosion potential of the bank of interest and the higher the NBS rating (Rosgen, 2009). Rating cut-offs are presented at the bottom of the NBS rating worksheet in Figure 2.12. This method requires survey of a representative riffle as well as longitudinal profile survey of at least twenty bankfull widths long or two full meander wavelengths (Rosgen, 1996b).

2.3.2.7 Method 7: Velocity Isovels

This method requires the greatest amount of field data collection. Vertical velocity profiles across the channel perpendicular to the bank of interest must be collected using current meters during at or near bankfull flow events. Lines of equal velocities (isovels) are then plotted on a cross section. Next, distance is measured from the streambank of interest to the core, or the fastest velocity, of the cross section. Velocity gradient is calculated by dividing the fastest velocity of the cross-section by this distance. An example of determining the velocity gradient is shown in Figure 2.15. The greater the velocity gradient is, the greater the near-bank stress and rating (Rosgen, 2009). Rating cut-offs are presented at the bottom of the NBS rating worksheet in Figure 2.12.

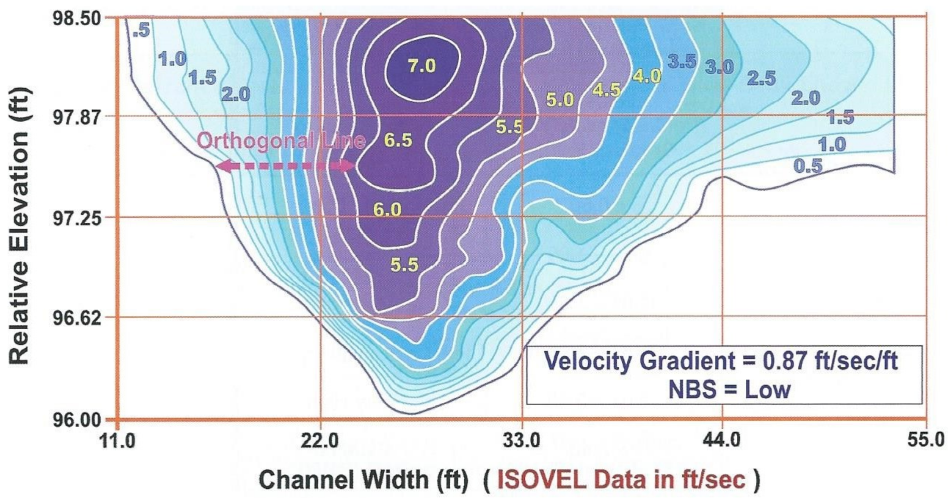


Figure 2.15 Example of Velocity Isovels and Gradient Calculation (Rosgen, 2009)

2.3.3 Measuring Annual Streambank Retreat Rates

The final item needed to create a BANCS model is manually measured bank retreat rates obtained from various BEHI/NBS-rated streambanks within a given hydrophysiographic region over a one-year time period. This can be accomplished in numerous ways, for example, utilizing erosion pins, terrestrial photogrammetry, and repeated cross profiling. Each technique has its advantages and limitations that should be taken into consideration before selection (Lawler, 1993a). For this application, Rosgen (2009) recommends the use of repeated cross profiling in combination with erosion pins.

Repeated cross-profiling or bank profiles are permanent, monumented cross sections at the streambanks of interest. These cross sections are marked with a toe pin of known elevation that is placed at or near the toe of the study streambank. A survey rod is then placed plumb on the toe pin so that the field practitioner can “profile” the study bank by taking level, horizontal measurements to the study bank at given vertical distances up the survey rod. The study bank can then be profiled at some time later (e.g. one year) so that when the two profiles of the same study bank are superimposed on one another, it is possible to calculate the bank retreat or change in area over time. This change in area is divided by the study bank height to obtain an average bank retreat rate in unit length per time. To develop a BANCS model, the lateral retreat rate should be in units of length per year. Bank erosion pins may also be installed, but are not required. These pins are utilized to rapidly assess bank erosion rates throughout the rainy season (Rosgen, 2009). Figure 2.16 depicts the bank profile procedure.

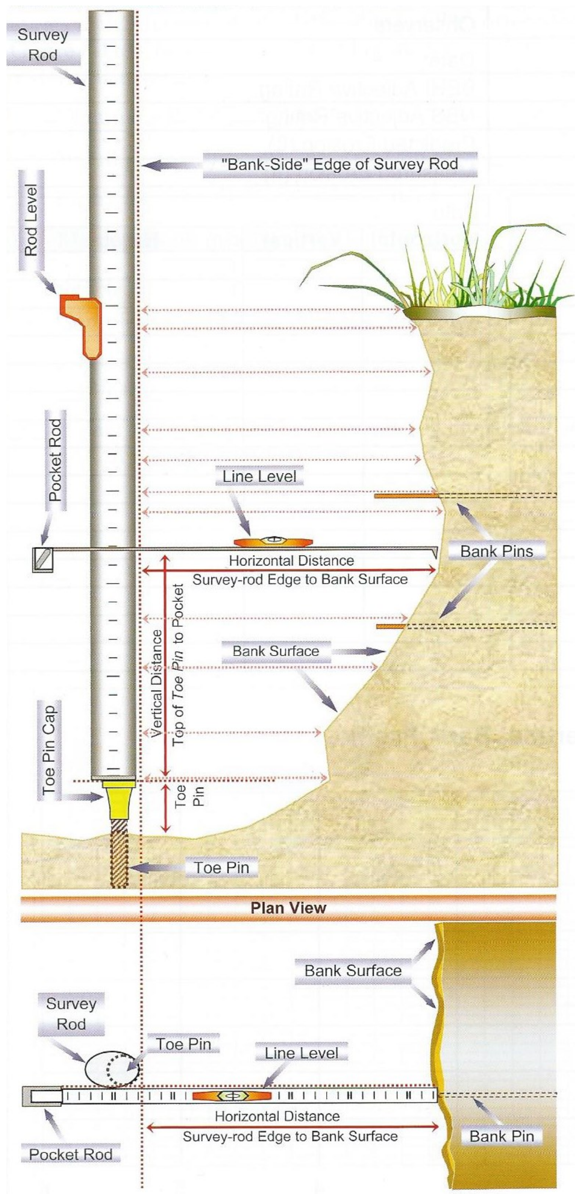


Figure 2.16 Example of Bank Profile Method and Erosion Pin Installation (Rosgen, 2009)

2.4 Developed Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Models

Ten BANCS models have been developed and published, with varying degrees of success, across numerous hydrophysiographic regions in the United States and India. As defined by Sass (2011), a hydrophysiographic region is "a region characterized by homogeneous climate, geology, soils and vegetative communities that affects the hydrology, or movement of water, of that region (p. 18)." Table 2.1 provides all of the known BANCS models that have been created and further outlines the Level III ecoregion (Omernik, 1987), geology (as described in each publication), and Köppen-Geiger climatic type (Peel, Finlayson, & McMahon, 2007) of each model, in an attempt to cover the full definition of a hydrophysiographic region. A map of all United States BANCS models by ecoregion is provided in Figure 2.17. Figure 2.18 provides an example of a BANCS model for the Middle Rockies ecoregion of Wyoming.

In addition to these published BANCS models, several draft models have also been created. The United States Fish and Wildlife Service (USFWS) of Maryland utilized a draft model that was created for the District of Columbia to predict streambank erosion rates (Davis & Starr, 2008; Eng, Fleming, & Starr, 2007). Hensley (2014) employed an unpublished curve created for North Carolina streams in the Piedmont region to predict erosion rates in Indiana and Georgia. Finally, a streambank erosion rate prediction curve was created and published for northeastern India based upon a significantly modified BANCS methodology. See Bandyopadhyay, Saha, Ghosh, and De (2013) for more details.

Table 2.1 Developed Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Models Organized by State, Country, Ecoregion, Geology and Climate

BANCS Model	Ecoregion	Geology	Climate
1) Arkansas, USA (Van Eps, Formica, Morris, Beck, & Cotter, 2004)	Ozark Highlands	Sedimentary	Warm temperate (Cfa)
2) California, USA (Kwan & Swanson, 2014)	Sierra Nevada	Igneous Metamorphic	Mediterranean (Csa/b)
3) Colorado, USA (Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009)	Southern Rockies	Sedimentary Metamorphic	Warm summer continental (Dfb)
4) Kansas (Sass & Keane, 2012)	Western Corn Belt Plains	Sedimentary Glaciation	Hot summer continental (Dfa)
5) New York, USA (Coryat, 2011)	Northeastern Highlands	Sedimentary Glaciation	Maritime temperate (Cfb)
6) New York, USA (Markowitz & Newton, 2011)	Northeastern Highlands	Sedimentary Glaciation	Maritime temperate (Cfb)
7) North Carolina, USA (Jennings & Harman, 2001; Patterson, Clinton, Harman, Jennings, & Slate, 1999)	Piedmont, Blue Ridge	Igneous Sedimentary Metamorphic	Warm temperate (Cfa)
8) Oklahoma, USA (Harmel, Haan, & Dutnell, 1999)	Ozark Highlands	Sedimentary	Warm temperate (Cfa)
9) Wyoming, USA (Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009)	Middle Rockies	Igneous Glaciation	Warm summer continental (Dfb), Continental subarctic (Dfc)
10) West Bengal, India (Ghosh, Pal, & Mukhopadhyay, 2016)	Chhota-Nagpur Plateau, Lower Gangetic Plains	Igneous Sedimentary Metamorphic	Humid subtropical (Cwa), Tropical savanna (Aw)

The main purpose of a BANCS model specifically created for a given hydrophysiographic region is to rapidly estimate how much sediment is being delivered to the stream through streambank erosion of varying BEHI/NBS-rated streambanks. Once BEHI and NBS ratings have been determined for a given streambank, the lateral bank retreat rate is extrapolated from the existing BANCS model for that given hydrophysiographic region. This rate can then be multiplied by the height and length of streambank that represents the same BEHI/NBS rating to obtain a volume of sediment eroded. The volume of sediment eroded can be converted into unit weight per year by simply assuming an average bulk density of the soil. This process is repeated along an entire stream length or reach to determine an approximate sediment yield from streambank erosion (Rosgen, 2009). Once a full-scale watershed sediment yield is obtained utilizing the BANCS model in conjunction with the overall watershed assessment tool, WARSSS, total maximum daily load (TMDL) documents for sediment can be developed for a given impaired watershed, as required by the U.S. EPA and the Clean Water Act. TMDLs provide the target sediment volume obtained from the watershed assessment and identifies problem areas where mitigation techniques can be implemented to reduce current sediment volumes.

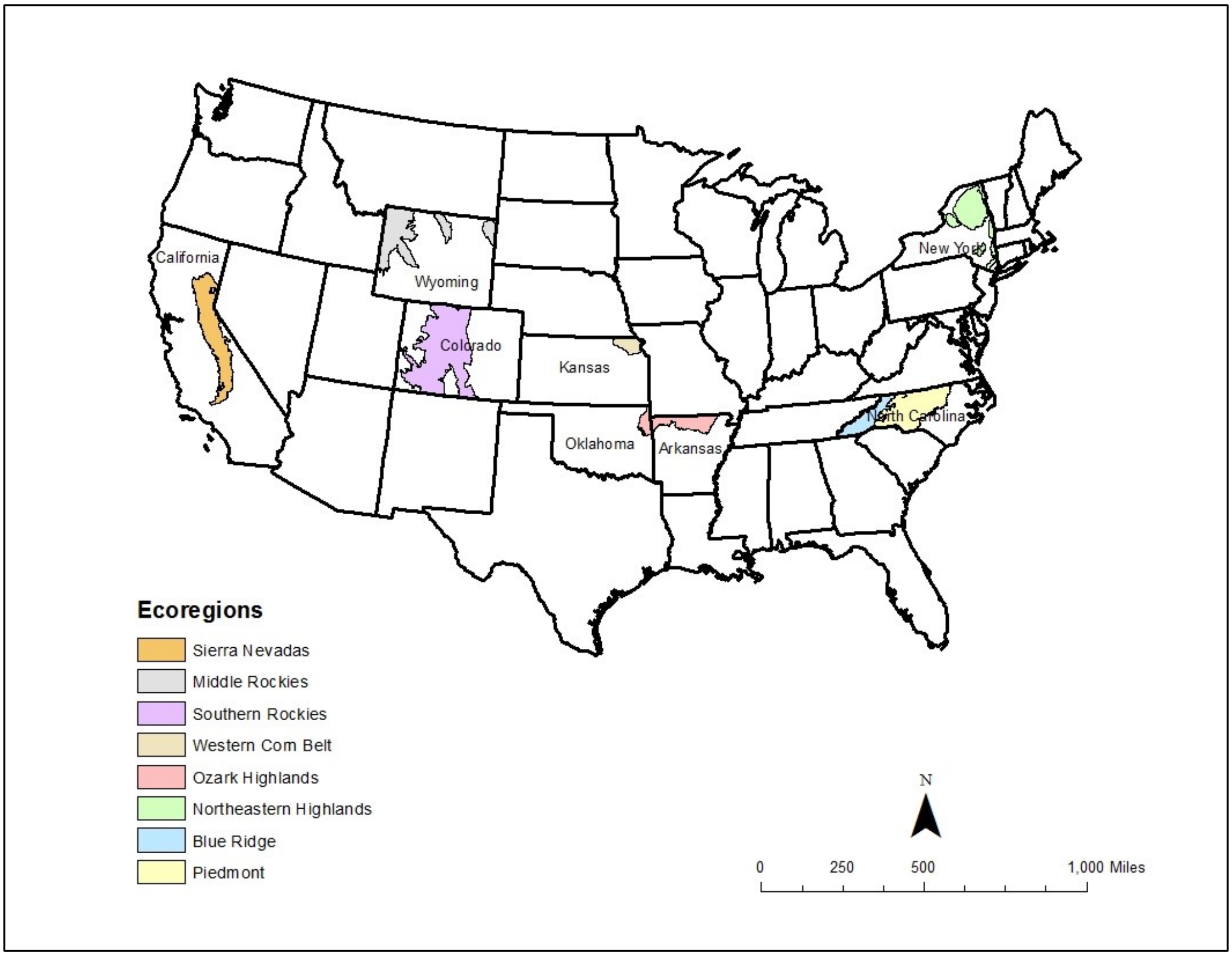


Figure 2.17 Created Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Models in the United States by Ecoregion

Other applications of the BANCS model include rapidly developing an inventory of stream channel riparian and stability conditions and prioritizing streambanks in need of restoration (Rosgen, 2001). The BEHI methodology has also been used to assess near-bank aquatic habitat condition and species diversity (Simpson, Turner, Brantley, & Helms, 2014). BANCS model limitations, criticism and modifications are presented in the following sections.

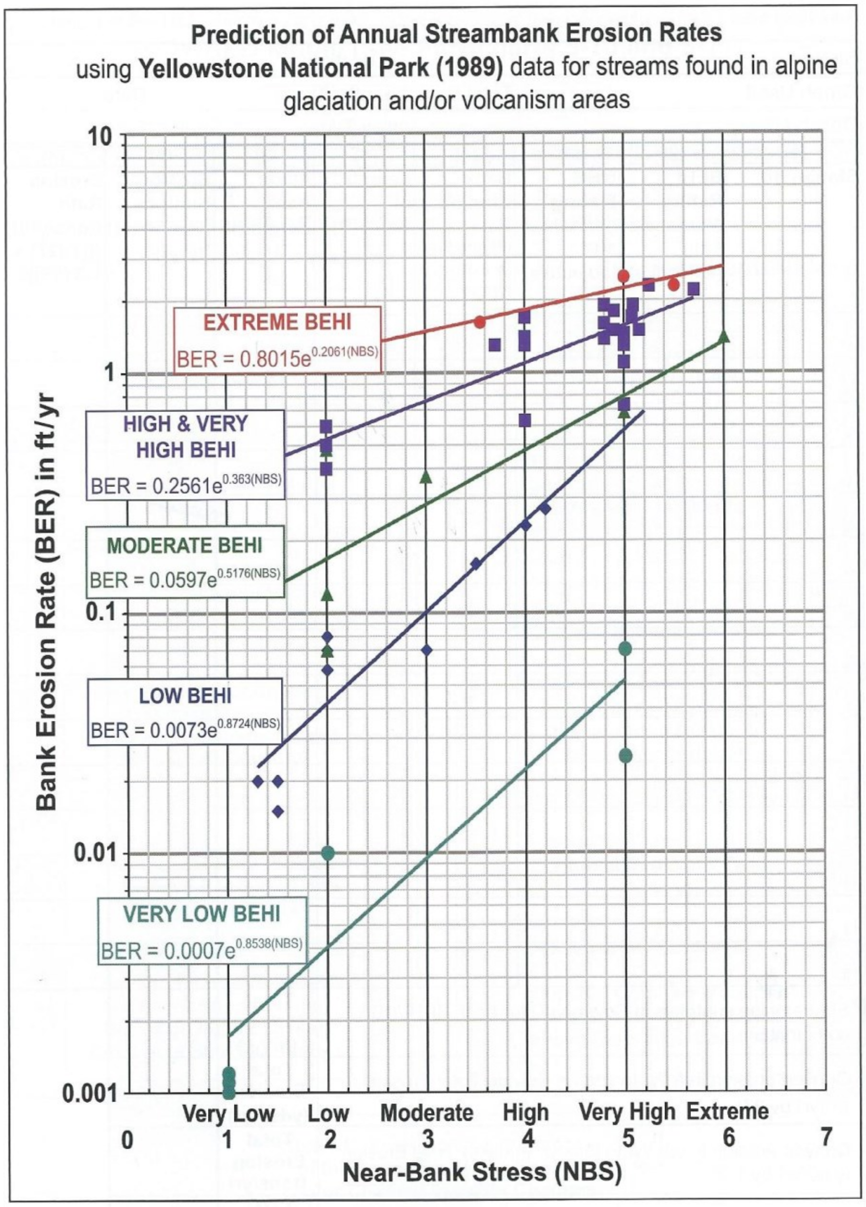


Figure 2.18 Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model for Wyoming (Rosgen, 2009)

2.5 Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model Limitations

There are four model limitations identified by the author. One limitation of the BANCS model is that streambank erosion rate prediction curves may only be valid in the hydrophysiographic region in which they were developed (Doyle & Harbor, 2000; Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009). Before a curve may be implemented in a new region to estimate sediment yield, an existing curve must be validated or a new curve must be created to guarantee accuracy in model predictions.

Another identified model limitation is that developed BANCS models are limited to streamflows that occurred during curve development. For example, the curves created in Colorado and Wyoming were based on measured bank erosion rates following streamflows that were 60 to 70 percent below normal (Rosgen, 1996b). Alternatively, the curves created for Oklahoma (Harmel et al., 1999) experienced flow rates that were up to four times the bankfull discharge or above the normal, observed streamflows. Therefore, when average annual flow rates are outside of these reported ranges, these curves may under- or over-estimate streambank erosion rates for that given year (Van Eps et al., 2004). Streamflows experienced for each of the ten created models are presented in Table 2.2.

A third possible limitation of the BANCS model methodology is that the streambank erosion rate measurement method selected may affect the overall model results and fit. As discussed in Section 2.3.3, there are several techniques that can be utilized to measure streambank retreat rates. As depicted in Table 2.2, so far, only three methods have been implemented to quantify annual streambank erosion rates for BANCS models: repeated bank profiles, bank pin measurements, and cross sections. Table 2.3 below provides the temporal scale, usage and limitations of each of these methods (Lawler, 1993a). Repeated cross profiles or bank profiles should provide the greatest accuracy in bank erosion measurement.

Finally, the BANCS methodology should only be utilized by professionals in the field of fluvial geomorphology, limiting its application. Rosgen (2009) cautions users of WARSSS, including those employing the BANCS methodology, by stating:

"Due to the nature of this methodology, it is essential that assessments be conducted by individuals with training and experience in geomorphology, hydrology, engineering, geology, soil science, plant science, and other related scientific disciplines. Individuals should be specifically trained and experienced in hillslope, hydrologic and channel processes (pg. 1-6)."

Table 2.2 Comparison of Methods and Factors Utilized in Creating Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Models

BANCS Model	# of Sites (Avg. # per Regression Line)[a]	Years of Data	Streamflows Experienced	Near-Bank Stress (NBS) Method	Erosion Rate Method	Model Fit	Notes
Arkansas (Van Eps et al., 2004)	24 (4.8)	1	1.3x greater than bankfull	NBS Method Selection*	Bank Profiles	R^2 not reported, visually a good fit (BANCS)	None
California (Kwan & Swanson, 2014)	137 (34.3)	1	65% below bankfull to 1.5x greater than bankfull	Near-bank max depth/ bkf mean depth (at bank)	Bank Profiles	R^2 = 0.37-0.77 (BANCS)	R^2 of individual BEHI regression lines; all sites on riffles
Colorado (Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009)	49 (12.3)	1	60-70% below bankfull	Velocity Isovels	Bank Profiles	R^2 = 0.92 (BANCS)	R^2 not provided for individual regression lines
Kansas (Sass & Keane, 2012)	16 (8)	4	At bankfull to 2.5x greater than bankfull	NBS Method Selection*	Bank Profiles	R^2 = 0.75-0.77 (BANCS, pre-modification)	R^2 of individual BEHI regression lines prior to recommended adjustment
New York (Coryat, 2011)	16 (n/a)	11	8x greater than bankfull	NBS Method Selection*	Corrected Bank Profiles†	BANCS not developed, R^2 = 0.23 (BEHI), R^2 = 0.37 (NBS)	R^2 for BEHI as predictor of erosion and NBS as a predictor of erosion
New York (Markowitz & Newton, 2011)	9 (3)	1	9x greater than bankfull	Near-bank max depth/ bkf mean depth (at riffle)	Repeated Cross Sections	No relationship (BANCS), R^2 = 0.53 (BEHI), R^2 = 0.20 (NBS)	See Coryat (2011) note
North Carolina (Jennings & Harman, 2001; Patterson, Clinton, Harman, Jennings, & Slate, 1999)	31 (6.2)	1	Not reported	Near-Bank Area/Total Bkf Area	Bank Profiles, Bank Pins	R^2 = 0.05-0.17 (BANCS) R^2 = 0.167 (BEHI)	See Kwan & Swanson (2014) and Coryat (2011) note
Oklahoma (Harmel et al., 1999)	29 (9.7)	1	4x greater than bankfull	Near-Bank Area/Total Bkf Area	Bank Pins	R^2 = -0.32-0.15 (BANCS)	See Kwan & Swanson (2014) note
Wyoming (Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009)	40 (8)	1	60-70% below bankfull	Velocity Isovels	Bank Profiles	R^2 = 0.84 (BANCS)	See Colorado - Rosgen (2001) note
West Bengal (Ghosh, Pal, & Mukhopadhyay, 2016)	24 (n/a)	5	Not reported	Near-bank max depth/ bkf mean depth	Repeated Cross Sections	BANCS not developed, R^2 = 0.283 (BEHI), R^2 = 0.278 (NBS)	See Coryat (2011) note; Averaged BEHI/NBS & erosion rates from both banks in cross section

[a]Avg. # per Regression Line = # of sites ÷ # of Bank Erosion Hazard Index regression lines; * NBS method selection: employed all available NBS methods at the time of development and used the highest NBS rating per site; † Corrected bank profiles: due to surveying errors, see Coryat (2011) for more details

Table 2.3 Streambank Erosion Rate Methods used in BANCS Model Creation: Temporal scale, usage & limitations (Lawler, 1993a)

Method	Temporal Scale	Usage	Limitations
Repeated Bank Profiles	Intermediate (1-50 years)	• Record bank retreat over time	• Error in survey, may not follow the same line • Not sensitive to erosion that occurs sporadically or is localized
Repeated Cross Sections	Intermediate (1-50 years)	• Record bank retreat & cross-section changes over time	• Error in survey, may not follow the same line, more so than above method • Not sensitive to erosion that occurs sporadically or is localized
Bank Pin Measurements	Short (<10 years)	• Record bank retreat over time	• May not reflect spatial variability of bank erosion • Measurements can be misinterpreted due to soil properties (i.e. shrink/swell clay) and/or movement of pins • Pins may become lost • Installation and/or presence of pins may amplify bank erosion

2.6 Criticisms of the Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model

As mentioned by Doyle & Harbor (2000) and Simon et al. (2007), the age-old question of geomorphology is: do we continue to develop and adjust form-based, empirically-derived relationships to understand stream process in various hydrophysiographic regions or do we focus on improving process-based models that, in theory, can be applied to any region? Even though Rosgen (2008) argues that “form and process are not mutually exclusive (p. 788),” like any other empirically-derived model that attempts to explain and estimate natural processes, the BANCS model has also been criticized.

Rosgen (2001) proclaims the BANCS methodology as “a practical method of computing streambank erosion rate (pg. 9),” but also admits that portions of the BANCS methodology can be time-consuming (Rosgen, 2009). This includes rating streambanks using the BEHI/NBS methods, validating an existing model before implementing its use in a new watershed, and creating a new BANCS model for different hydrophysiographic regions as Rosgen (2001) states:

“streambank erosion measurements are very time consuming… (p. 15).” However, once a BANCS model has been created or validated for a region, the process is expedited. Doyle & Harbor (2000) contend that the field practitioner should prioritize accuracy by utilizing a physically-based model over speed, afforded by the BANCS model or other empirically-derived models, to guarantee proper application of the results.

Because these prediction curves are limited to location, some creators of BANCS models have suggested that the BEHI method may need to be adjusted to fit specific hydrophysiographic regions. For example, Sass & Keane (2012) implemented a woody vegetation adjustment in place of weighted root density and the root depth-to-study bank height ratio. This adjustment was based on their finding that streambanks without woody vegetation eroded three times more than streambanks with woody vegetation in their study watershed. This adjustment improved the fit of their prediction curve but has not since been tested in other regions. Markowitz & Newton (2011) and Sass & Keane (2012) observed bank mass failure that led to the creation of a shelf below bankfull. Due to high levels of clay in the failed bank material, this shelf was often resistant to fluvial entrainment, depending on stream stage. This process was perceived as a dominant streambank erosion process in both study watersheds. Because of this, each proposed adding an adjustment to the BEHI to lower the rating of an otherwise, high-rated BEHI study bank to account for this cohesive soil type. These findings were later addressed in Rosgen (2014) and will be discussed in the following section. Alternatively, Harmel et al. (1999) suggested including a bulk density or compaction factor for bank materials to the BEHI rating. This suggestion was later disputed by Doyle & Harbor (2000), who asserted that adding this component would be “a fundamental reorientation of the method towards a more physically based approach (p. 1191)” and therefore, provides additional evidence that more time should be spent on improving physically-based models rather than empirically-derived models.

Another concern is that rating eroding streambanks using the semi-quantitative BANCS methodology may be subject to user bias. Coryat (2011) indicates that stratification of unstable layers on streambanks used in the creation of this particular set of New York curves may have been unintentionally ignored. The author states that unstable layers subject to seepage are historically present in the watershed that was used to create the curves and that suspiciously, none of the study banks were adjusted for stratification. The author believes that at least three of these study banks may have had the presence of unstable layers and should have been adjusted for stratification, as erosion rates were significantly larger than the rest, suggesting possible failure due to seepage. Markowitz & Newton (2011) experienced a different kind of user bias in that BEHI assessments on study banks were conducted following a flow event that was nine times greater than bankfull, potentially exacerbating BEHI scores. Rathbun (2011) found through field application and experience that bank angle was often misinterpreted when visually estimated and recommends the use of an inclinometer. This author also found based on experience that field practitioners, and more specifically non-professionals, are more prone to evaluate and rate atypical or highly erosive streambanks rather than streambanks that are representative of the stream of interest.

The potential for user bias is not limited to just the qualitative components of the BANCS methodology, but also for one of the quantitative pieces as well: the determination of bankfull stage (Johnson & Heil, 1996; Roper, Buffington, Archer, Moyer, & Ward, 2008; Williams, 1978). As mentioned previously, identifying bankfull stage on stable streams is often easy to determine visually as there tends to be some kind of field indicator present, such as a low, connected floodplain where incipient flooding occurs, a break in slope and/or change in particle distribution, staining of rocks, etc. (Rosgen, 1996b). However, on unstable and incising streams, this is not always the case, making it difficult to quantify the bankfull height (Juracek & Fitzpatrick, 2003; Simon et al., 2007). Proper estimation of bankfull in these situations requires either (1) calibration of bankfull stage to known streamflows with data from an established stream gage or (2) utilization of a developed regional curve for ungauged sites to accurately pinpoint bankfull stage (Dunne & Leopold, 1978; Rosgen, 1996b). Often times, field practitioners assume bankfull discharge to be the discharge at the 1.5-year reoccurrence interval from a flood frequency analysis of stream gauge data (e.g. Markowitz & Newton, 2011). This is not a safe assumption, as bankfull reoccurrence interval has been found to range from 1 to as much as 32 years (Williams, 1978). A misinterpretation of bankfull height can lead to an invalid score for study bank height-to-bankfull height ratio and may affect the overall BEHI and NBS rating.

Another point of criticism is that although Rosgen (2009) provides a detailed procedure for applying and validating existing streambank erosion rate prediction curves, the author does not provide a detailed procedure for developing new curves. Methods and factors that vary amongst developed BANCS models are:

- Number of streambank sites employed
- Number of years streambank erosion data is collected
- Streamflows experienced
- NBS method(s) applied
- Streambank erosion measurement method implemented

Variation in these factors can be seen in Table 2.2, which compares these unknown parameters and methods across the ten developed BANCS models, as well as each model's fit. Although the lack of a detailed procedure to develop a BANCS model has never been directly criticized, several creators of the BANCS models identified some or all of these unknown methods and/or factors as a primary cause of the high variability that they observed in their results (e.g. Coryat, 2011; Harmel et al., 1999; Jennings & Harman, 2001; Markowitz & Newton, 2011; Patterson et al., 1999).

Finally, Lawler, Grove, Couperthwaite, & Leeks (1999) point out that averaging bank retreat rates and reporting them in unit length, volume, or weight per year, as the BANCS model does, masks the spatial and temporal variability. In other words, the streambank erosion process(es) that occurred because of existing boundary conditions of a given streambank at some moment of time is masked. Therefore, predicting sediment yield from streambank erosion using historical analysis and empirical relationships assumes that future boundary conditions and hydraulic and gravitational forces that act on a streambank will mimic that of the past.

Further evaluation of existing streambank erosion rate prediction curves demonstrates that the BANCS methodology typically addresses the spatial variability of streambank erosion but in some existing curves, lacks temporal variability. For example, the curves that were created for Wyoming and Colorado were only developed based on data from a one-year period (Rosgen, 2001; Rosgen, 1996b; Rosgen, 2009), which clearly masks the temporal variability of streambank erosion and as a result, prediction is limited to those kinds of flows. Kwan & Swanson (2014) and Sass & Keane (2012) integrate the temporal scale into the creation of their models by collecting streambank erosion data over multiple years with varying streamflows. Rosgen (2015) addresses this criticism by encouraging future BANCS model creators to develop separate curves for all ranges of streamflows (i.e. bankfull, flood, and drought years).

Additionally, in studies that span multiple years, the spatial variability may be masked if BEHI/NBS ratings are not re-scored every year (e.g. Coryat, 2011; Sass & Keane, 2012). Kwan

& Swanson (2014) conducted the only multi-year study in which BEHI/NBS ratings were re-evaluated every year for each study bank, which may provide one explanation for the high level of success that they experienced when developing their prediction curve.

2.7 Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model Modifications

In order to address the aforementioned limitations and criticisms, modifications to the BANCS model have been presented and implemented. In the first edition of Rosgen (1996a) there were three methods presented to estimate NBS: velocity isovels (method 7), near-bank stress-to-mean shear stress ratio (method 6), and near-bank area-to-total bankfull area ratio. Patterson et al. (1999) and Harmel et al. (1999) utilized the latter ratio when developing curves in North Carolina and Oklahoma, respectively. Based on their highly variable results, these authors recommended not utilizing the near-bank area-to-total bankfull area ratio in the future to rate NBS. Following this research, Rosgen (2001) agreed with these finding and has since removed this ratio from subsequent publications (Rosgen, 1996b; Rosgen, 2009).

Rosgen (2014) addresses concerns raised by Markowitz & Newton (2011) and Sass & Keane (2012) about the BANCS model over-scoring BEHI ratings on streambanks that contain high amounts of clay. This is accomplished by subtracting 20 points from the overall BEHI rating for banks that are primarily composed of clay. The BANCS model methodology presented in Section 2.3 above incorporates both of these modifications.

Other modifications to the BANCS model, and more specifically the BEHI methodology, have also been proposed and utilized. Often times, the BEHI method is used as a stand-alone procedure to rank eroding streambanks in streams impaired by sediment. Streambanks ranked highest (i.e. Extreme BEHI rating) are then placed on the top of a mitigation/restoration list. This is generally a quick and cost-effective way to locate streambank sites that may be contributing high amounts of sediment to the system. To address some of the limitations and criticisms presented in the previous section, some local and state government agencies have modified the BEHI method.

The Michigan Department of Environmental Quality (MDEQ) developed their own standard operating procedure to assess streambank erosion potential using a modified version of the BEHI methodology. This procedure was developed as part of EPA-funded 319 Non-Point

Source (NPS) or Clean Michigan Initiative NPS grant applications to improve impaired surface waters in the state (MDEQ, 2008). The MDEQ modified the BEHI procedure to address the limitation that the BEHI methodology can only be used by professionals and the criticism that the model is subject to user bias. They adjusted the BEHI procedure by eliminating the need to determine bankfull stage, which allows non-professionals with limited training to implement the procedure. The overall BEHI score was adjusted to show this modification. As mentioned in the previous section, the MDEQ found that bank angle was one component that was difficult for users to estimate and recommend the use of inclinometers to reduce user bias. The standard operation procedure also provides recommendations for selecting representative reaches to include in the BEHI ratings (Rathbun, 2011). Finally, to more quantitatively evaluate eroding streambanks using the BEHI, MDEQ (2008) recommends performing a soil ribbon test to estimate bank material.

The Cleveland (Ohio) Metroparks recently published another example of a modified BEHI procedure. They addressed (1) the limitation that the created BANCS model can only be used by professionals and (2) the criticism that the BEHI method can be time-consuming and subjective. They modified the BEHI methodology by:

- Adding a “Pre-Screening Questionnaire” as a tool to rapidly eliminate banks that were expected to rank as “low” or “very low,”
- Discarding the study-bank-height-to-bankfull height ratio to allow non-professionals with limited training to utilize this methodology, as inspired by MDEQ modified BEHI methodology, and
- Requiring that the assessment be conducted by two to four people to prevent user bias.

BEHI scores were adjusted to mimic these modifications. The authors found that 16 out of 18 streambanks evaluated using the original BEHI methodology and the modified BEHI methodology obtained the same BEHI rating. To improve these results, the authors proposed to consider the numerical scores first, in case the ratings were close to a set adjective cutoff value (Newton & Drenten, 2015).

Finally, in an attempt to reduce the cost and time inherent to BEHI assessments, Connell (2012) developed a modified BEHI, called the Bank Erosion Susceptibility Index (BESI) that could be used in conjunction with a kayak equipped with a geo-referenced Streambank Video

Mapping System (SVMS). The BESI incorporates five BEHI parameters that could be visually measured: bank angle, surface protection, and bank height, with an added categorical-rated parameter of riparian diversity that combines the root depth-to-study bank height ratio and the weighed root density (Hensley, 2014). Connell (2012) found that variability between BESI users did exist, concluding that future users should have a solid understanding of bank erosion processes in addition to proper training and field experience in BESI application.

2.8 Research Objectives

As demonstrated in the previous sections, there are many limitations and criticisms of the BANCS model methodology that have yet to be addressed. The research objectives of this thesis were to:

1. Evaluate the BANCS model's repeatability and sensitivity and
2. Examine the developmental process of a BANCS model by attempting to create an annual streambank erosion rate prediction curve for South-Central Kansas, located in the Central Great Plains ecoregion.

The expected outcome of this research was to provide a robust methodology that can be utilized as a guide for future BANCS model creation.

The BANCS methodology that is presented in Section 2.3 was utilized in this thesis work. Other modifications that have been developed and/or implemented (i.e. MDEQ, 2008; Newton & Drenton, 2015; Connell, 2012) but are not incorporated in the current BANCS methodology (Rosgen, 2014) were not reviewed in this research.

Chapter 3 - Repeatability and Sensitivity of the Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model

3.1 Introduction

Excess sediment is the second leading cause of stream impairment in the United States (U.S. EPA, 2016). This pollutant may lead to poor water quality, damage to aquatic ecosystems, and sedimentation of downstream waterbodies, such as water supply and flood control reservoirs. Sediment is a non-point source pollutant but various case studies have identified channel erosion, such as streambank erosion, as the main contributor of sediment in some impaired watersheds (Belmont et al., 2011; Bull, 1997; Kronvang et al., 1997; Mukundan et al., 2010; Rondeau et al., 2000; Trimble, 1997; Wilson et al., 2008).

Although it is natural for streambanks to erode (Florsheim et al., 2008), changes in regional climate and watershed land use, type, and/or management can contribute to stream instability that results in both physical and biological degradation. Stream instability may cause accelerated bank erosion and channel degradation and/or aggradation, as the stream works to change its dimensions, pattern, and profile to reach a dynamic equilibrium under new discharge and/or sediment conditions. Therefore, it is essential to identify and quantify streambank erosion in sediment-impaired watersheds, especially those that have been influenced by anthropogenic processes and extreme natural events.

Because streambanks are typically not composed of homogenous materials and do not experience the same hydrologic events every year, it is very difficult to estimate and predict streambank erosion (Bull, 1997). Nevertheless, various models have been developed to obtain a predicted or estimated sediment yield from streambank erosion. One such model is the "Bank Assessment for Non-Point Source Consequences of Sediment" (BANCS) model. It is an empirically-derived, process-integrated model used to rapidly estimate annual streambank erosion rates in a given hydrophysiographic region (Rosgen, 2001). The BANCS model consists of two parameters to predict streambank erosion: (1) the Bank Erosion Hazard Index (BEHI), and (2) the Near-Bank Stress (NBS) rating.

The BEHI provides an adjective rating or scored ranking of bank erodibility based on visual and measured assessment of a streambank of interest. Seven variables comprise the BEHI method to develop an overall BEHI score and rating (Rosgen, 2009). These variables are defined as follows:

1) Study Bank Height-to-Bankfull Height Ratio (Ranking of 1 to 10 points): Height to the top of the bank divided by the bankfull height. This ratio adjusts for scale and identifies possible channel degradation which may result in accelerated bank erosion. The closer the ratio is to one, the more likely the channel is not degrading and the lower the risk of erosion.
2) Root Depth-to-Study Bank Height Ratio (Ranking of 1 to 10 points): Prevailing root depth divided by the height to the top of the bank. This measures streambank reinforcement from roots and may identify possible channel degradation. The closer the ratio is to one, the greater the stability of the streambank.
3) Weighted Root Density (Ranking of 1 to 10 points): Estimated percentage of root density multiplied by the root depth-to-study bank height ratio. Higher densities of root mass provide greater bank cohesion. Therefore the greater the density, the less risk to erosion.
4) Bank Angle (Ranking of 1 to 10 points): Measured in degrees. Greater bank angles result in a higher risk of bank instability caused by the gravitational force on the streambank.
5) Surface Protection (Ranking of 1 to 10 points): Percentage of streambank surface protected by vegetation, woody debris, large rock, etc. The greater the percentage of protection, the lower the risk of streambank erosion.
6) Bank Material Adjustment: Adjust the final BEHI score from the addition of rankings obtained from variables 1 through 5 by -20 points to +10 points based upon bank material. The presence of bedrock and boulder bank materials results in an automatic final BEHI score of 0-19.5 points which means that these banks have the lowest erosion potential. Points may be added to the score if the material in the bank is considered to be highly erodible, such as gravel or composite matrix and sand. Points may be subtracted from the score if the bank material is highly resistive to erosion such as medium to large cobble and banks with high amounts of clay.
7) Stratification of Bank Material: Adjust the final BEHI score from the addition of rankings obtained from variables 1 through 6 by up to +10 points based upon the

presence and type of bank material layers that may be subject to piping or entrainment (Rosgen, 2009).

Point rankings obtained from variables 1 through 7 are summed to obtain a final BEHI score and then are converted to a BEHI rating. BEHI ratings of a particular streambank can be Very Low (0-9.5 points), Low (10-19.5 points), Moderate (20- 29.5 points), High (30-39.5 points), Very High (40-45 points), and Extreme (46-50 points), where the latter would represent a streambank highly susceptible to bank erosion (Rosgen, 2009).

The NBS rating provides an adjective rating of the amount of fluvial force (or applied shear stress) induced by the outer one-third of the channel flow adjacent to the eroding bank of interest (Rosgen, 2009). NBS ratings can be divided into 6 categories ranging from Very Low to Extreme, where an "Extreme" NBS rating represents the greatest applied shear stress on a given bank. There are seven methods that can be used to determine the NBS rating and are ordered with increasing level of detail and resources needed to complete the method. They are as follows:

1) Presence of Transverse/Central Bars or Channel Pattern Changes
2) Radius of Curvature-to-Bankfull Width ratio
3) Pool Slope-to-Average Water Surface Slope ratio
4) Pool Slope-to-Riffle Slope ratio
5) Near-bank Maximum Depth-to-Bankfull Mean Depth ratio
6) Near-bank Shear Stress-to-Bankfull Shear Stress ratio
7) Velocity Isovels (Rosgen, 2009)

The field practitioner selects one or several of these methods that best represent the site conditions and then uses the highest (not the average) of these ratings as the dominant near-bank stress (Rosgen, 2009). Rosgen (2009) cautions users by stating: "The [order of methods] are not necessarily synonymous with reliability of prediction (pg. 5-68)."

BANCS models may be limited to the hydrophysiographic region in which a particular model was developed (Rosgen, 2001; Rosgen, 1996; Rosgen, 2009) and the streamflows that occurred during curve development (Van Eps et al., 2004). Also, the BANCS methodology is intended to only be implemented by professionals with training and experience in the field of fluvial geomorphology (Rosgen, 2009). Ten BANCS models have been developed and published, with varying degrees of success, across numerous hydrophysiographic regions in the

United States (See Figure 2.17) and eastern India. Curve development techniques and results are summarized in Table 2.2.

As mentioned by Doyle & Harbor (2000) and Simon et al. (2007), the age-old question of geomorphology is: do we continue to develop and adjust form-based, empirically-derived relationships to understand stream process in various hydrophysiographic regions or do we focus on improving process-based models that, in theory, can be applied to any region? Even though Rosgen (2008) argues that "form and process are not mutually exclusive (p. 788)," like any other empirically-derived model that attempts to explain and estimate natural processes, the BANCS model has also been criticized. Criticisms include:

- Model development is time-consuming (Rosgen, 2009);
- BEHI methodology may need to be adjusted to fit specific hydrophysiographic regions (Harmel et al., 1999; Markowitz & Newton, 2011; Sass & Keane, 2012); and
- Features of the BANCS methodology may be subject to user bias, such as bankfull stage identification (Coryat, 2011; Johnson & Heil, 1996; Juracek & Fitzpatrick, 2003; Markowitz & Newton, 2011; Rathbun, 2011; Roper et al., 2008; Simon et al., 2007; Williams, 1978).

In addition to these criticisms, it appears that lack of a detailed procedure for developing new curves could explain the wide variability of results. Methods and factors that vary amongst developed BANCS models include:

- Number of streambank sites employed;
- Number of years streambank erosion data is collected;
- Streamflows experienced;
- NBS method(s) applied; and
- Streambank erosion measurement method implemented.

Table 2.2 summarizes all ten developed models. Although the lack of a detailed procedure to develop a BANCS model has never been directly criticized, several creators of the BANCS models identified some or all of these unknown methods and/or factors as a primary cause of the high variability that they observed in their results (e.g. Coryat, 2011; Harmel et al., 1999; Jennings & Harman, 2001; Markowitz & Newton, 2011; Patterson et al., 1999).

Finally, Lawler et al. (1999) points out that averaging bank retreat rates and reporting them in unit length, volume, or weight per year, as the BANCS model does, masks the spatial and temporal variability of streambank erosion. Therefore, predicting sediment yield from streambank erosion using historical analysis and empirical relationships assumes that future boundary conditions and hydraulic and gravitational forces that act on a streambank will mimic that of the past.

This study aims to address the criticism that the BANCS model is subject to user bias by conducting (1) a repeatability experiment designed to test repeatability of the BANCS model by model users and (2) a sensitivity analysis of the model methodology to identify those variables of the BANCS model most sensitive to measurement error. This type of analysis is essential for both model validation and informing future BANCS model investigations.

3.2 Study Area Description

The Little Arkansas River watershed (HUC 11030012), shown in Figure 3.1, is located in south-central Kansas and drains 3,693 km^2 (USGS, 2014). Found in the Central Great Plains ecoregion, the watershed was once mixed-grass prairie but is now dominated by cropland (Chapman et al., 2010). Geology and soils vary throughout the watershed containing consolidated, sedimentary rocks of shale, limestone, sandstone and siltstone and unconsolidated rock of fluvial-deposited and wind-deposited silt and sand. The southwest portion of the Little Arkansas River watershed consists of sand dunes; the remaining watershed area comprises of less permeable materials of silt and sandy-silt and some deposits of clay (Albert & Stramel, 1966). The climate in this region classifies as hot summer continental (Dfa), with hot, humid summers and cold winters (Peel et al., 2007). The average precipitation occurring in this region ranges from 690 mm in the west to 860 mm in the east, with the majority of the precipitation falling in the spring and summer months (NRCS, 2007).

According to the Kansas Department of Health and Environment (KDHE), the Little Arkansas River is impaired by excess total suspended solids (TSS), threatening aquatic ecosystems (KDHE, 2014) and increasing water treatment costs downstream.

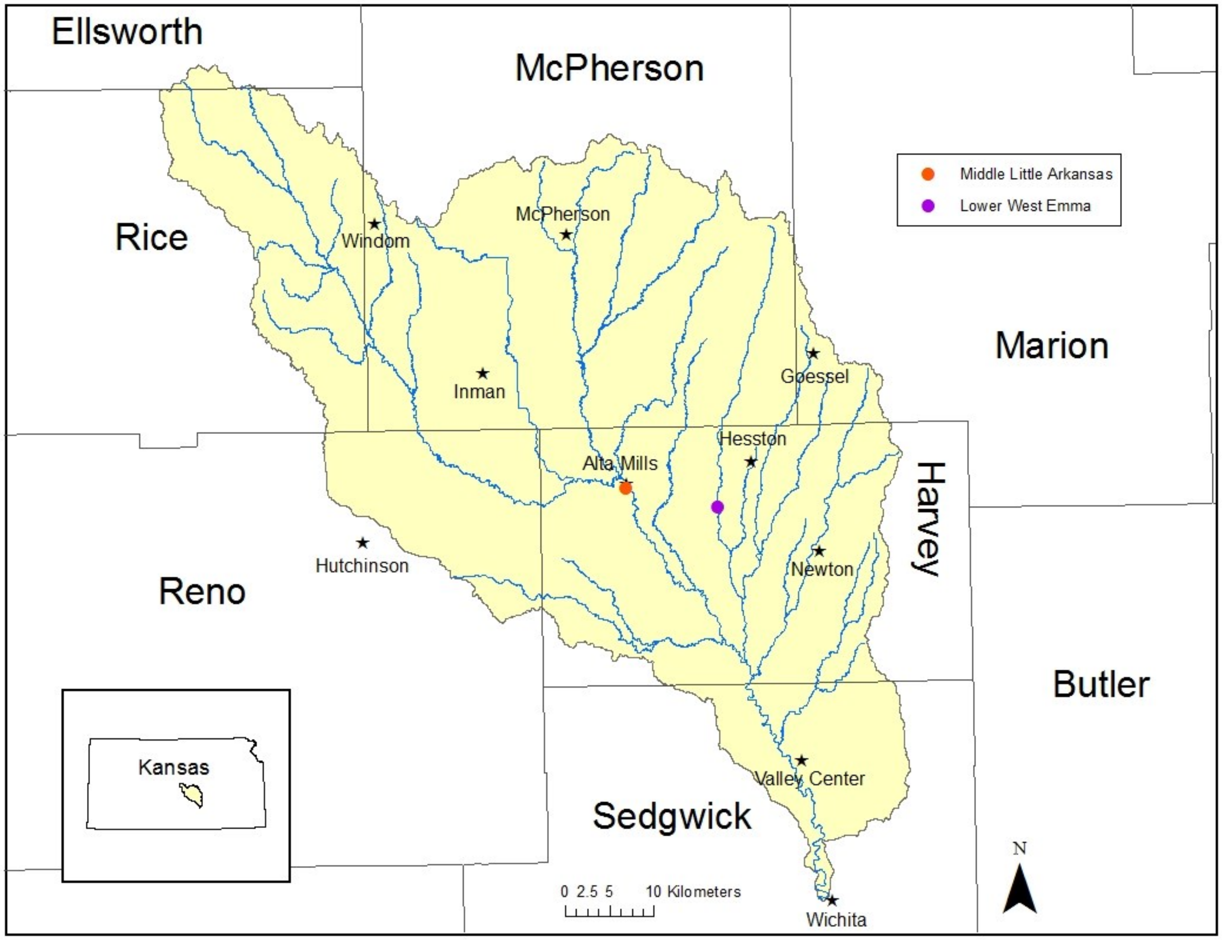


Figure 3.1 Repeatability Study Reach Locations within the Little Arkansas River Watershed of South-Central Kansas

Two reaches, one on the mainstem of the Little Arkansas River and another on a tributary called West Emma Creek, were chosen for the study. The Little Arkansas River reach, also known as the Middle Little Arkansas (MLA) reach, has a drainage area of 1,922 km^2 and a Rosgen stream classification of E5. An E5 stream type is defined as a sinuous sand-bed stream with a flat gradient, very low bankfull width-to-bankfull mean depth ratios, a riffle-pool sequence, and a well-developed, connected floodplain (Rosgen, 1996b). Three streambanks were selected for analysis within the reach with bank heights ranging from 5.8 to 10.5 m.

Alternatively, the West Emma Creek reach, also known as the Lower West Emma (LWE) reach, drains 223 km^2. This reach classified as a Rosgen stream type of B5c, or a sand-bed stream that is moderately entrenched with a flat gradient and a narrow valley (Rosgen, 1996b). Three streambanks from this reach with bank heights ranging from 1.7 to 2.1 m were chosen to be included in the study. Study banks were selected to represent a wide variety of streambanks found in the Little Arkansas River watershed. Figure 3.2 through Figure 3.9 depict the location and features of each of the six study banks chosen. See Appendix A for stream classification worksheets.

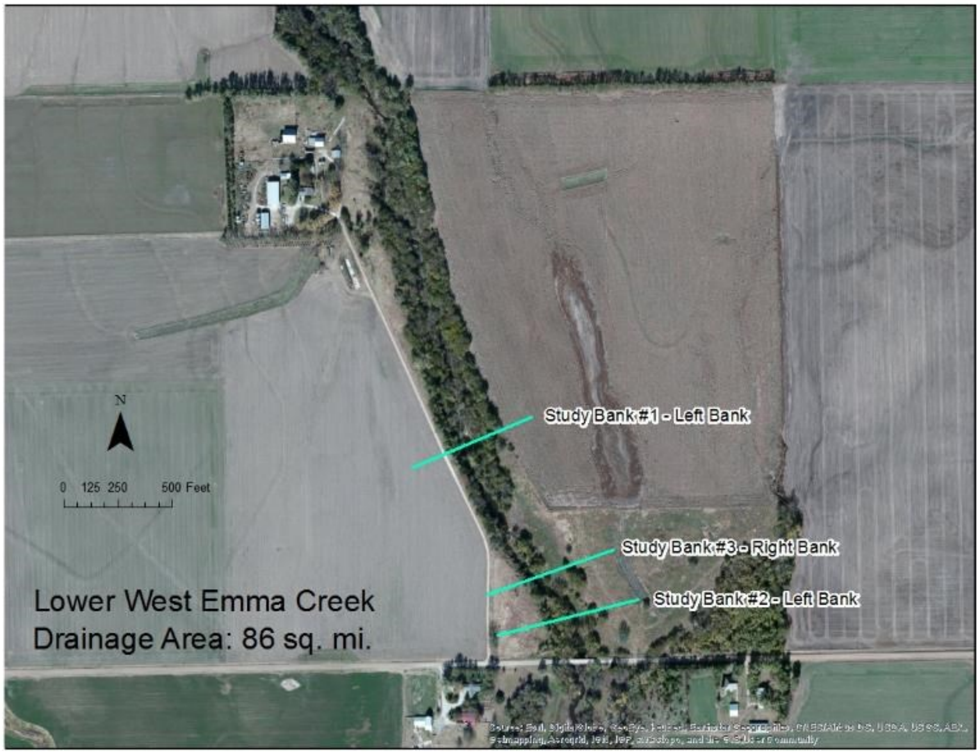


Figure 3.2 Lower West Emma Reach - Study Bank Locations

Figure 3.3 Lower West Emma Study Bank #1

Figure 3.4 Lower West Emma Study Bank #2

Figure 3.5 Lower West Emma Study Bank #3

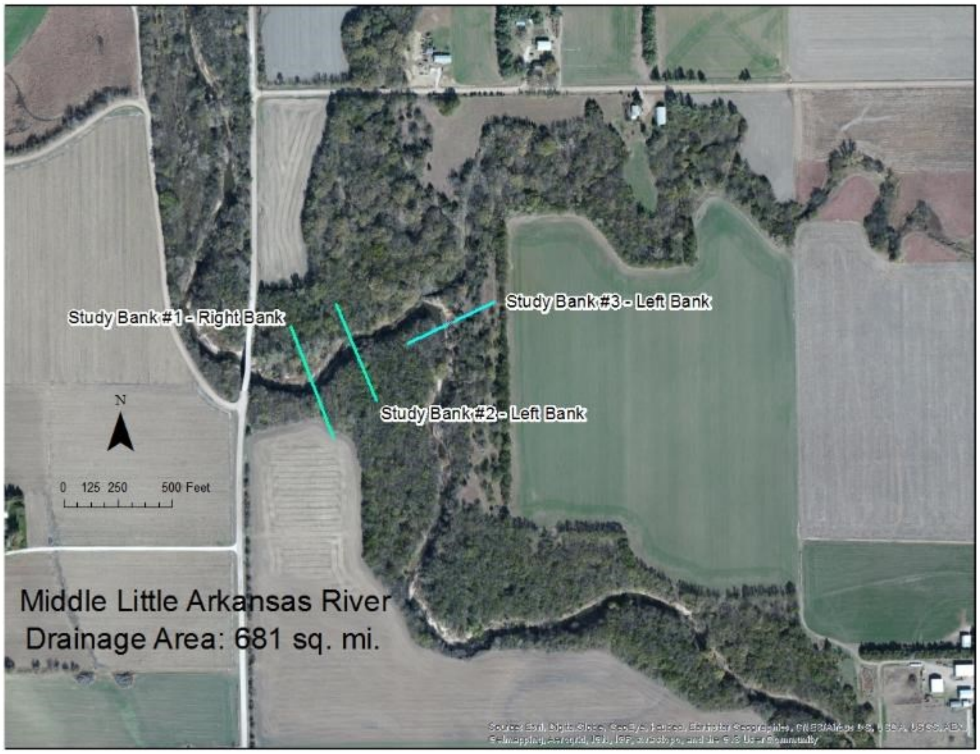


Figure 3.6 Middle Little Arkansas Reach - Study Bank Locations

Figure 3.7 Middle Little Arkansas Study Bank #1

Figure 3.8 Middle Little Arkansas Study Bank #2

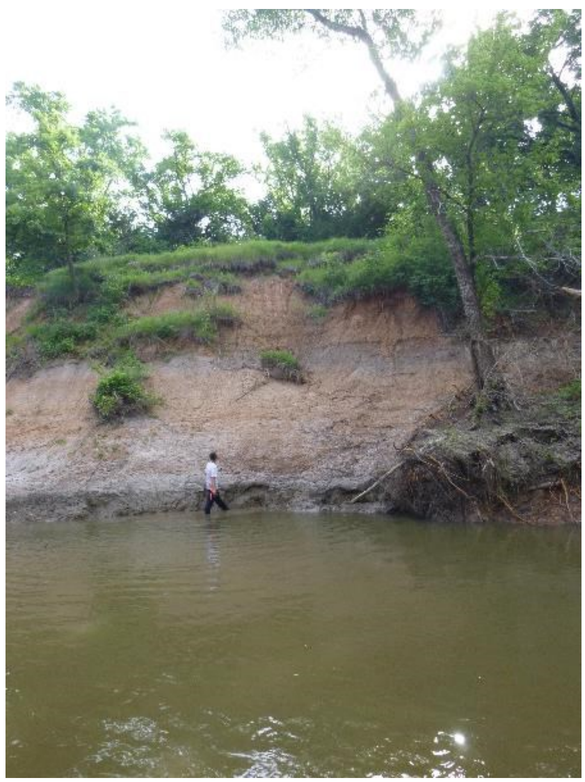


Figure 3.9 Middle Little Arkansas Study Bank #3

3.3 Repeatability of the Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model

3.3.1 Methods

To test whether different and/or the same BANCS model users obtained the same BEHI/NBS rating for a specific streambank of interest, a repeatability analysis was conducted. The following questions were addressed through this analysis:

1) Is there a rater component in the observed variability in BEHI/NBS ratings?
2) Is there a level of training component in the observed variability in BEHI/NBS ratings?

In order to answer these questions, thirty-two professionals in the field of fluvial geomorphology, hereafter denoted "raters," were asked to participate in the study. Of those thirty-two raters, ten agreed to participate (see Appendix B for IRB). Of these ten raters, eight had been formally trained by the BANCS model creator, Dr. Dave Rosgen. Dr. Rosgen offers the following short course series:

- Level I. Applied Fluvial Geomorphology
- Level II. River Morphology and Applications
- Level III. River Assessment and Monitoring
- Level IV. River Restoration and Natural Channel Design (Wildland Hydrology, 2015)

Each course builds upon the previous and ultimately provides students with an understanding of fluvial geomorphology, Rosgen's stream classification system, Watershed Assessment for River Stability & Sediment Supply (WARSSS), and natural channel design techniques. Although students are introduced to the BANCS model in Level I, detailed explanation and application is not presented until Level III. Six raters received at least Level III training, two raters received at least Level I training, and two raters had university training. Each rater had applied and utilized the BANCS model at least once within the last three years.

Two dates were selected to test the repeatability of the BANCS model: June 30 and August 4, 2015. Due to rain and increased streamflow, the August 4th date had to be re-scheduled to August 14, 2015. Two raters were unable to attend this date due to schedule conflicts, leaving eight participants on August 14th. Of the eight remaining raters, five had had Level III training, two had at least Level I training, and one had university training.

Prior to the first assessment date, raters were provided with assessment instructions, a copy of the BANCS model portion (pgs. 3-50 through 3-97) of the River Stability Field Guide (Rosgen, 2014), and a copy of the section titled “Field Determination of Bankfull Stage” (pgs. 5-8 through 5-9) from Applied River Morphology (Rosgen, 1996b). On each assessment date, raters received a packet with an itinerary, instructions, aerial photographs of each site with drainage area, regional curves for south-central Kansas, and six blank BEHI and NBS worksheets. See Appendix C for an example packet. Raters were instructed to assess each of the six study banks on both dates. A brief training was given at the beginning of each assessment date by Dr. Tim Keane, professor in the Department of Landscape Architecture and Regional and Community Planning at Kansas State University. Dr. Keane specializes in stream morphology and process, has completed all four short courses provided by Dr. Rosgen, and has been invited in the past by Dr. Rosgen to assist with short courses. During the training, Dr. Keane explained the methodology for both BEHI and NBS assessment, describing variables but not providing real-world examples. Raters broke out in three randomly assigned groups. Each group of raters was provided with 15 foot and 25 foot survey rods, 100 foot measuring tape, pitch and angle, a hard copy of the River Stability Field Guide (Rosgen, 2014), and at least one student assistant. Groups went to one of the three study banks and rotated through until all banks were assessed by each rater along a given reach. Each rater measured and recorded data necessary for BEHI scoring for each streambank to obtain a final BEHI rating. Since surveyed cross-section and profile data of each stream reach was not provided to calculate ratios and obtain NBS ratings, raters were instructed to select the NBS method(s) that they would use to obtain an NBS rating for each streambank, assuming that method 7, velocity isovels, was not a feasible option. Raters were asked not to communicate with other raters during the assessment related to the measurements and scoring until after worksheets were turned in following the second assessment date. Raters were also asked to avoid observing others take measurements.

Individual rater data from both assessment dates were input into RIVERMorph 5.2.0 Professional (Stantec Consulting Services, 2013) to obtain BEHI ratings. The BEHI delineation methodology used in the RIVERMorph software is based upon the table form of Figure 2.6 found in Rosgen (2001) (E. Morris, Stantec, personal communication, January 22, 2016). A reproduction of this table is shown in Table 3.1. If final BEHI scores obtained in RIVERMorph were in transition zones between categories, then a BEHI rating was selected based on what the rater determined the BEHI rating was in the field or, if the rater did not determine BEHI ratings in the field, a BEHI rating was selected that brought the rating closer to the assumed BEHI rating (See Table 3.2). For example, if the BEHI score obtained was 29.7 and the assumed BEHI rating for that study bank was High, then a BEHI rating of High was given.

Table 3.1 Streambank Characteristics Used to Develop Bank Erosion Hazard Index (BEHI), as used by RIVERMorph 5.2.0 Professional (Reproduced from Rosgen, 2001)

Adjective Hazard or Risk Rating Categories		Bank Height/ Bankfull Height	Root Depth/Bank Height	Root Density (%)	Bank Angle (Degrees)	Surface Protection (%)	Totals
Very Low	Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80	5-9.5
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	
Low	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55	10-19.5
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	
Moderate	Value	1.2	0.49-0.3	54-30	61-80	54-30	20-29.5
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	
High	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15	30-39.5
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	
Very High	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10	40-45
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	
Extreme	Value	>2.8	<0.05	<5	<119	<10	46-50
	Index	10	10	10	10	10	

The NBS methods selected by raters during each assessment date were also input into RIVERMorph 5.2.0 Professional. Information needed to calculate NBS ratings was measured by the author and used consistently throughout. Therefore, it is assumed that these data were collected correctly. The highest NBS rating obtained from the methods each individual rater selected was used as the rater's final NBS rating.

Study streambanks were analyzed following the assessment dates by Dr. Keane and the author to obtain BEHI and NBS ratings that were assumed to be correct. Detailed measurements were taken by the observers and measurements and ratings obtained by all raters were considered to finalize the assumed BEHI and NBS ratings. The ratings obtained are provided in Table 3.2. BEHI and NBS worksheets for the six study banks are presented in Appendix H. It is noted that

Lower West Emma study bank #1 and #2 are also known as Lower West Emma Pool XS and Lower West Emma ISCO, respectively.

Table 3.2 Assumed Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) Ratings for all Streambanks

Study Bank	BEHI Rating (Score)	NBS Rating (Method)
Lower West Emma #1	High (30.2)	Extreme (2)
Lower West Emma #2	High (36.2)	High (5)
Lower West Emma #3	Moderate (28.8)	Extreme (3,6)
Middle Little Arkansas #1	High (36.6)	High (5)
Middle Little Arkansas #2	Low (17.1)	Extreme (3,6)
Middle Little Arkansas #3	High (35.8)	Extreme (2)

BEHI can be expressed as both an ordinal category from Very Low to Extreme (BEHI rating) and a continuous value between 0 and 50 points (BEHI score). Both sets of data were analyzed using two different types of statistical analysis approaches. NBS is only expressed as an ordinal category and was analyzed as such. First, the BEHI and NBS ratings (Very Low to Extreme) obtained by raters were examined. Kendall's coefficient of concordance (W) was utilized to analyze overall agreement of BEHI and NBS ratings between raters ($m_{overall}$=8[1]) assessing streambanks (n=6) twice (k=2) and to analyze agreement between raters within training groups. Training was divided into two groups: Training group A - at least Level III training and Training group B - university to Level II training. Training group A had 5 raters (m_A) assessing 6 streambanks (n) twice (k) and Training group B had 3 raters (m_B) assessing 6 streambanks (n) twice (k). Kendall's coefficient of concordance was calculated using the following equation:

$$W = \frac{(m-1)\overline{r_s}+1}{m} \qquad \text{(Eq. 5)}$$

Where $\overline{r_s}$ is the mean of the pairwise Spearman correlations (Legendre, 2010). Values of W range from 0 to 1 where a value of 1 indicates raters obtained the same BEHI and NBS ratings for the set of assessed streambanks. Obtaining W values of 0.9 or better is considered to be very good (Minitab, 2016). The null hypothesis when assessing overall agreement utilizing the Kendall's coefficient of concordance approach is the following: H_0: Raters are not in agreement

[1] The two raters that did not make the 2nd assessment date were dropped from this analysis.

with one another. An F statistic was computed to test the significance of W using the following equation:

$$F = (m-1)W/(1-W) \qquad \text{(Eq. 6)}$$

This value is then compared to the critical value of F with $v_1 = n - 1 - (2/m)$ and $v_2 = v_1(m-1)$ degrees of freedom and a Type I error rate of 5% (Legendre, 2010). Since streambanks were assessed twice, raters (m) were multiplied by 2 ($m_{overall} = 16$, $m_A = 10$, $m_B = 6$) to calculate W, F, v_1, and v_2. Minitab 17 Statistical Software was utilized to compute W and test statistics were computed and compared in Microsoft Excel. See Appendix D for the Minitab data input worksheets.

Additionally, BEHI scores (0-50 points) were analyzed utilizing a different statistical approach to test for agreement between groups of raters based on training. To test for a level of training component in observed BEHI score variability, a linear mixed model with a randomized complete block design (RCBD) was set up as follows:

- **Block**: Date of assessment and streambank – Random effect
- **Treatment**: Level of training – Fixed effect

The block contains the date of assessment and streambank, both of which are assumed to be random, environmental effects. Alternatively, the treatment factor, level of training, is a fixed effect, meaning that it contains systematic levels that could be replicated for future experiments. The null hypotheses tested are as follows:

1) H_0: Mean BEHI score of Training group A and Training group B are equal
2) H_0: Variance of BEHI scores of Training group A and Training group B are equal

The linear mixed model with a RCBD utilized is as follows:

$$y_{kj} = \mu + \tau_k + p_j + e_{kj} \qquad \text{(Eq. 7)}$$

Where y_{kj} is the BEHI score observed on block j by training group k, μ is the overall intercept, τ_k is the fixed effect for level of training k (a or b), p_j is the random effect of block units, streambank and assessment date, j (1-12), and e_{kj} is the random experimental error. SAS was employed to compute test statistics and p-values using the PROC GLIMMIX procedure and were compared to a Type I error rate of 5%. See Appendix D for the complete SAS code.

In practice, BEHI and NBS ratings obtained by a rater would be applied to an appropriate regional BANCS model to predict annual streambank erosion rates. To illustrate the potential range in erosion rates that the group of raters in this study would have obtained, the relative difference between streambank erosion rate predictions based on the assumed BEHI and NBS ratings of Table 3.2 and BEHI and NBS ratings per study bank obtained by each individual rater on both assessment dates was assessed and compared. Since a BANCS model has not yet been validated for the study region, streambank erosion rates were predicted utilizing the Colorado BANCS model (Rosgen, 2009), as shown in Figure 3.10. This curve has not been validated for this region and is being used for example purposes only.

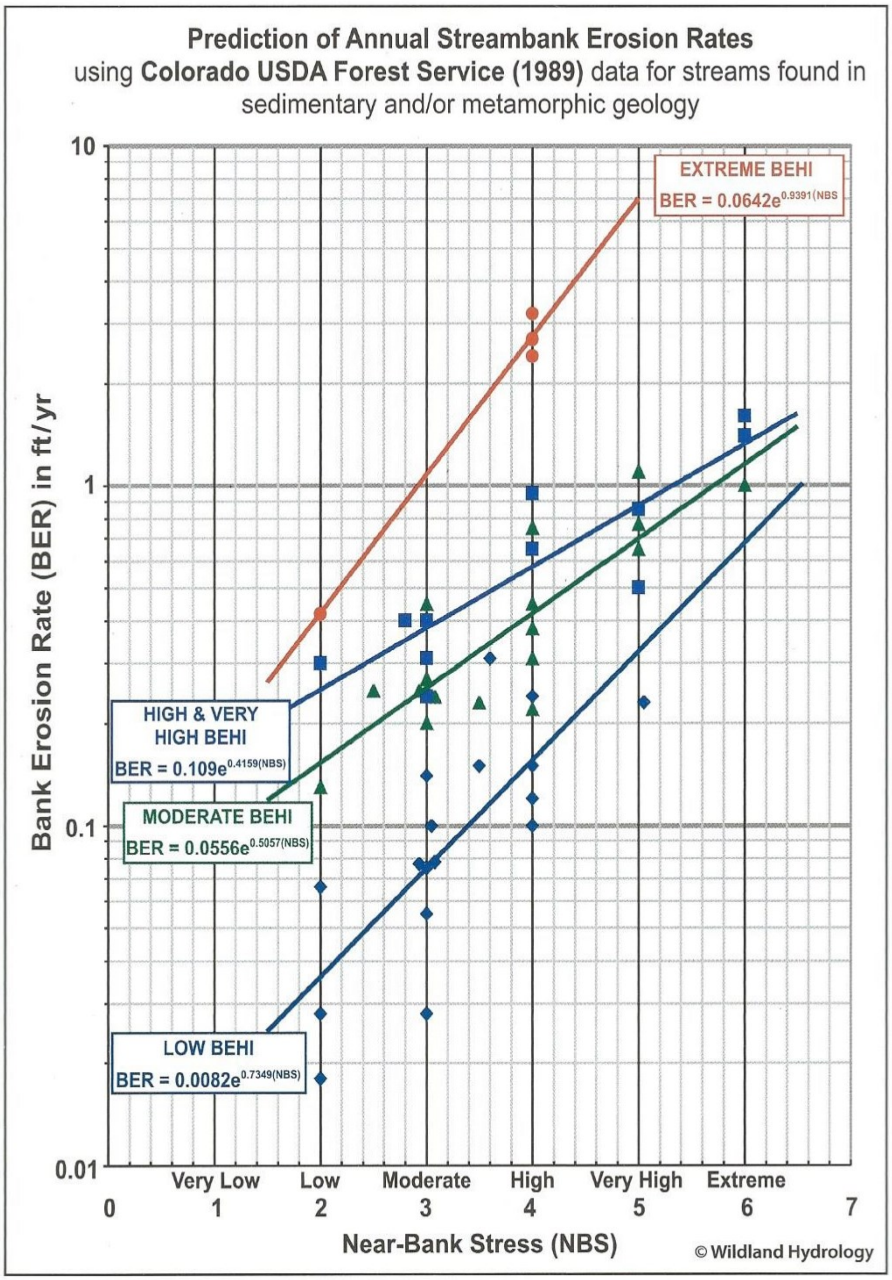


Figure 3.10 Colorado Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model utilized to predict Streambank Retreat Rates (Rosgen, 2014)

3.3.2 Results and Discussion

3.3.2.1 Repeatability of the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) Ratings

The results from the ten BANCS assessment raters on each evaluation date for individual study banks are depicted in Figure 3.11 through Figure 3.22. The sample statistic variables presented in each figure represent the following:

- X = sample mean
- S = sample standard deviation
- Mo = sample mode
- M = sample median
- IQR = sample interquartile range

A total of 108 BEHI/NBS ratings were obtained from study raters. Differences in BEHI ratings obtained by a rater per assessment date ranged from of 0 to 3 categories while NBS ratings ranged from 0 to 4 categories. Tables of the BANCS assessment results and BEHI parameter variability and mean can be found in Appendices E and F, respectively.

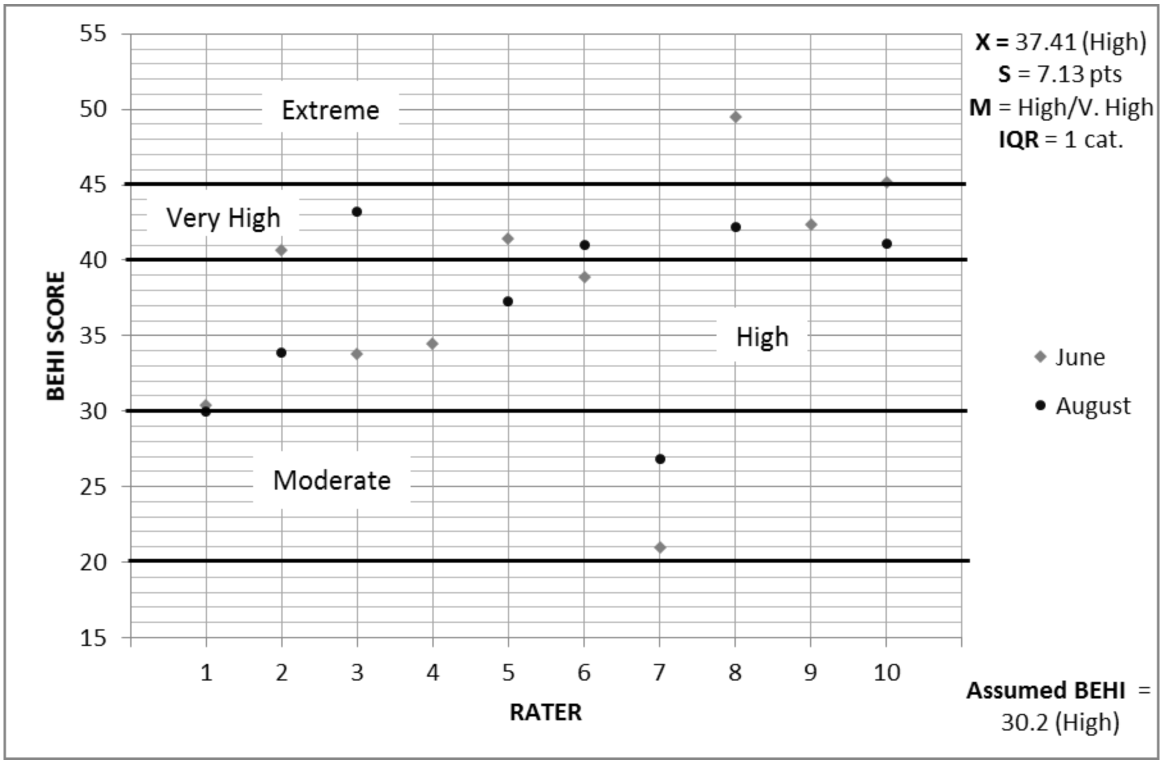


Figure 3.11 Lower West Emma Study Bank #1 Rater Bank Erosion Hazard Index (BEHI) Scores[2]

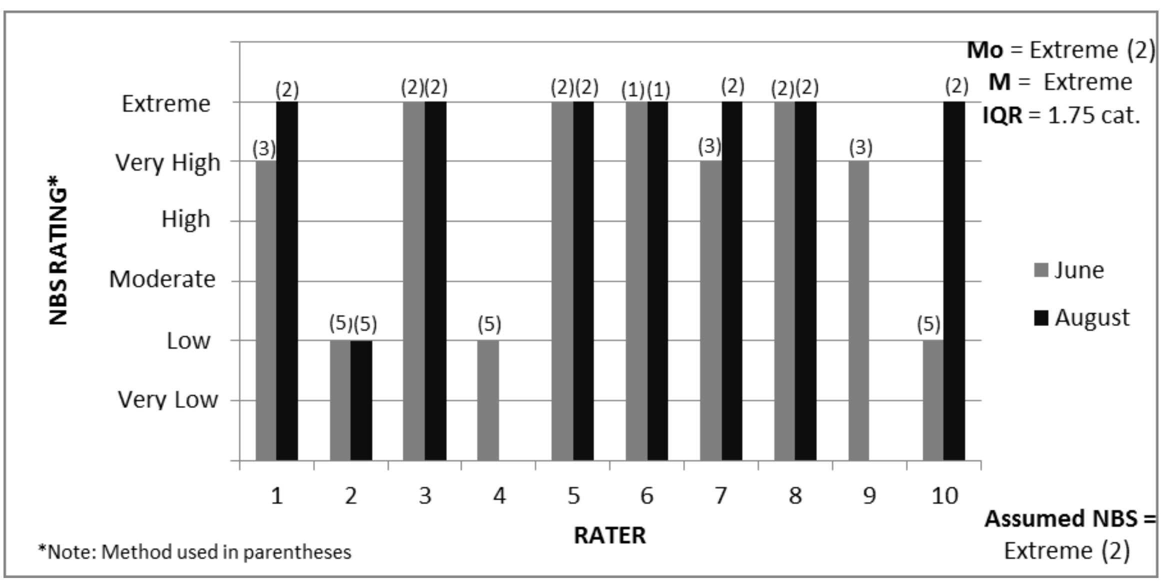


Figure 3.12 Lower West Emma Study Bank #1 Rater Near-Bank Stress (NBS) Ratings[2]

---

[2] X = sample mean, S = sample standard deviation, M = sample median, Mo = sample mode, IQR = sample interquartile range

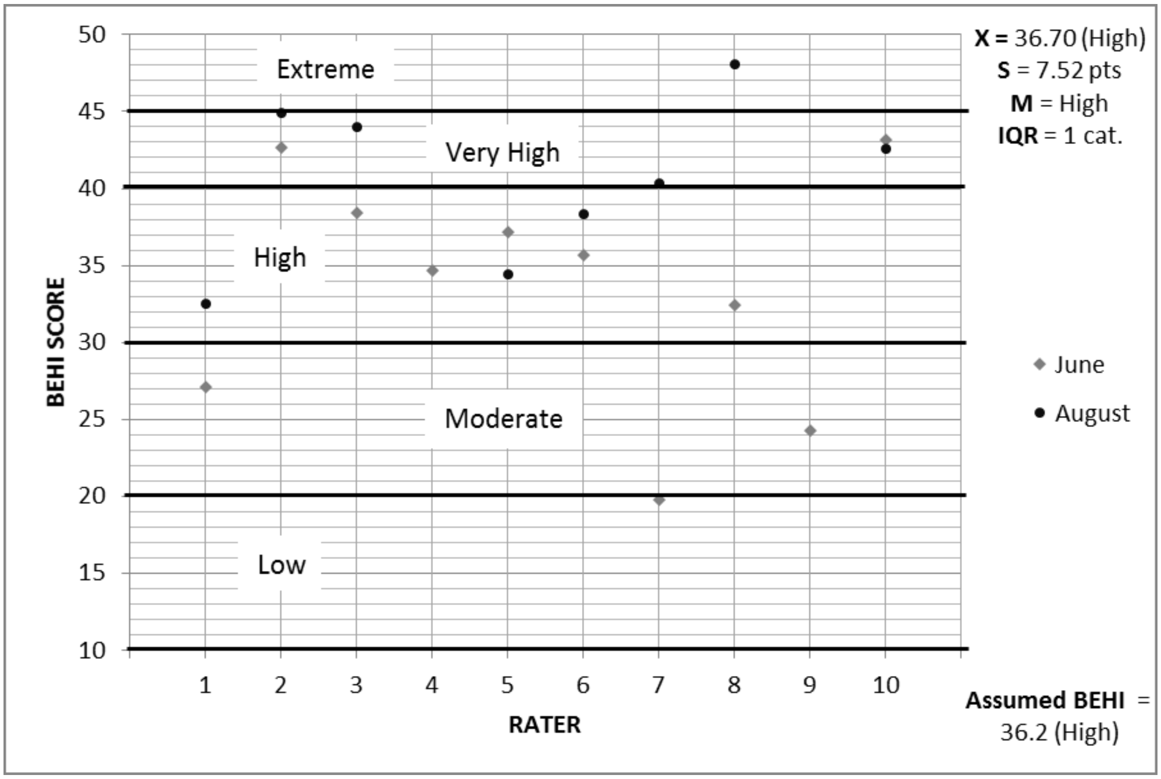


Figure 3.13 Lower West Emma Study Bank #2 Rater Bank Erosion Hazard Index (BEHI) Scores[3]

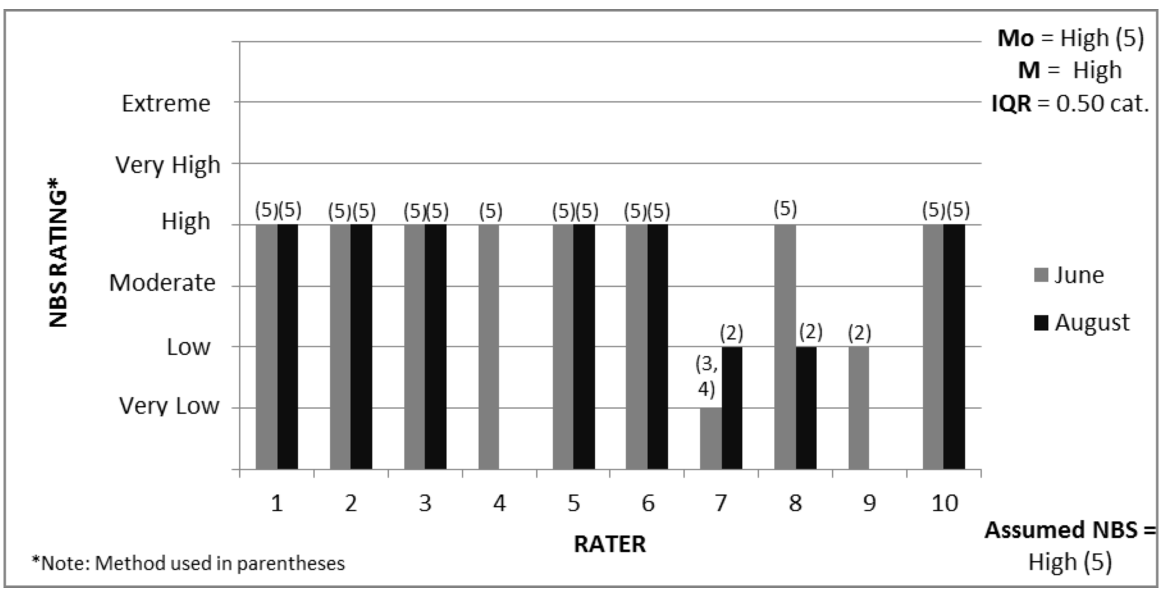


Figure 3.14 Lower West Emma Study Bank #2 Rater Near-Bank Stress (NBS) Ratings[3]

[3] X = sample mean, S = sample standard deviation, M = sample median, Mo = sample mode, IQR = sample interquartile range

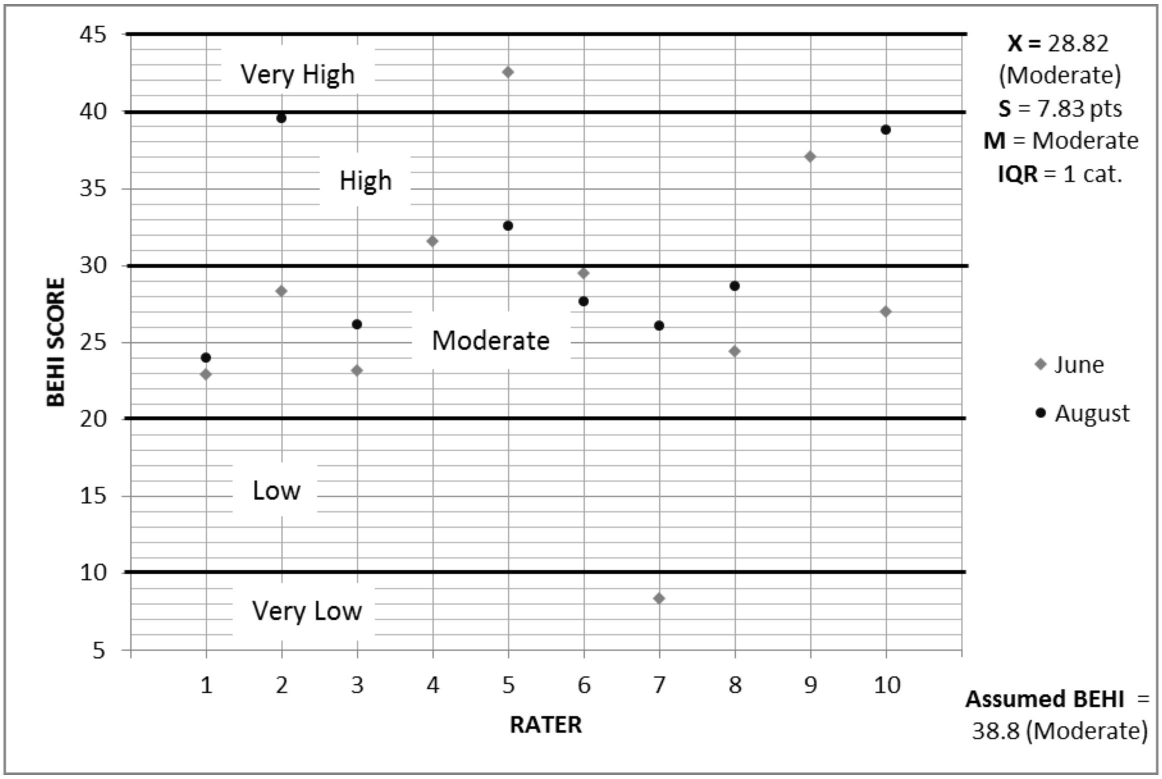


Figure 3.15 Lower West Emma Study Bank #3 Rater Bank Erosion Hazard Index (BEHI) Scores[4]

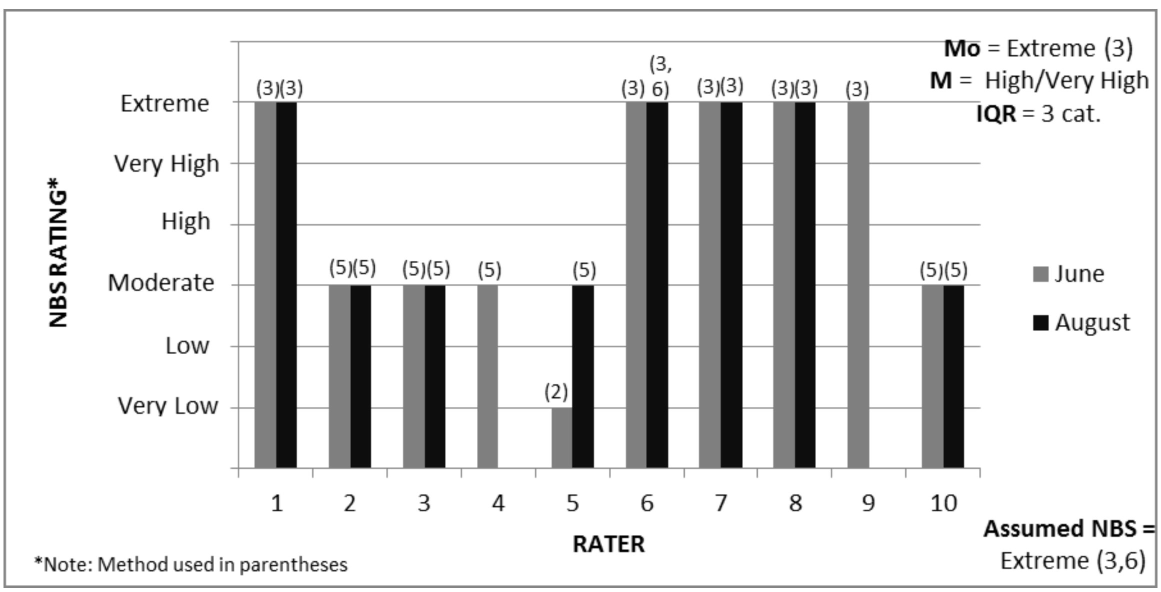


Figure 3.16 Lower West Emma Study Bank #3 Rater Near-Bank Stress (NBS) Ratings[4]

---

[4] X = sample mean, S = sample standard deviation, M = sample median, Mo = sample mode, IQR = sample interquartile range

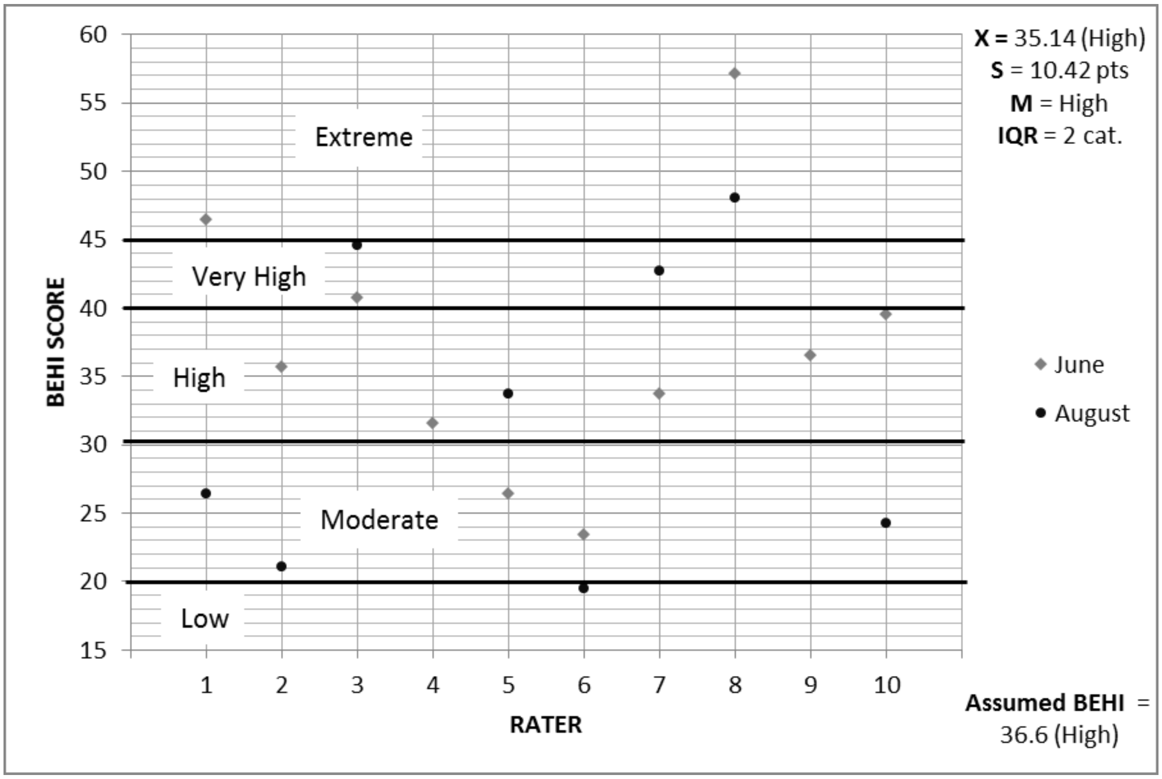


Figure 3.17 Middle Little Arkansas Study Bank #1 Rater Bank Erosion Hazard Index (BEHI) Scores[5]

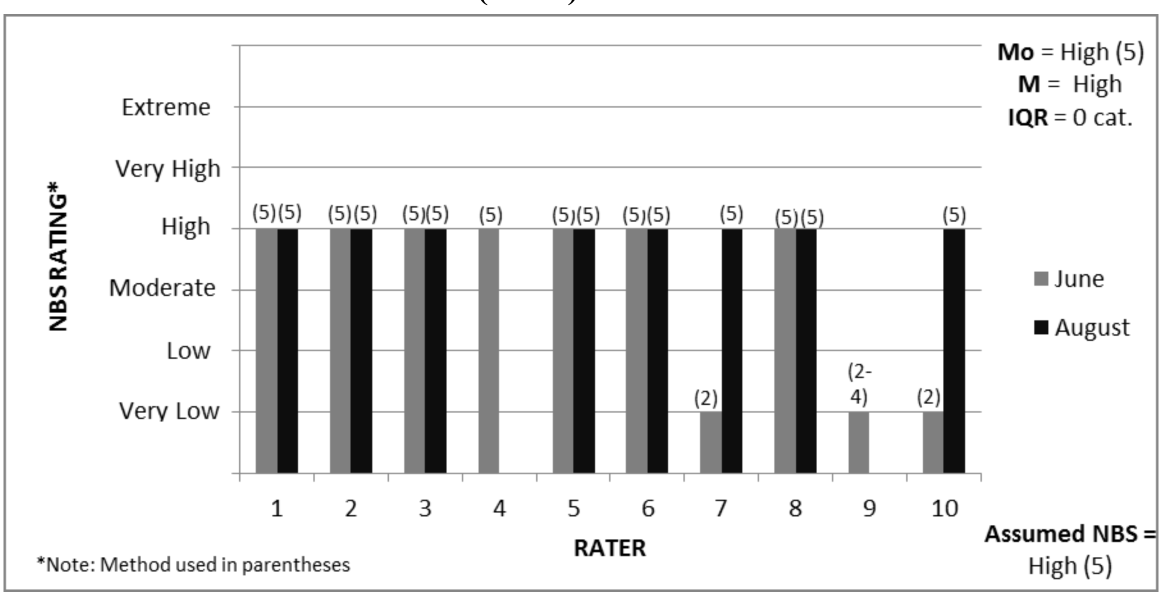


Figure 3.18 Middle Little Arkansas Study Bank #1 Rater Near-Bank Stress (NBS) Ratings[5]

---

[5] X = sample mean, S = sample standard deviation, M = sample median, Mo = sample mode, IQR = sample interquartile range

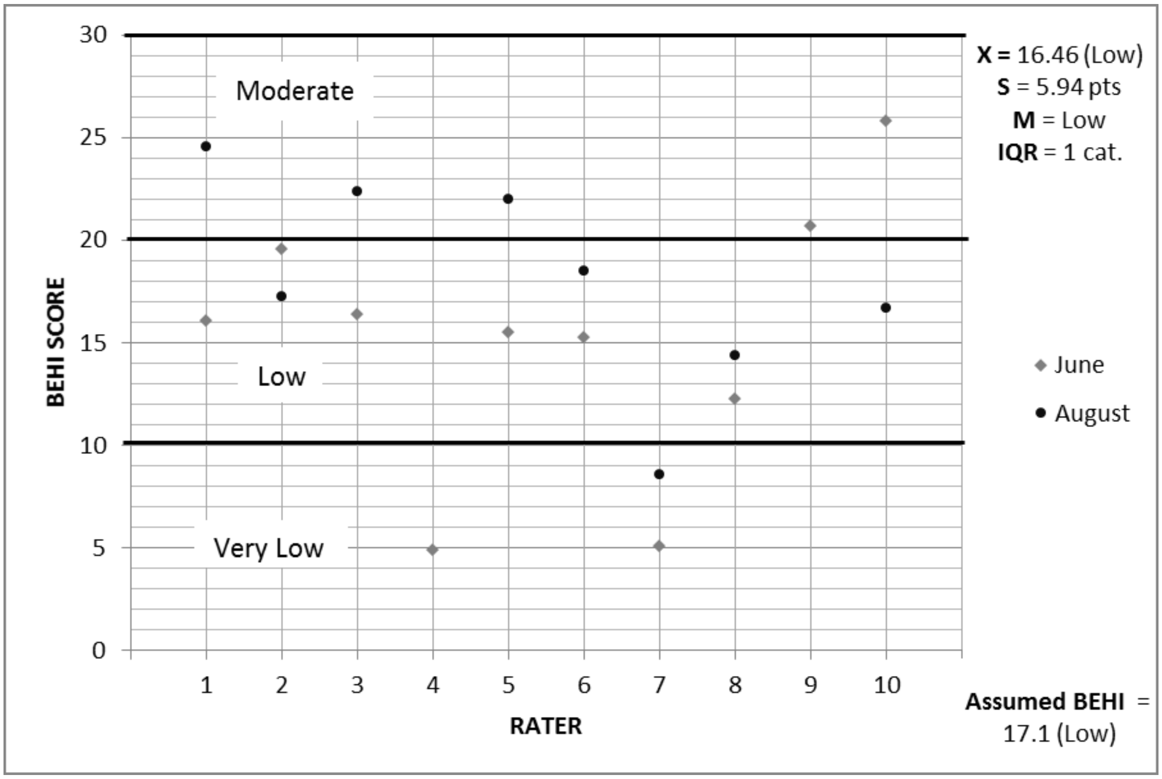


Figure 3.19 Middle Little Arkansas Study Bank #2 Rater Bank Erosion Hazard Index (BEHI) Scores[6]

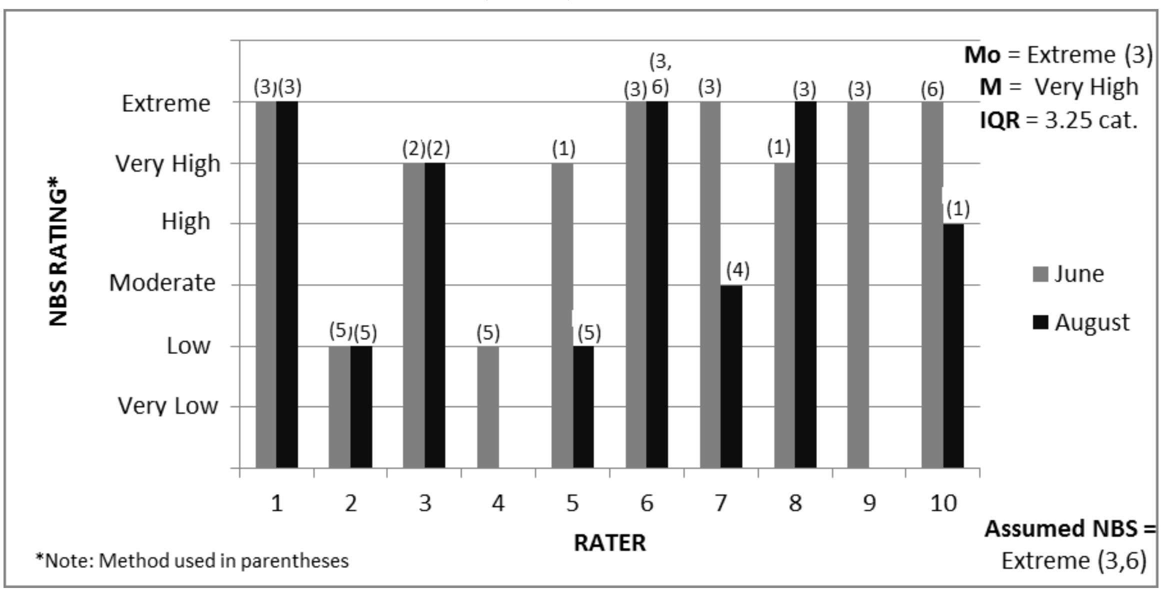


Figure 3.20 Middle Little Arkansas Study Bank #2 Rater Near-Bank Stress (NBS) Ratings[6]

---

[6] X = sample mean, S = sample standard deviation, M = sample median, Mo = sample mode, IQR = sample interquartile range

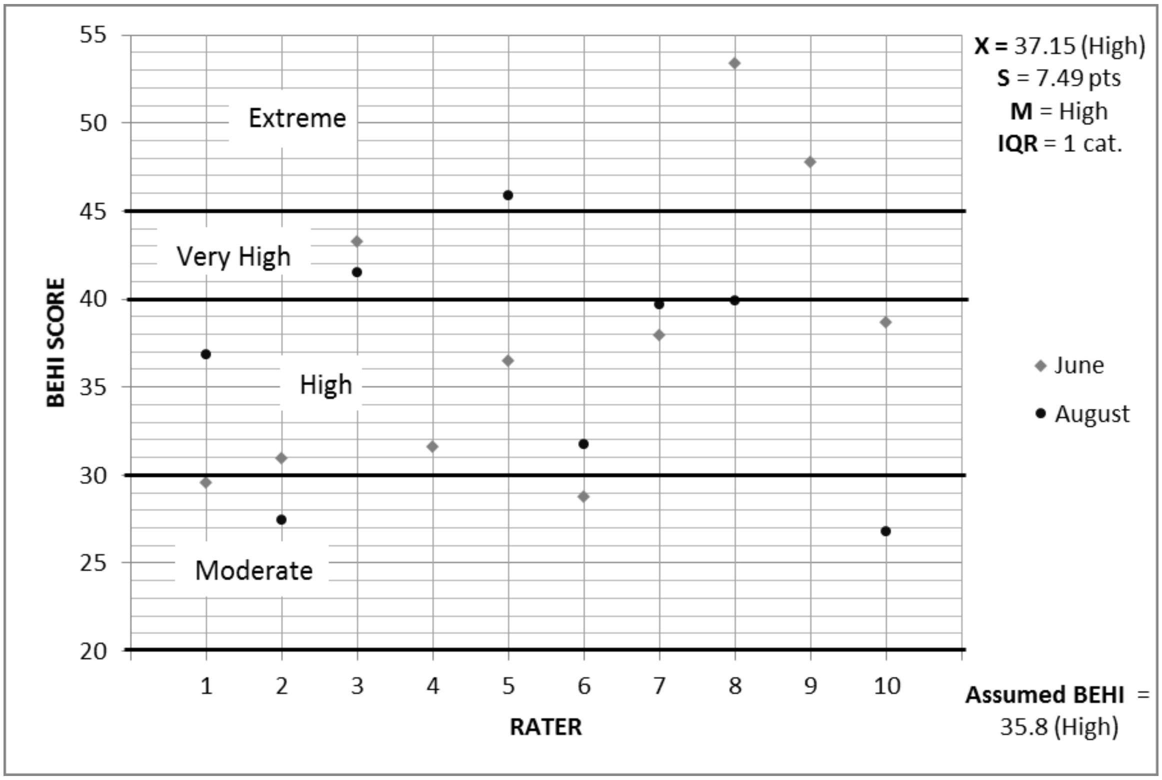


Figure 3.21 Middle Little Arkansas Study Bank #3 Rater Bank Erosion Hazard Index (BEHI) Scores[7]

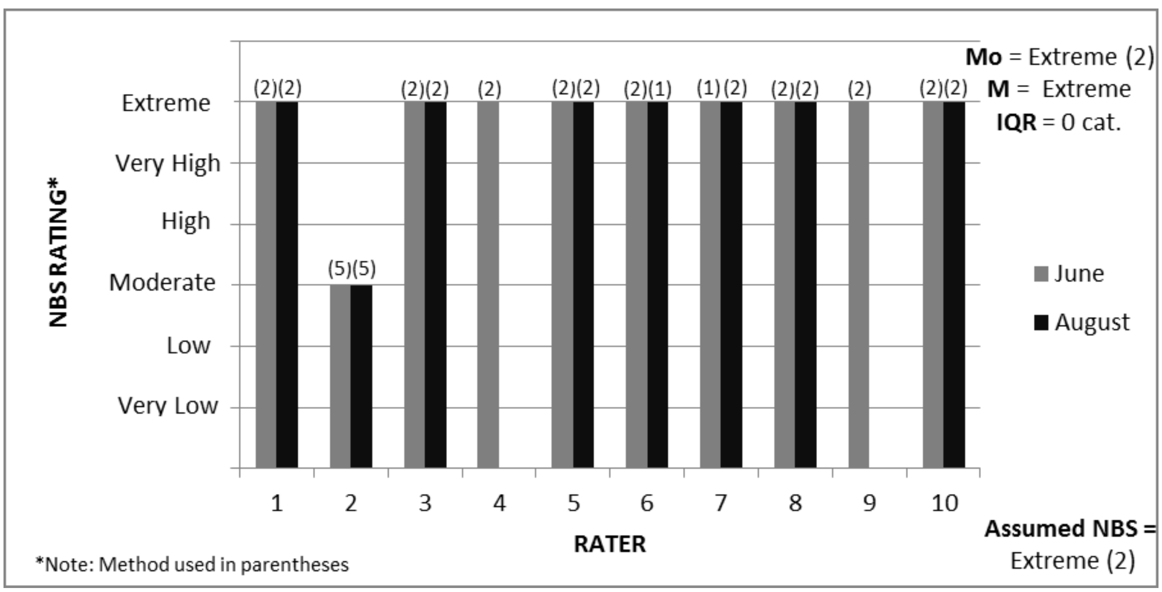


Figure 3.22 Middle Little Arkansas Study Bank #3 Rater Near-Bank Stress (NBS) Ratings[7]

---

[7] X = sample mean, S = sample standard deviation, M = sample median, Mo = sample mode, IQR = sample interquartile range

For each study bank, the mean BEHI score and mode NBS rating as well as the measures of spread for BEHI score/ratings and NBS ratings are presented in Table 3.3. The mean BEHI rating (based on score) and the mode NBS rating happened to be the same as the assumed BEHI and NBS rating described in the Methods section and portrayed in Table 3.2, suggesting that calculating a measure of central tendency among several raters may provide the most precise BEHI or NBS rating. Standard deviation for BEHI scores varied from 5.9 to 10.4 BEHI points, while interquartile range of BEHI ratings obtained ranged from 1 to 2 categories. Alternatively, interquartile range for NBS ratings varied from 0 to 3.3 NBS categories. This indicates that the BEHI/NBS methodology may be subject to user bias. Figure 3.23 and Figure 3.24 portrays the box and whisker plot of these findings. The box represents the interquartile range, or results from 50% of raters, whiskers represent the maximum and minimum values obtained, and the asterisks represent "outliers" of the dataset. Observations were considered to be outliers if they were 1.5 times the interquartile range from the upper and lower edges of the box. Since the dataset was limited to only 18 observations per streambank and number of outliers and rater(s) obtaining these values were not consistent throughout all streambanks, these identified outliers were not removed from further analysis.

Table 3.3 Summary Statistics of Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) Ratings Obtained by Raters

Study Bank	Mean Bank Erosion Hazard Index (BEHI) Rating (Score)	BEHI Interquartile Range (categ.)	BEHI Standard Deviation (pts)	Mode Near-Bank Stress (NBS) Rating (Method)	NBS Interquartile Range (categ.)
LWE #1	High (37.4)	1.0	7.1	Extreme (2)	1.8
LWE #2	High (36.7)	1.0	7.5	High (5)	0.5
LWE #3	Moderate (28.8)	1.0	7.8	Extreme (3)	3.0
MLA #1	High (35.1)	2.0	10.4	High (5)	0.0
MLA #2	Low (16.5)	1.0	5.9	Extreme (3)	3.3
MLA #3	High (37.2)	1.0	7.5	Extreme (2)	0.0

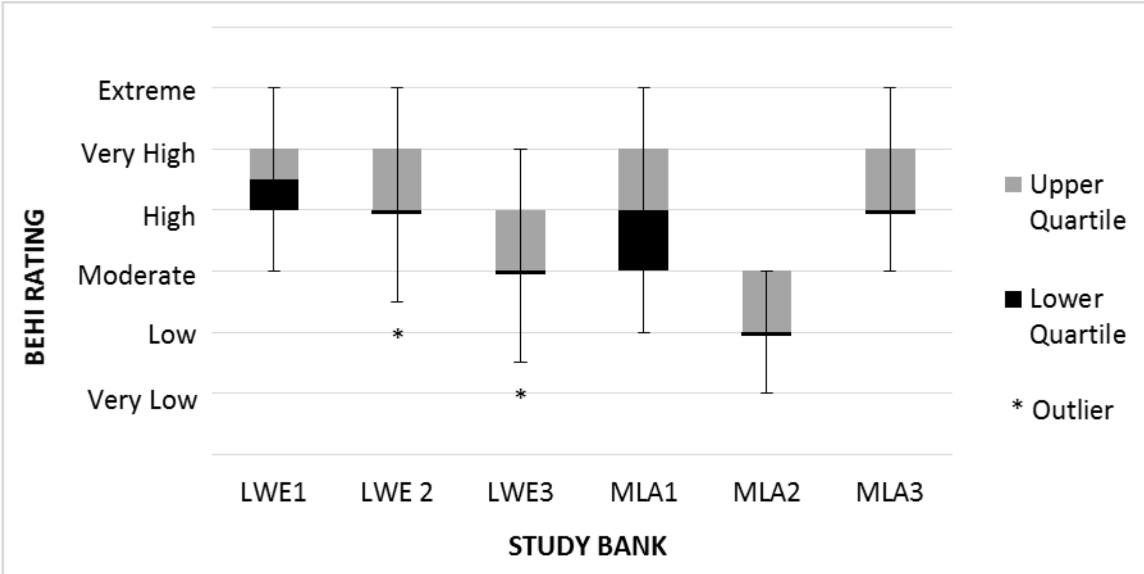


Figure 3.23 Bank Erosion Hazard Index (BEHI) Rating Box and Whisker Plot[8]

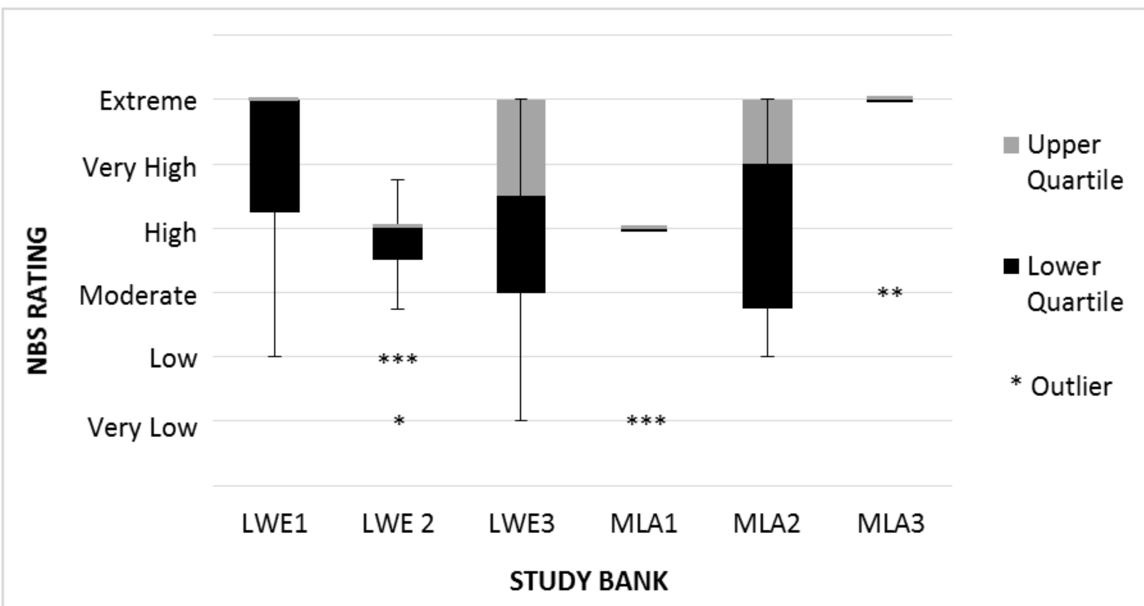


Figure 3.24 Near-Bank Stress (NBS) Rating Box and Whisker Plot[8]

[8] LWE#: Lower West Emma Study Bank #; MLA#: Middle Little Arkansas Study Bank #; Box represents interquartile range; whiskers represent minimum and maximum ratings obtained; asterisks represent outliers or observations 1.5 times the interquartile range from the upper and lower edge of the box

Table 3.4 provides the mean BEHI rating and the mode NBS rating obtained by the groups that have received Rosgen level III training or better, group A, and university to Rosgen level II training, group B. Cells with bolded text represent the group that obtained the closest to the assumed BEHI/NBS rating per study bank. Training group A obtained BEHI ratings that were the same as the assumed rating for all six study banks while Training group B only obtained the same BEHI rating for four of the six study banks. Alternatively, Training group B NBS ratings were more similar to assumed NBS ratings than Training group A NBS ratings. This is because four of the six raters in Training group A never selected NBS methods 3, 4, or 6, while raters of Training group B were open to all NBS methods to describe applied shear stress. Instead, these raters in Training group A consistently selected methods 1, 2, and/or 5. It is possible that raters that only selected methods 1, 2, and/or 5 may have been influenced from personal experience or experience of others.

Table 3.4 Mean Bank Erosion Hazard Index (BEHI) and Mode Near-Bank Stress (NBS) Ratings for Training Groups[9]

Study Bank	Mean BEHI Rating (Score)		Assumed BEHI Rating (Score)	Mode NBS Rating (Method)		Assumed NBS Rating (Method)
	Training Group A	Training Group B		Training Group A	Training Group B	
LWE #1	**High (36.8)**	**High (38.3)**	High (30.2)	**Extreme (2)**	**Extreme (2)**	Extreme (2)
LWE #2	**High (37.3)**	**High (35.8)**	High (36.2)	**High (5)**	Low (2), High (5)	High (5)
LWE #3	**Moderate (29.8)**	**Moderate (27.2)**	Moderate (28.8)	Moderate (5)	**Extreme (3)**	Extreme (3,6)
MLA #1	**High (31.8)**	Very High (40.3)	High (36.6)	**High (5)**	**High (5)**	High (5)
MLA #2	**Low (17.5)**	**Low (14.8)**	Low (17.1)	Moderate (5), Extreme (3)	**Extreme (3)**	Extreme (3,6)
MLA #3	**High (35.0)**	Very High (40.6)	High (35.8)	**Extreme (2)**	**Extreme (2)**	Extreme (2)

[9] Training group A received Rosgen Level III training or better; Training group B received university training to Rosgen Level II training; Cells with bolded text represent the group that obtained BEHI/NBS ratings similar to the assumed BEHI/NBS ratings

Table 3.5 provides the interquartile range of BEHI and NBS ratings obtained by each training group. Cells with bolded text represent the training group that had the lowest spread between raters. BEHI score standard deviation was lowest in Training group A for all six study banks. Alternatively, training did not appear to influence the precision of NBS ratings, as the training group that had the lowest interquartile range varied per study bank.

Table 3.5 Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) Ratings Standard Deviation for Training Groups[10]

Study Bank	Interquartile Range BEHI Categories (BEHI points)		Sample IQR BEHI Categories (BEHI points)	Interquartile Range NBS Category		Sample IQR NBS Category
	Training Group A	Training Group B		Training Group A	Training Group B	
LWE #1	**1.0 (4.6)**	2.0 (10.4)	1.0 (7.1)	4.0	**1.0**	1.8
LWE #2	**1.0 (5.3)**	2.0 (10.6)	1.0 (7.5)	**0.0**	2.0	0.5
LWE #3	**1.0 (6.5)**	1.0 (10.0)	1.0 (7.8)	**3.0**	**3.0**	3.0
MLA #1	**2.0 (9.3)**	2.0 (10.5)	2.0 (10.4)	**0.0**	3.0	0.0
MLA #2	**1.0 (5.2)**	2.0 (7.1)	1.0 (5.9)	4.0	**2.0**	3.3
MLA #3	**1.0 (6.3)**	2.0 (8.3)	1.0 (7.5)	**0.0**	**0.0**	0.0

The Kendall's coefficient of concordance (W) used to test for agreement of BEHI ratings between raters was 0.57, which suggests raters were not using the same standard to assess for BEHI ratings of streambanks and therefore were not always in agreement. When testing the significance of W, the critical value of F (2.36) was much less than the F test statistic (19.61), providing evidence to reject the null hypothesis that raters are not in agreement with one another, based on a Type I error rate of 5%. Legendre (2010) states that rejecting the null hypothesis does not mean that all raters are in agreement; rather, it means that at least two of the raters are in agreement.

For NBS ratings, the Kendall's coefficient of concordance (W) for overall agreement was 0.29, meaning that raters were in poor agreement with one another. The critical value of F (2.36) was again less than the F test statistic (6.13). Therefore, the null hypothesis was rejected with 95% confidence which means that at least one rater was in agreement with another. Although

[10] Training group A received Rosgen Level III training or better; Training group B received university training to Rosgen Level II training; Cells with bolded text represent the group that had the lowest interquartile range (IQR)

concordance statistics were not significant, the low values of W suggest the current methodology used to determine BEHI and NBS ratings may not always be repeatable.

The Kendall's coefficients of concordance (W) for BEHI and NBS ratings of Training group A were 0.57 and 0.21, respectively, showing poor agreement among raters of group A. The null hypothesis was rejected when testing the significance of W for BEHI ratings of Training group A, based on a Type I error rate of 5%. This means that at least one rater within group A obtained the same BEHI rating as another rater within the group. Alternatively, the null hypothesis was not rejected for NBS rating of Training group A with 95% confidence, meaning that there was not enough evidence to state that at least one rater was in agreement with another when obtaining NBS ratings.

For Training group B, the Kendall's coefficients of concordance (W) were 0.65 and 0.52 for BEHI and NBS ratings, respectively. The null hypothesis that there is not agreement amongst raters of Training group B was rejected for both BEHI and NBS ratings, with 95% confidence. Therefore, there is enough evidence to conclude that at least two raters agree on BEHI or NBS ratings within Training group B.

When comparing the two training groups, concordance coefficients were quite similar for BEHI ratings within training groups, with group A obtaining a lower W (0.57) than group B (0.65) and both rejecting the null hypothesis. Since the sample size for group B was smaller (3) than group A (5), it is difficult to conclude that training has an effect on obtaining repeatable BEHI results based upon this analysis. For NBS ratings, Kendall's coefficient of concordance for group A was much lower (0.21) than group B (0.52). Additionally, the null hypothesis could not be rejected when testing the significance of W for group A. If there was an effect of training on NBS ratings, one would expect that Training group A would obtain more repeatable ratings between raters than Training group B, as they have received model implementation training by the creator, Dr. Rosgen. These results suggest that level of training may not have an effect on obtaining the correct NBS rating. A similar observation was made when comparing interquartile ranges of NBS ratings obtained per study bank between training groups in Table 3.5. The results of the Kendall's coefficient of concordance analysis can be found in Appendix D.

To further analyze the effect of training on BEHI ratings, an additional statistical analysis was conducted on numerical BEHI scores obtained by raters using a linear mixed model with RCBD. The p-value computed to test for difference in mean BEHI scores between training groups A and B was 0.38. Therefore, based on a Type I error rate of 5%, there is not enough evidence to conclude that there is a significant difference between the mean BEHI scores of training group A and B. A similar observation can be made when comparing the mean BEHI scores obtained by each training group per study bank in Table 3.4, as many of the mean scores per study bank are relatively close to one another. Alternatively, the computed p-value to test for differences between variances of BEHI scores obtained by the two training groups was 0.005. Therefore, there is evidence to conclude that there is a significant difference in variances between level of training group A and B, with 95% confidence. Once again, a similar observation can be made when comparing BEHI rating interquartile range of each group per study bank, as shown in Table 3.5. Generally, BEHI rating interquartile range of Training group B was 2 times greater than that of Training group A. This finding indicates that an increased level of training may result in more precise BEHI scores/ratings. See Appendix D for SAS output of results.

A meaningful statistical analysis could not be conducted to assess agreement within raters. Instead, BEHI, NBS, and combination of BEHI/NBS ratings obtained by raters per study bank from both assessment dates were compared. Table 3.6 provides the percentage of times an individual rater obtained the same BEHI or NBS rating per study bank and the percentage of times an individual rater obtained the same BEHI/NBS rating combination in both the June and August rating events. Raters obtained the same BEHI ratings 17 to 50 percent of the time, the same NBS ratings 33 to 100% of the time, and the same BEHI/NBS rating combination 17 to 50% of the time. Assuming BEHI and NBS variables did not change appreciably between the two rating events, these results suggest that individuals applying repeated BEHI and NBS assessments on the same bank were less than 50% likely to obtain the same combination of ratings.

Table 3.6 Percentage of Times Rater Obtained the Same Bank Erosion Hazard Index (BEHI) Rating, Near-Bank Stress (NBS) Rating, and Combination of BEHI/NBS Ratings per Study Bank [11]

Rater	Same BEHI Rating Obtained	Same NBS Rating Obtained	Same BEHI/NBS Rating Combination Obtained
1	50%	83%	33%
2	33%	100%	33%
3	50%	100%	50%
5	17%	67%	17%
6	50%	100%	50%
7	50%	33%	17%
8	50%	67%	33%
10	33%	50%	17%

3.3.2.1 Rater Streambank Erosion Rate Predictions

Based on the results obtained by all the raters from this assessment (see Appendix E), the potential range in streambank erosion rate predictions was assessed utilizing the Colorado BANCS model (Rosgen, 2009; Figure 3.10). Resulting streambank erosion rates predicted from the assumed BEHI/NBS ratings (see Table 3.2) is compared with the range of erosion rates that would have been obtained by the raters in this study in Table 3.7.

Table 3.7 Comparison of Predicted Streambank Retreat Rates based on the Colorado Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model (Rosgen, 2014) of Assumed Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) Ratings and BEHI/NBS Ratings obtained by Raters

Study Bank	Assumed BEHI/NBS Rating Prediction (m/yr)	Maximum Prediction (m/yr)	Minimum Prediction (m/yr)	Mode Prediction (m/yr)	Median Prediction (m/yr)
LWE #1	**0.4**	5.5*	0.1	**0.4**	**0.4**
LWE #2	**0.2**	**0.2**	0.01*	**0.2**	**0.2**
LWE #3	**0.4**	**0.4**	0.03*	**0.4**	0.1
MLA #1	**0.2**	0.8	0.05	**0.2**	**0.2**
MLA #2	**0.2**	0.4	0.003*	**0.2**	0.1
MLA #3	**0.4**	5.5*	0.1	**0.4**	**0.4**

*: Prediction is estimated via extrapolation as BEHI and/or NBS ratings were outside of curve range; Bolded text represent rater prediction values that are the same as the assumed BEHI/NBS rating prediction value

[11] Raters 4 and 9 only assessed streambanks once

Streambank erosion rate prediction was quite variable across raters, with a maximum range of 0.1 to 5.5 meters of bank retreat per year for both Lower West Emma #1 and Middle Little Arkansas #3. For these study banks, predicted bank retreat rates were 0.2 to 13.6x the assumed BEHI/NBS prediction value. However, the majority of raters obtained the same prediction rate as the assumed BEHI/NBS. Alternatively, the remaining study banks had lower ranges of prediction, with a minimum range of 0.19 and a maximum range of 0.75 meters per year. The mode rater prediction value was equal to the assumed BEHI/NBS rating prediction value for all study banks. The median rater prediction value was the same as the assumed BEHI/NBS rating prediction value for four of the six study banks. Lower West Emma #3 median prediction value was 75% lower than the assumed while Middle Little Arkansas #2 was 50% lower.

The findings from this analysis and those from the BEHI and NBS repeatability analysis imply that streambanks should be assessed and rated by more than one rater to obtain a more precise BEHI or NBS rating by calculating a measure of central tendency based on all of the assessments, particularly during model creation. The number of raters depends on the level of uncertainty with which model creators and/or applicators are comfortable.

Margins of error were calculated to provide insight on how many raters are needed to improve BEHI and NBS rating precision, using the following equation (Lenth, 2009):

$$ME = \frac{t * IQR}{\sqrt{n}} \qquad \text{(Eq. 8)}$$

Where t = t distribution critical value, IQR = mean sample interquartile range for BEHI (1.2 categories) or NBS (1.4 categories) ratings, and n = number of raters. Values of t were obtained for confidence intervals of 80%, 90%, and 95%. Figure 3.25 and Figure 3.26 depict decreasing margins of error when number of raters increase for BEHI and NBS ratings, respectively.

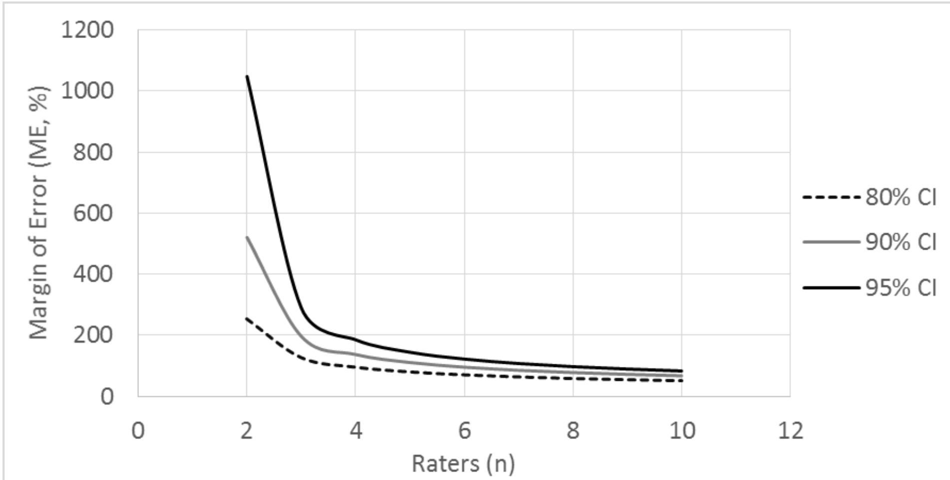


Figure 3.25 Margin of Error (ME) versus Number of Raters (n) Needed to Assess for Bank Erosion Hazard Index (BEHI) Ratings, based on 80%, 90%, and 95% Confidence Intervals (CI)

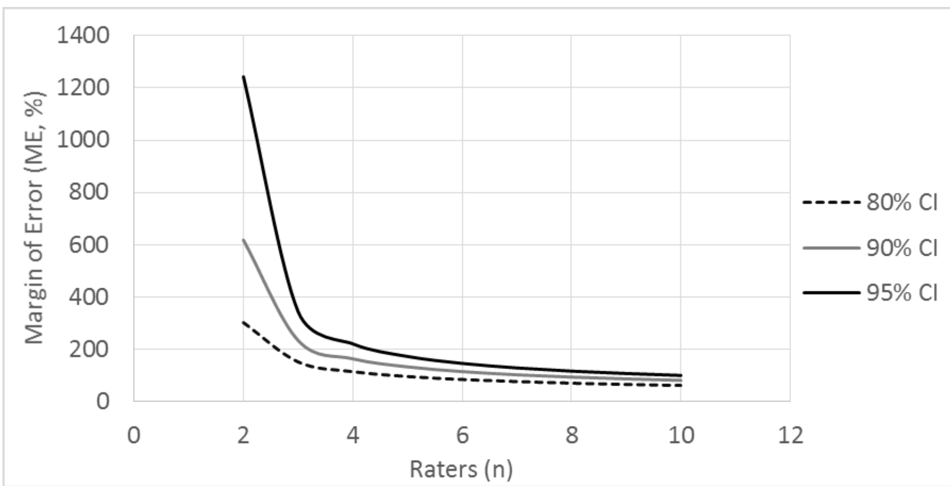


Figure 3.26 Margin of Error (ME) versus Number of Raters (n) Needed to Assess for Near-Bank Stress (NBS) Ratings, based on 80%, 90%, and 95% Confidence Intervals (CI)

Margins of error are quite large for both BEHI and NBS ratings. BEHI ratings had margins of error ranging from 50% to 1,050%, based on an 80% and 95% confidence interval, respectively. NBS ratings had slightly greater margins of error of 60% to 1,240%, based on an 80% and 95% confidence interval, respectively. Margins of error could be decreased if additional raters assessed streambanks. For example, in order to obtain a margin of error of 10% with 90% confidence, more than 500 raters would be required. Five hundred raters assessing one streambank is not feasible. Based on evaluating Figure 3.25 and Figure 3.26, it seems that the ideal number of raters needed to assess a streambank for BEHI and NBS is four, as this is when the curve begins to flatten as it reaches margins of error of 70% and 80% for BEHI and NBS, respectively. Unfortunately, having four raters on-site may also be difficult and unreasonable. Therefore, it is recommended that at least two, preferably four, trained professionals should assess a streambank to obtain a measure of central tendency, such as a mean BEHI score, median BEHI rating, or mode (or maximum) NBS rating, and use these values as the final BEHI and NBS ratings for a given streambank.

3.4 Sensitivity of the Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model

3.4.1 Methods

In order to identify variables of the BANCS model with a significant influence upon BEHI/NBS ratings, a sensitivity analysis was conducted. A one-at-a-time design approach was adopted to test sensitivity of BEHI parameters by adjusting a single parameter while holding all others constant, to quantify the change in BEHI rating output from a base-case scenario (Hamby, 1994). Based on the one-at-a-time approach, a sensitivity function was developed for each study bank with all BEHI parameters to measure which BEHI parameter(s) is commonly the most sensitive, or has the greatest influence on the final BEHI rating. Individual BEHI parameters were positively and negatively adjusted by up to three standard deviations from a base case scenario, or until a minimum or maximum value was reached. Study bank base-case scenarios and the BEHI parameter standard deviations utilized were based on the mean value and standard deviation for each of the BEHI parameters that were obtained by the ten raters.

The base-case scenario and each adjusted scenario were input into RIVERMorph 5.2.0 Professional (Stantec Consulting Services, 2013) to obtain BEHI ratings. The BEHI delineation methodology used in the RIVERMorph software is based upon the table form of Figure 2.6 found in Rosgen (2001) (E. Morris, Stantec, personal communication, January 22, 2016). A reproduction of this table is shown in Table 3.1. The mean bank material and stratification adjustments were rounded to the nearest point to input as a whole number into RIVERMorph. Appendix F provides the standard deviation and base-case scenario for each BEHI parameter per study bank as well as the final base-case scenario BEHI score and rating based on these mean values.

To develop a sensitivity function per study bank, percent change in the BEHI parameter was plotted on the x-axis and the change in BEHI category on the y-axis. Sensitivity was ranked based on two metrics. The first metric (R_1) involved ranking BEHI parameters based on a minimum change in BEHI parameter ($|\Delta X|$) that resulted in a change in BEHI category. For each study bank, parameters were ranked from 1 to 8, where 1 represented the smallest $|\Delta X|$.

The second sensitivity metric (R_2) was calculated using Equation 9.

$$S = \Delta X_{+} + |\Delta X_{-}| \qquad \text{(Eq. 9)}$$

Where S = sensitivity measure, ΔX_+ = positive percent change of BEHI parameter when BEHI category change occurs or a maximum is reached, and ΔX_- = negative percent change of BEHI parameter when BEHI category change occurs or a minimum is reached. The smaller the value of S, the more sensitive the parameter. For every study bank, BEHI parameters were ranked from 1 to 8, where a ranking of 1 represented the smallest value of S.

The average rank (R_{avg}) for each BEHI parameter per study bank was then obtained for the final sensitivity ranking. Based on these average rankings, a parameter was identified as sensitive if it ranked in the top 3 most sensitive parameters for the majority, if not all, of the study banks. The Kruskal-Wallis test and Tukey's Honest Significant Difference (Tukey HSD) test were applied to ranking data to determine if a BEHI parameter was significantly more sensitive than another parameter, based on a Type I error rate of 5%. Analyses were run in JMP (version 9, SAS); input to JMP is provided in Appendix D.

To further analyze the parameters identified as sensitive, sensitivity functions based on data obtained from all study banks were developed where percent change in the identified, sensitive BEHI parameter was plotted on the x-axis and the change in BEHI points on the y-axis. Each polynomial function created represented the sensitivity for that specific parameter for a different study bank and/or scenario.

In addition to identifying parameters that have the greatest influence on the output, an uncertainty analysis was conducted. A parameter identified as uncertain means that its variability, measured through standard deviation, influences the variability of the output. Uncertainty of a parameter is calculated using Equation 10.

$$U = \max Y - \min Y \quad \text{(Eq. 10)}$$

Where U = uncertainty measure, maxY = maximum BEHI score (pts) when BEHI parameter base-case scenario is adjusted by +2 BEHI parameter standard deviations, and minY = minimum

BEHI score (pts) when BEHI parameter base-case scenario is adjusted by -2 BEHI parameter standard deviations (Downing, Gardner, & Hoffman, 1985). The larger the uncertainty measure (U), the greater the influence the uncertainty of a given parameter has on the overall uncertainty of the BEHI rating output (Hamby, 1994).

Similar to the sensitivity analysis, uncertainty measures were ranked from 1 to 8 for each study bank, where 1 represented a BEHI parameter that had the largest uncertainty (U). All rankings were compared across the six study banks. The top three BEHI parameters that obtained the highest uncertainty values across study banks were classified as an uncertain. As with sensitivity rankings, the Kruskal-Wallis test and Tukey HSD was implemented to assess for significant differences between uncertainty rankings of BEHI parameters, based on a Type I error rate of 5%. Input to the JMP software used to run the analysis is provided in Appendix D.

It is not feasible to conduct a one-at-a-time sensitivity analysis of parameters of various NBS methods since only site-specific method selection was obtained from study participants. Instead, a comparison analysis of dominant NBS ratings obtained per rater and study bank was implemented. All measurements necessary to calculate NBS ratings were obtained by the author and were assumed to be correct. Based on these measurements, the rater-chosen method that obtained the highest NBS rating was selected as the dominant NBS rating for a specific streambank. These results were compared and discussed.

3.4.2 Results and Discussion

3.4.2.1 Bank Erosion Hazard Index (BEHI)

Sensitivity functions of BEHI parameters created for all six study banks are presented in Figure 3.27 through Figure 3.32 below. Sensitivity rankings are presented in Table 3.8.

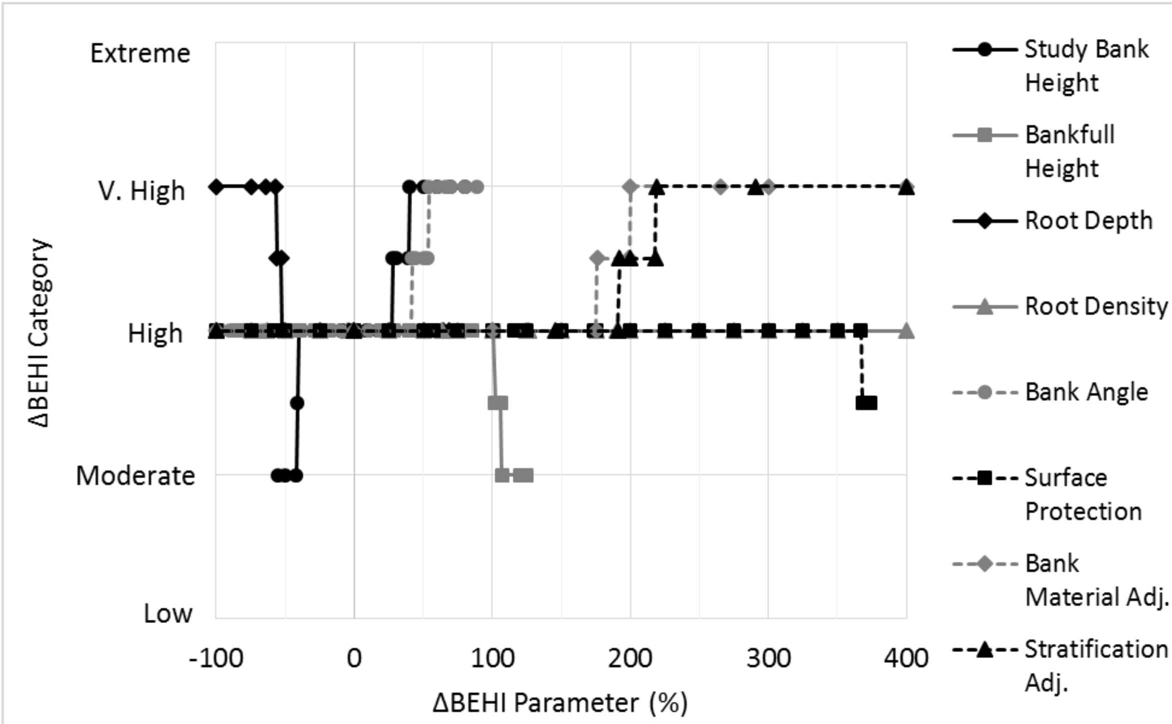


Figure 3.27 Lower West Emma Study Bank #1 Bank Erosion Hazard Index (BEHI) Parameter Sensitivity Function (Base Case BEHI Category: High)

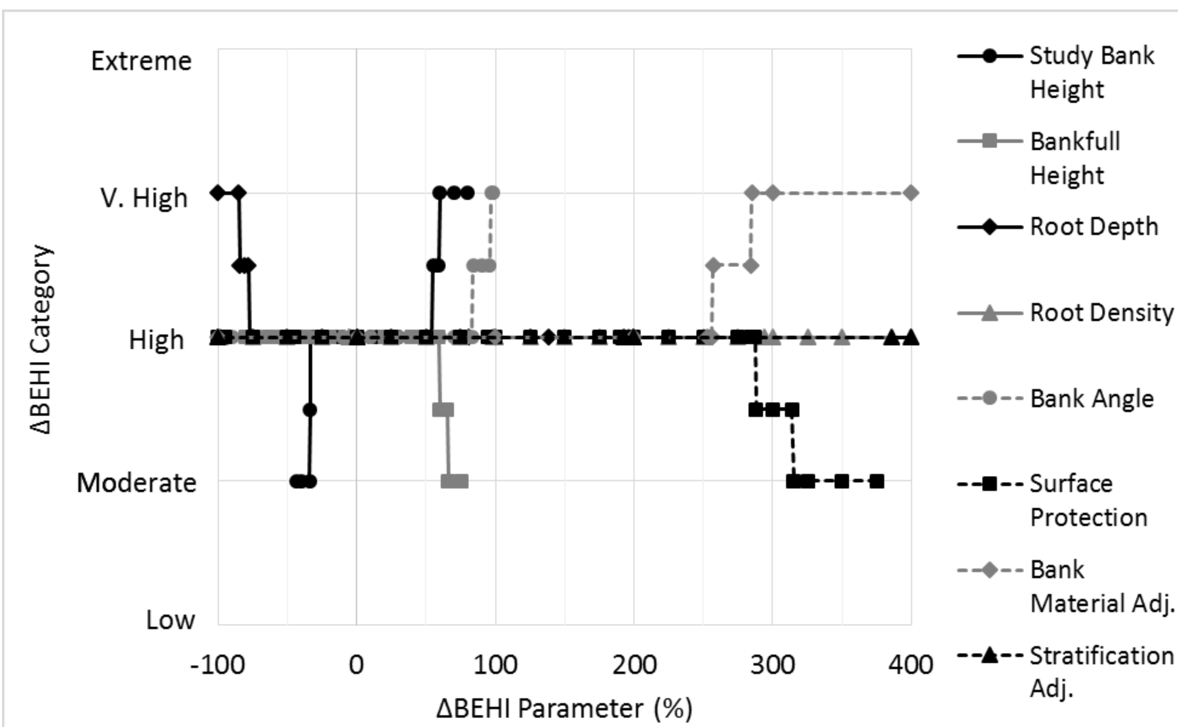


Figure 3.28 Lower West Emma Study Bank #2 Bank Erosion Hazard Index (BEHI) Parameter Sensitivity Function (Base Case BEHI Category: High)

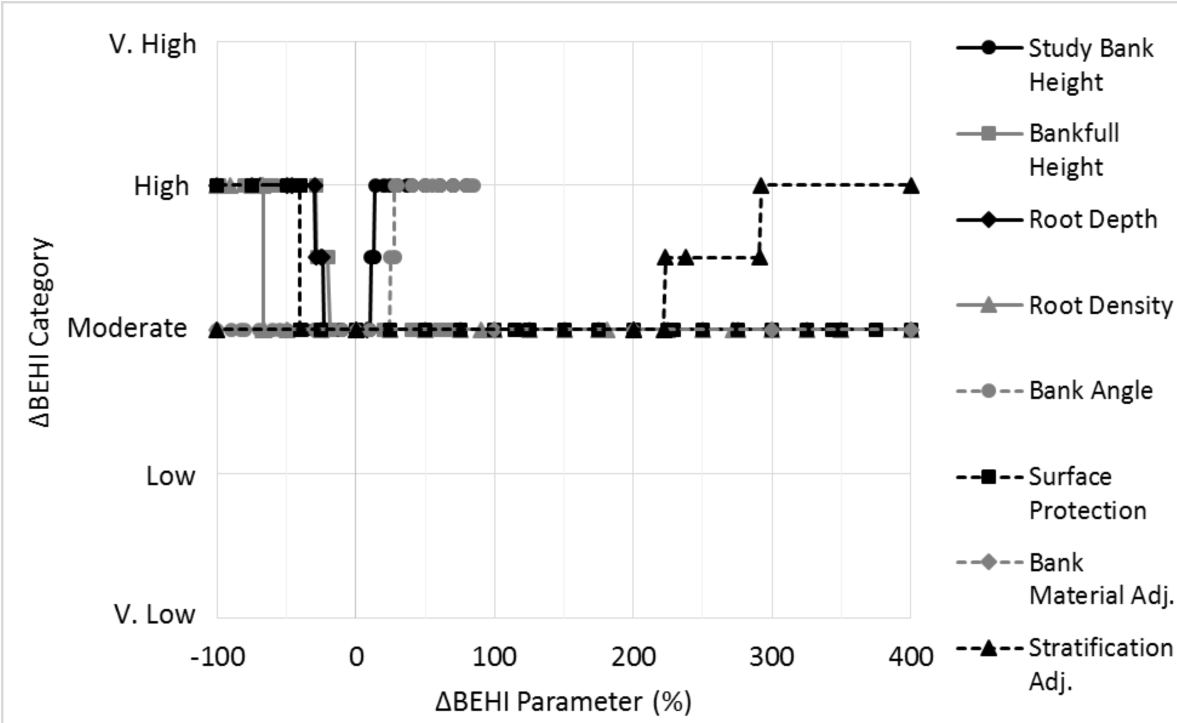


Figure 3.29 Lower West Emma Study Bank #3 Bank Erosion Hazard Index (BEHI) Parameter Sensitivity Function (Base Case BEHI Category: Moderate)

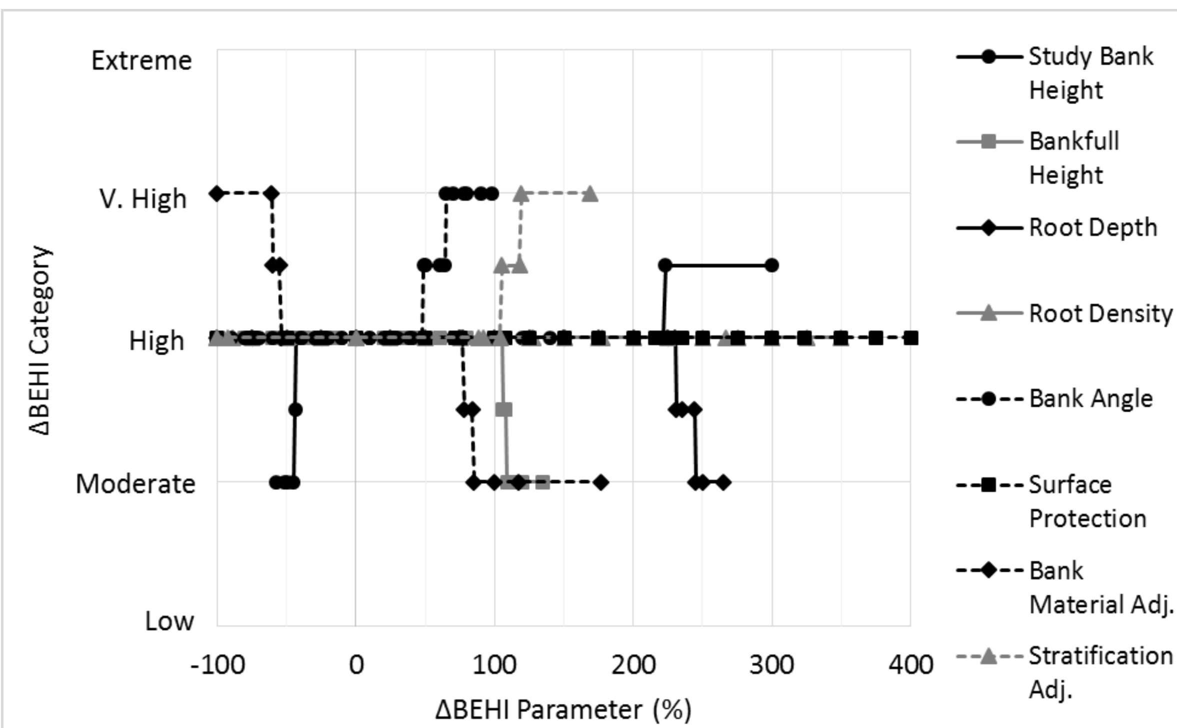


Figure 3.30 Middle Little Arkansas Study Bank #1 Bank Erosion Hazard Index (BEHI) Parameter Sensitivity Function (Base Case BEHI Category: High)

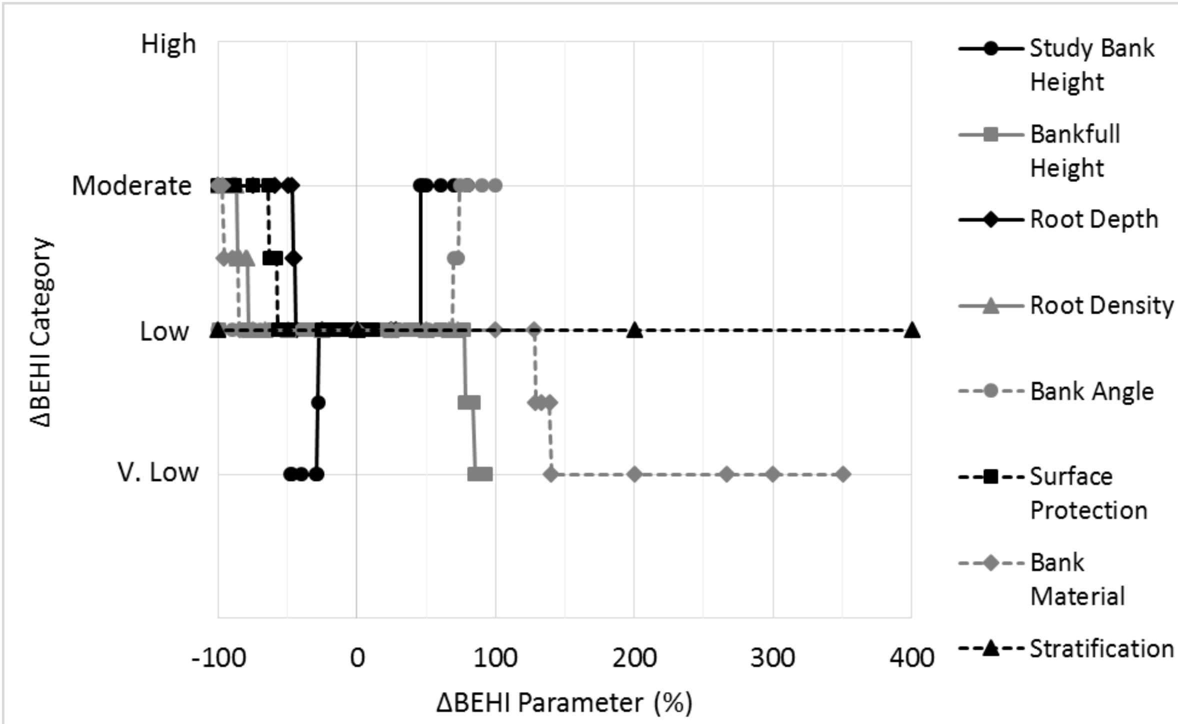


Figure 3.31 Middle Little Arkansas Study Bank #2 Bank Erosion Hazard Index (BEHI) Parameter Sensitivity Function (Base Case BEHI Category: Low)

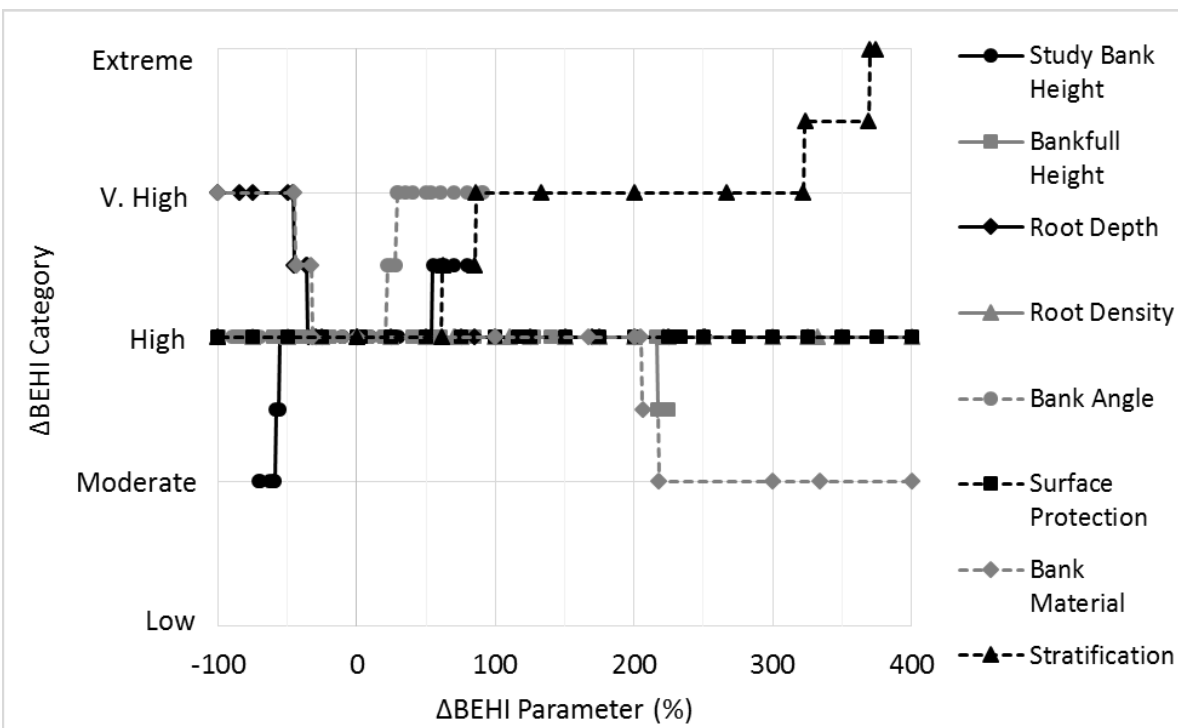


Figure 3.32 Middle Little Arkansas Study Bank #3 Bank Erosion Hazard Index (BEHI) Parameter Sensitivity Function (Base Case BEHI Category: High)

Table 3.8 Sensitivity Rankings for Bank Erosion Hazard Index (BEHI) Parameters per Study Bank

	LWE #1			LWE #2			LWE #3			MLA #1			MLA #2			MLA #3			Overall Mean		
BEHI Variable	R_1	R_2	R_{avg}	R_1	R_2	R_{avg}	R_1	R_2	R_{avg}	R_1	R_2	R_{avg}	R_1	R_2	R_{avg}	R_1	R_2	R_{avg}	R_1	R_2	R_{avg}
Study Bank Height	1	1	**1**	1	1	**1**	1	2	**1.5**	1	5	**3**	1	3	**2***	4	1	**2.5**	1.5	2.2	**1.8**
Bankfull Height	4	4	4	2	2	**2**	2	3	**2.5**	5	4	4.5	5	6	*5.5*	6	6	*6*	4	4.2	4.1
Root Depth	3	3	**3**	3	4	**3.5***	3	1	**2**	6	6	*6*	2	2	**2***	3	5	4*	3.3	3.5	**3.4**
Root Density	8	8	*8*	8	8	*8*	6	7	*6.5**	8	8	*8*	6	4	5	8	8	*8*	7.3	7.2	*7.3*
Bank Angle	2	2	**2**	4	3	**3.5***	4	4	4	2	2	**2***	4	5	4.5	1	2	**1.5**	2.8	3	**2.9**
Surface Protection	7	6	*6.5*	6	5	*5.5**	5	6	5.5	8	8	*8*	3	1	**2***	8	8	*8*	6.2	5.7	*5.9*
Bank Material Adj.	5	7	*6*	5	6	*5.5**	7	8	*7.5*	3	1	**2***	7	7	*7*	2	4	**3**	4.8	5.5	5.2
Stratification Adj.	6	5	5.5	7	7	*7*	8	5	*6.5**	4	3	3.5	8	8	*8*	5	3	4*	6.3	5.2	*5.8*

R_1: BEHI parameter ranking based on a minimum change in BEHI parameter that resulted in a change in BEHI category

R_2: BEHI parameter ranking based on the summation of positive percent change of BEHI parameter when BEHI category change occurs or a maximum is reached and negative percent change of BEHI parameter when BEHI category change occurs or a minimum is reached

R_{avg}: Average ranking

* represents tie

Cells with bolded text represent top 3 most sensitive parameters per bank; cells with italicized text represent top 3 least sensitive parameters per bank

Study bank height was determined to be the most sensitive BEHI parameter, as its R_{avg} ranking was in the top three most sensitive BEHI parameters for all six study banks. In other words, study bank height has the greatest influence on the final BEHI rating meaning a relatively small error in measurement may cause a shift in BEHI rating. Accurate study bank height measurement appears to be more critical for shorter banks (e.g. Lower West Emma) versus taller banks (e.g. Middle Little Arkansas), as shown by the steeper slopes of Lower West Emma polynomial sensitivity functions in Figure 3.33. Bank angle and root depth were also found to be sensitive BEHI parameters for four of the six study banks. Figure 3.34 shows the bank angle sensitivity function for all six study banks. Since bank angles of study banks ranged between 50 and 65 degrees, two hypothetical scenarios were input to measure sensitivity when bank angle was 30 degrees versus 100 degrees. Based upon these scenarios, it appears that the greater the bank angle, the more measurement accuracy is needed. Figure 3.35 shows that as root depth approaches study bank height, root depth measurement requires greater accuracy, as indicated by the steeper polynomial slopes of study banks where root depth to study bank height ratio is greater than 0.5.

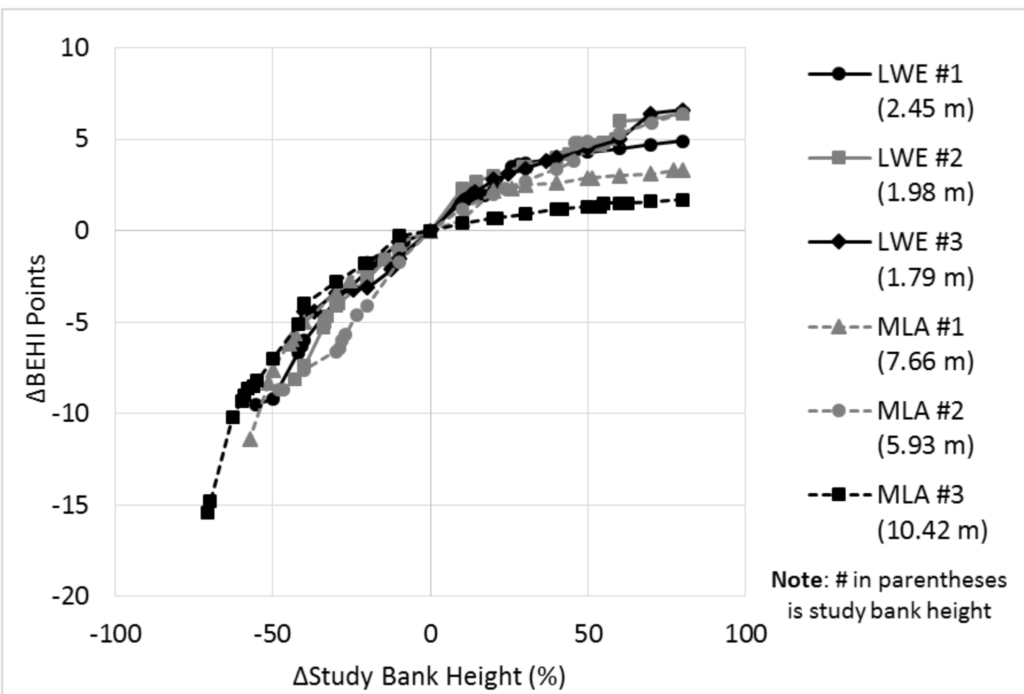


Figure 3.33 Study Bank Height Sensitivity Function for all Study Banks[12]

[12] LWE #: Lower West Emma Study Bank #; MLA #: Middle Little Arkansas Study Bank #

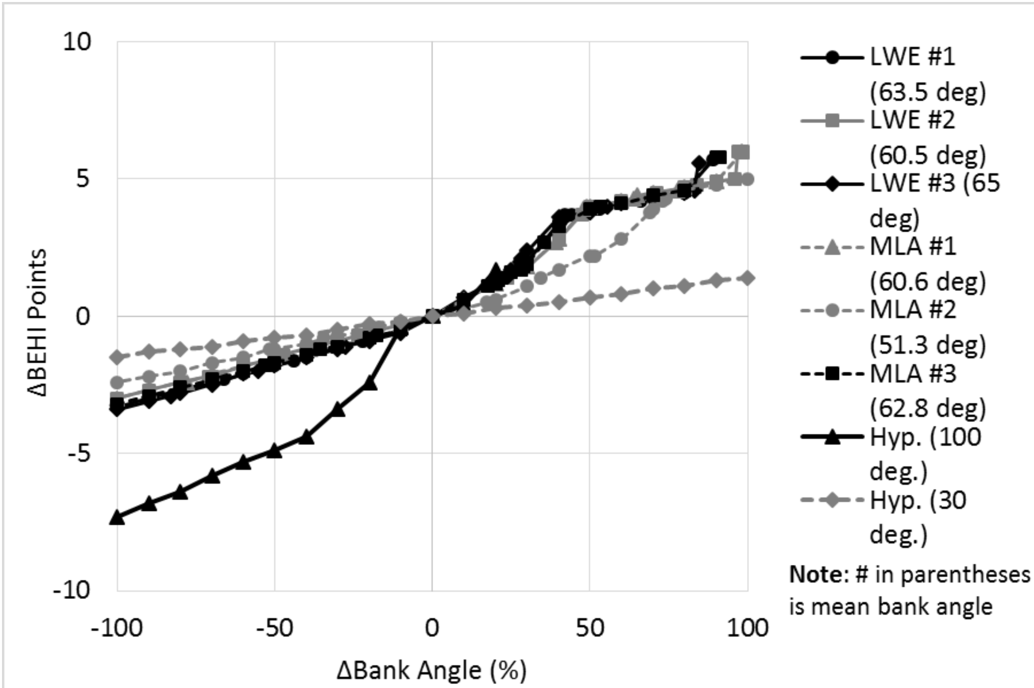


Figure 3.34 Bank Angle Sensitivity Function for all Study Banks[13]

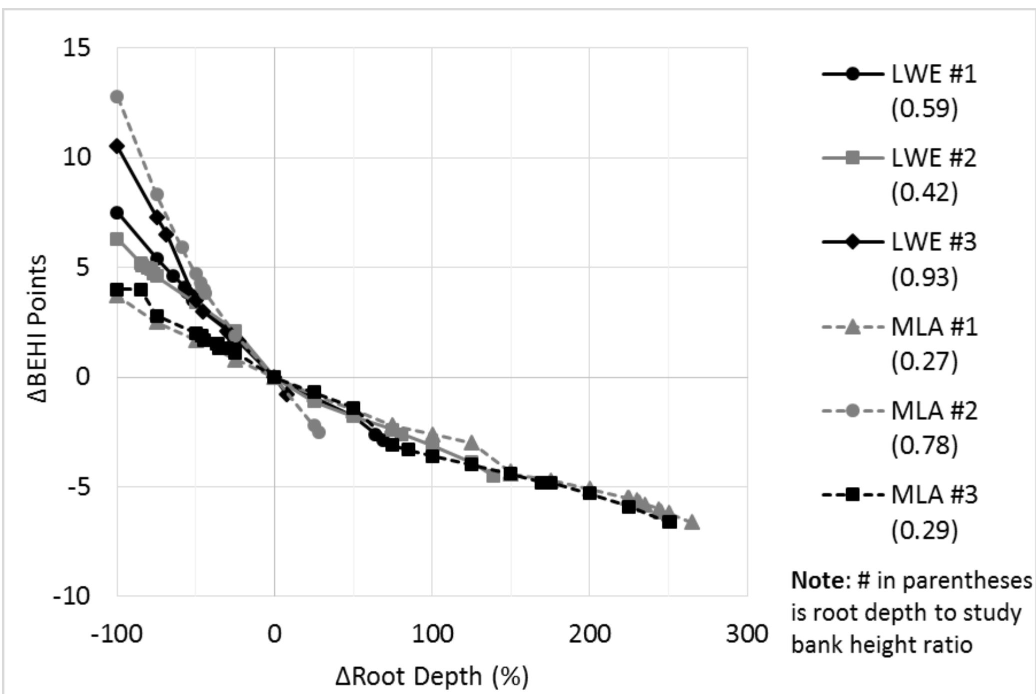


Figure 3.35 Root Depth Sensitivity Function for all Study Banks[13]

---

[13] LWE #: Lower West Emma Study Bank #; MLA #: Middle Little Arkansas Study Bank #; Hyp.: Hypothetical scenario

This sensitivity analysis was supplemented with the Kruskal-Wallis test which identified that a significant difference does exist among average sensitivity rankings (R_{avg}) with 95% confidence. Paired comparisons between parameter R_{avg} rankings using Tukey's HSD indicated that significant differences exist between study bank height and the stratification and bank material adjustment rankings, based on a Type I error rate of 5%. Study bank height had a lower R_{avg} of 1.8 while bank material and stratification adjustment had a higher rankings (i.e. less sensitive) of 5.2 and 5.8, respectively. Results of this analysis can be found in Appendix D.

Root density was found to be one of the least sensitive BEHI parameters, as it was ranked in the top three least sensitive parameters for five of the six study banks. This means that raters could often times be off by as much as three standard deviations or more from the actual root density and it did not affect the final BEHI category. It is noted that these five banks had low, mean root densities ranging from 8 to 16.3% while the bank where root density was not included in the top three least sensitive had a root density of 57.9%. This suggests that higher root densities may require more accurate measurement. Additionally, BEHI ratings for four of the six study banks were least impacted by changes to surface protection and the bank material adjustment. Like root density, surface protection was low (5.8 to 21.1%) for five of the six study banks. Alternatively, Middle Little Arkansas study bank #2 had a surface protection of 89.7% and ranked in the top three *most* sensitive parameters for that specific study bank. Again, this suggests that greater surface protection may require more accurate measurement. Figure 3.36 shows that the presence of bank material that requires an adjustment, such as sand or clay, necessitates more accurate identification to obtain properly adjusted BEHI ratings, as defined by the steep linear slopes of study banks where mean bank material adjustment was greatest.

Uncertainty rankings are presented in Table 3.9. The uncertainty of the bank material adjustment was determined to contribute the most to the uncertainty of the overall BEHI rating results, ranking at number one for all six study banks. This indicates that raters were least comfortable identifying and adjusting for bank material at each study bank which could also explain the wide range of BEHI ratings obtained by raters. Root depth and study bank height were also two BEHI parameters with great levels of uncertainty, ranking in the top three most uncertain BEHI parameters for five of the six study banks. This suggests that BEHI rating variability observed across raters could also be explained by poor measurement/estimation of study bank height and root depth, which are both sensitive parameters of the BEHI methodology that require accurate measurements.

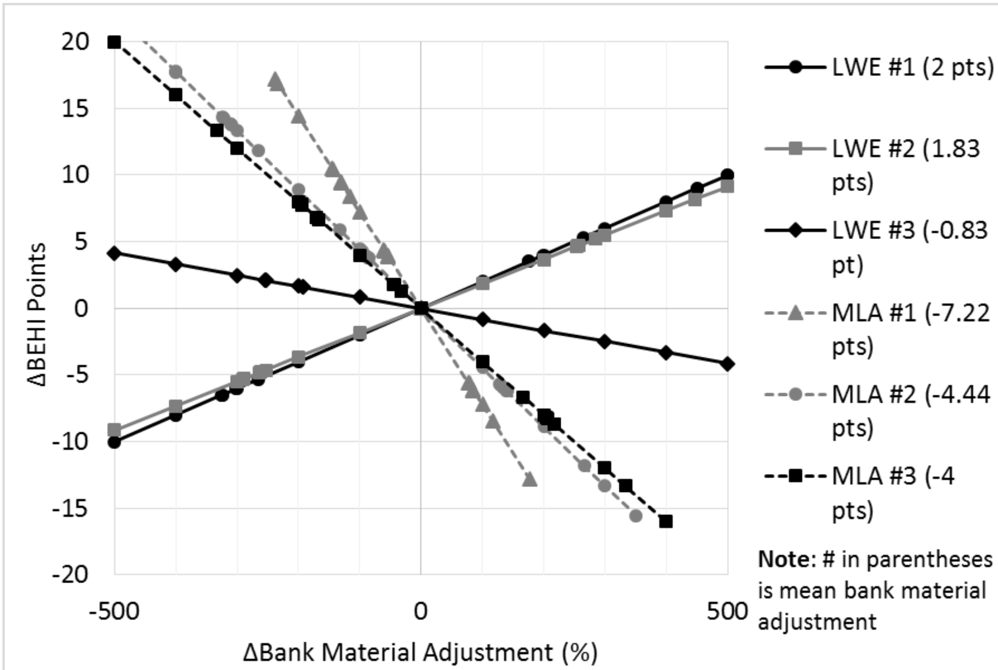


Figure 3.36 Bank Material Adjustment Sensitivity Function for all Study Banks[14]

Table 3.9 Uncertainty Rankings of Bank Erosion Hazard Index (BEHI) Parameters per Study Bank

	Uncertainty – Pts (Rank)						
BEHI Parameter	LWE #1	LWE #2	LWE #3	MLA #1	MLA #2	MLA #3	Overall Mean
Study Bank Height	*3.6 (7)*	**7.3 (3)**	**6.3 (3)**	**11.2 (2)**	**13.5 (3)**	6.3 (4)	**8 (3.7)**
Bankfull Height	*4.5 (6)*	5.8 (5)	**7.1 (2)**	*5 (6)*	8.3 (4)	*2.8 (7)*	5.6 (5)
Root Depth	**10.4 (2)**	**10.9 (2)**	*3.9 (8)*	8 (4)	**15.3 (2)**	**8.8 (2)**	**9.6 (3.3)**
Root Density	*1.7 (8)*	*2.2 (8)*	*5.1 (6)*	*1.1 (8)*	8 (5)	*1.5 (8)*	*3.3 (7.2)*
Bank Angle	5.3 (4[*])	*5.2 (6)*	6 (5)	7 (5)	*2.2 (6)*	*3.9 (6)*	*4.9 (5.2)*
Surface Protection	5.3 (4[*])	6 (4)	6.2 (4)	*2.5 (7)*	*1.3 (8)*	4.3 (5)	*4.3 (5.3)*
Bank Material	**19 (1)**	**17 (1)**	**19 (1)**	**29 (1)**	**24 (1)**	**27 (1)**	**22.5 (1)**
Stratification	**7 (3)**	*5 (7)*	*4 (7)*	**10 (3)**	*2 (7)*	**8 (3)**	6 (5)

Pts = BEHI points; LWE# = Lower West Emma Study Bank #; MLA # = Middle Little Arkansas Study Bank #; [*] represents tie; Cells with bolded text represent top 3 most uncertain parameters per bank; Cells with italicized text represent top 3 most certain parameters per bank

[14] LWE #: Lower West Emma Study Bank #; MLA #: Middle Little Arkansas Study Bank #; pts: points

Alternatively, root density was found to have the least impact on overall model uncertainty, as it was in the bottom three rankings of five of the six study banks. Once again, the bank that was not included in this group had a root density 3.5 times greater than the other five banks, suggesting that banks exhibiting higher root densities may result in greater levels of measurement uncertainty.

The Kruskal-Wallis test indicated that there is a significant difference between uncertainty rankings, based on a Type I error rate of 5%. Furthermore, the Tukey HSD identified the bank material adjustment uncertainty ranking to be significantly different than the root density ranking as well as the bankfull height, surface protection, bank angle, and stratification adjustment ranking, all of which had an average ranking of 5 or higher compared to the bank material average uncertainty ranking of 1. Appendix D provides the results from this analysis.

3.4.2.2 Near-Bank Stress (NBS)

According to Hamby (1994), the definition of a sensitive variable is one "which [has] significant influence on assessment results (p. 137)." Although a one-at-a-time design approach cannot be utilized to conduct a sensitivity analysis of the NBS methodology due to limited data, one may argue that NBS method selection has an effect on NBS rating results. Therefore, NBS method selection should not only be treated like an independent variable of the NBS methodology but as a sensitive, independent variable. Evidence to support this argument is presented in Table 3.10.

Table 3.10 Near-Bank Stress (NBS) Rating Results for Study Banks per NBS Method

Study Bank	NBS Method						
	#1	*#2*	*#3*	*#4*	*#5*	*#6*	*#7*
LWE #1	**Extreme**	**Extreme**	Very High	Very Low	Low	X	XX
LWE #2	X	Low	Very Low	Very Low	**High**	Very Low	XX
LWE #3	X	Very Low	**Extreme**	Very Low	Moderate	**Extreme**	XX
MLA #1	X	Very Low	Very Low	Very Low	**High**	Very Low	XX
MLA #2	High/Very High	Very High	**Extreme**	Moderate	Low	**Extreme**	XX
MLA #3	**Extreme**	**Extreme**	Low	Very Low	Moderate	Very Low	XX

X: Consensus among participants that this method did not represent site conditions
XX: Participants assumed this was not a feasible option
Bolded items indicate highest or dominant NBS rating at a given streambank.

This table demonstrates how variable NBS ratings can be across site-specific selected methods, assuming NBS parameters within each method were measured correctly. Variable NBS ratings were directly related to varying site conditions, further illustrating the need to use as many methods as possible to obtain the correct dominant NBS rating. For example, if a rater did not identify Method 5 as representative of the site conditions of Lower West Emma Study Bank #2, they would obtain a NBS rating of Very Low/Low which is off by two to three categories from the actual NBS rating of High. This is exhibited in Figure 3.14, where four ratings were determined to be in the Very Low and Low category. The percentage of raters who selected incorrect NBS rating method(s) per site and the maximum and minimum number of categories they were off by as a result, are presented in Table 3.11. This table suggests that selecting NBS methods based on site conditions is not only a sensitive parameter, but also is subject to user bias.

Table 3.11 Summary Statistics of Incorrectly Selecting Near-Bank Stress (NBS) Methods per Study Bank

Study Bank	Percentage of Raters Selecting Incorrect NBS Methods	Maximum # of NBS Categories Off	Minimum # of NBS Categories Off
Lower West Emma #1	39%	4	1
Lower West Emma #2	22%	3	2
Lower West Emma #3	50%	5	3
Middle Little Arkansas #1	17%	3	3
Middle Little Arkansas #2	56%	4	1
Middle Little Arkansas #3	11%	3	3

Furthermore, three of the four published BANCS models that only selected one NBS method to describe applied shear stress, other than method #7, obtained poor model fit (e.g. Harmel et al., 1999; Jennings & Harman, 2001; Markowitz & Newton, 2011; Patterson et al., 1999). Markowitz & Newton (2011) even acknowledged that the use of multiple NBS methods "may have produced a more accurate [NBS] rating (p. 29)." This further validates the argument that NBS method selection is a sensitive variable of the BANCS model.

3.5 Conclusions

A repeatability and sensitivity analysis was conducted on the BEHI/NBS methodology to address the criticism that the methodology is subjective, resulting in non-repeatable BEHI/NBS ratings, leading to both variable bank erosion rate prediction and BANCS models with poor fit. Based on findings in this study, the BANCS methodology may have repeatability issues when BEHI/NBS ratings are obtained by a single rater, supporting the argument that this methodology is subjective. However, study results indicate BEHI/NBS rating precision can be improved if:

- BEHI/NBS ratings are collected by at least two, preferably four, trained professionals to obtain ratings based on a measure of central tendency, i.e. mean of BEHI score or median of BEHI rating and mode (or maximum) of NBS,
- Sensitive BEHI parameters, such as study bank height, root depth and bank angle, and uncertain BEHI parameters, such as bank material, are measured and adjusted for accurately, and
- All reasonably possible NBS methods that are representative of site conditions are utilized to obtain the dominant NBS rating.

It is expected that if future BANCS model users implement these suggestions, the margins of error for obtaining precise BEHI/NBS ratings would decrease. This expectation should be investigated in subsequent research. In addition to this, a replicated BEHI sensitivity analysis should occur in order to determine if the same BEHI parameters are sensitive in other hydrophysiographic regions. A sensitivity analysis of independent variables within each site-specific, user-selected NBS method should also be evaluated based on data obtained by several individual raters and/or groups of raters, as this type of analysis was not conducted in this study and could yield additional insights to improve repeatability of the BANCS methodology. Furthermore, current NBS methods should be examined to determine if each method is accurately estimating near-bank stress or if alternate methods should be utilized instead. A detailed field methodology for bank material identification and adjustment, such as a soil ribbon protocol, should also be created to eliminate the uncertainty of this parameter, especially on banks composed primarily of silt and/or clay, and expedite soil texture analysis. Finally, future studies should examine the effect of seasons on BEHI/NBS ratings in temperate regions of the globe, especially regions with deciduous, riparian forests, to determine if time of year has an effect on the variability of BEHI/NBS ratings.

Chapter 4 - Examination of the Developmental Process of a Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model

4.1 Introduction

Excess sediment is the second leading cause of stream impairment in the United States (U.S. EPA, 2016), resulting in poor water quality, damage to aquatic ecosystems, and sedimentation of downstream waterbodies, such as federal reservoirs. Sediment is a non-point source pollutant, but several case studies have identified accelerated stream degradation and bank erosion as the main contributor of sediment in some impaired watersheds (Belmont et al., 2011; Bull, 1997; Kronvang et al., 1997; Mukundan et al., 2010; Rondeau et al., 2000; Trimble, 1997; Wilson et al., 2008).

Although streambank erosion is natural and an essential component to aquatic ecosystems (Florsheim et al., 2008), drastic changes in regional climate and watershed land use, type, and/or management can create stream instability that results in both physical and biological degradation. Stream instability causes accelerated bank erosion and channel degradation and/or aggradation, as the stream works to change its dimensions, pattern, and profile to reach a dynamic equilibrium under new discharge and/or sediment conditions. Therefore, it is essential to identify and quantify streambank erosion in sediment-impaired watersheds, especially those that have been influenced by anthropogenic processes and extreme natural events.

Because streambanks are typically not composed of homogenous materials and do not experience the same hydrologic events every year, it is very difficult to estimate and predict streambank erosion (Bull, 1997). Nevertheless, various methods have been developed to assist in the calculation of the sediment yield that originates from streambank erosion. One such method is the development of an empirically-derived “Bank Assessment for Non-Point Source Consequences of Sediment” (BANCS) model for a specific hydrophysiographic region. The BANCS model methodology was developed by Rosgen (2001) as part of the overall watershed assessment tool, Watershed Assessment for River Stability & Sediment Supply (WARSSS), which is used to comprehensively investigate sediment sources. A BANCS model is a process-integrated streambank erosion rate prediction curve that allows rapid estimation of annual streambank erosion rates, in unit length per year. A curve is developed solely on empirical relationships of streambank physical properties and estimated localized shear stress, as reflected by the two model parameters: (1) the Bank Erosion Hazard Index (BEHI), and (2) the Near-Bank Stress (NBS) rating. The BEHI provides an adjective rating of bank erodibility based on visual and measured assessment of a streambank of interest, while the NBS rating provides an adjective rating of the amount of applied shear stress induced by the outer one-third of the channel flow adjacent to the eroding bank of interest (Rosgen, 2009).

Ten BANCS models have been developed and published, with varying degrees of success, across numerous hydrophysiographic or ecoregions in the United States (see Figure 2.17) and eastern India. A developed BANCS model is limited to the:

- Hydrophysiographic region in which it was developed (Rosgen, 2001; Rosgen, 1996; Rosgen, 2009) and
- Streamflows that occurred during the curve development stage (Van Eps et al., 2004).

A BANCS model may also be limited to the accuracy of the erosion rate measurement technique utilized to create the model (Lawler, 1993a).

Like any other empirically-derived model that attempts to explain and estimate natural processes, the BANCS model has also been criticized. Criticisms of the BANCS model include:

- Creation is time-consuming (Rosgen, 2009) and time would be better spent improving and/or utilizing more robust, physically-based models (Doyle & Harbor, 2000);
- Methodology may need to be adjusted for specific hydrophysiographic regions (Harmel et al., 1999; Markowitz & Newton, 2011; Sass & Keane, 2012);
- Implementation may be subjective, such as bankfull identification (Coryat, 2011; Johnson & Heil, 1996; Juracek & Fitzpatrick, 2003; Markowitz & Newton, 2011; Rathbun, 2011; Roper et al., 2008; Simon et al., 2007; Williams, 1978); and
- Implementation and prediction of streambank sediment loss as an average length per year masks the spatiotemporal variability of streambank erosion (Lawler et al., 1999).

In addition to these criticisms, it appears that lack of a detailed procedure for developing new curves could contribute to the wide variability observed in published curves. Methods and factors that vary amongst developed BANCS models include:

- Number of streambank sites employed;
- Number of years streambank erosion data is collected;
- Streamflows experienced;
- NBS method(s) applied; and
- Streambank erosion measurement method implemented.

Differences between created models are summarized in Table 2.2. Although the lack of a detailed procedure to develop a BANCS model has never been directly criticized, several creators of the BANCS models identified some or all of these unknown methods and/or factors as a primary cause of the high variability that they observed in their results (e.g. Coryat, 2011; Harmel et al., 1999; Jennings & Harman, 2001; Markowitz & Newton, 2011; Patterson et al., 1999).

In this chapter, the developmental process of a BANCS model was examined through the creation of a streambank erosion rate prediction curve for the Little Arkansas River watershed located in the Central Great Plains ecoregion. Results from the repeatability and sensitivity analyses (See Chapter 3) were applied to this model creation process with the objective of improving BANCS model development.

4.2 Study Area Description

The Little Arkansas River watershed (HUC 11030012), shown in Figure 4.1, is located in south-central Kansas and drains 3,693 km^2 (USGS, 2014). According to Kansas Department of Health and Environment (KDHE), the Little Arkansas River is impaired by excess total suspended solids (TSS), threatening aquatic ecosystems (KDHE, 2014). As defined by the U.S. EPA, TSS includes sediment particles of silt and clay, algae, plankton, fine organic debris, and other particulate matter (U.S. EPA, 2012).

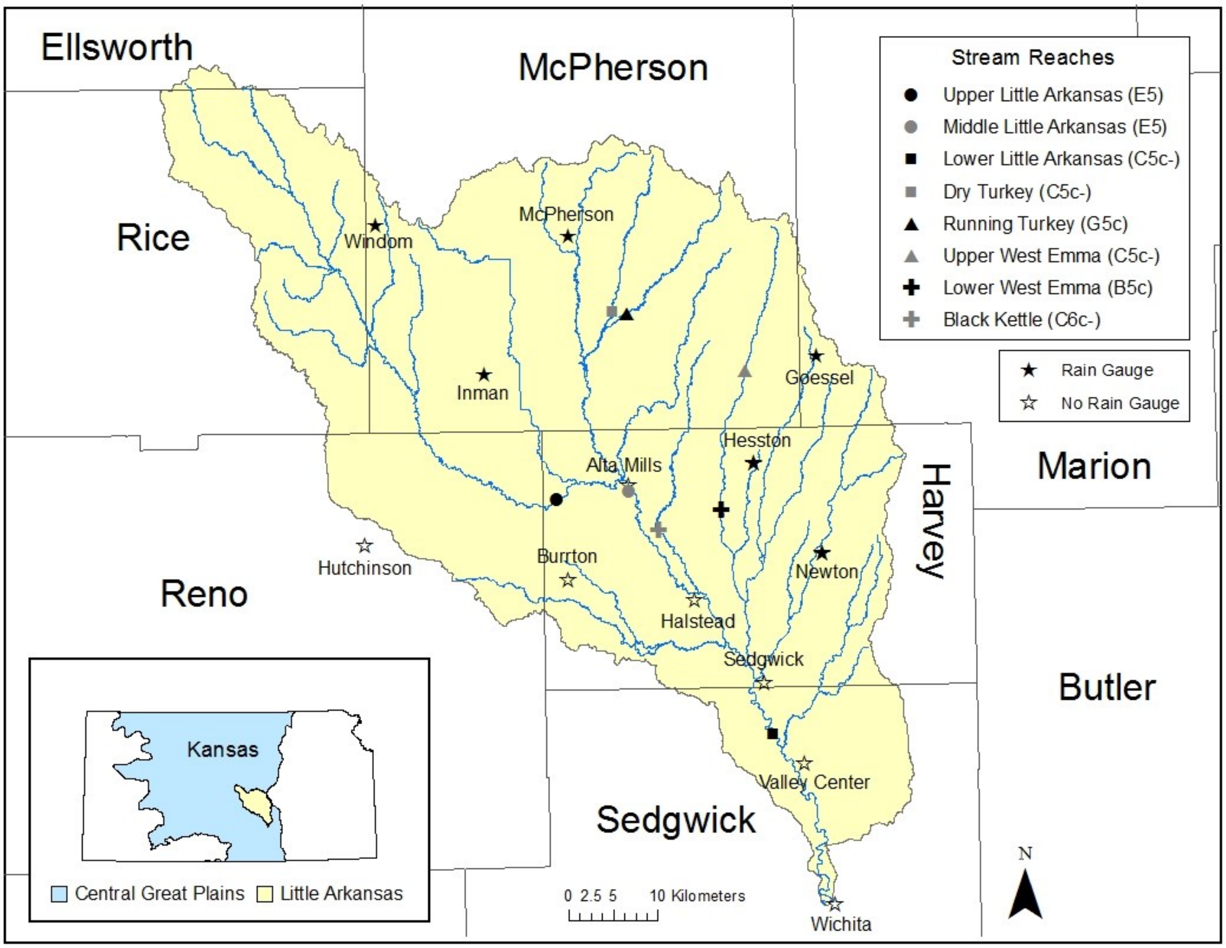


Figure 4.1 Study Stream Reach Locations with Rosgen Stream Reach Classification (Rosgen, 1996b) and Rain Gauge Locations within the Little Arkansas River Watershed, located in the Central Great Plains Ecoregion of South-Central Kansas

Excess TSS in the Little Arkansas may be increasing water treatment costs downstream as well. Water from the Little Arkansas River is used to artificially recharge the Equus Beds aquifer, located in the southwestern portion of the Little Arkansas River watershed, as shown in Figure 4.2. The Equus Bed aquifer is part of the High Plains aquifer and is used to supply water to the City of Wichita, Kansas. Because the City was expected not to meet its water demand by 2010, another source of water had to be established (Warren, Blain, Shorney, & Klein, 1995). As a solution to this problem, the artificial recharge system of the Equus Beds aquifer was implemented in 2013. The river water must first be treated to remove sediment and atrazine before it is injected into the aquifer (Ziegler, 2014). Greater sediment loads results in greater operational costs.

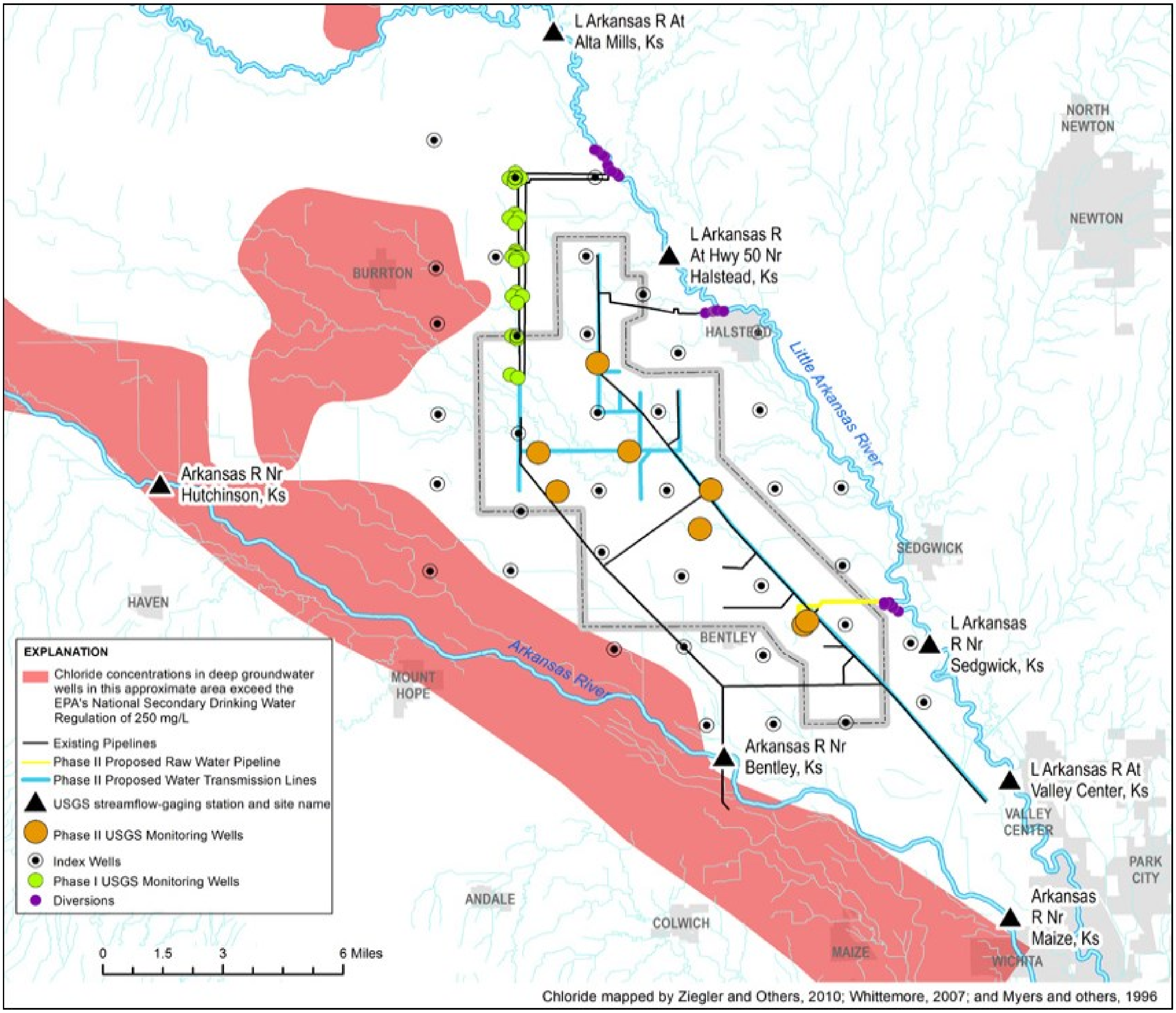


Figure 4.2 Equus Beds Groundwater Recharge Project (Ziegler, 2014)

The Little Arkansas watershed is located in the Central Great Plains ecoregion, with the majority in the Wellington-McPherson Lowland, the very north portion of the watershed in the Smoky Hills and a small, northwestern portion in the Great Bend Sand Prairie. The watershed was once mixed-grass prairie but is now dominated by cropland (Chapman et al., 2010).

Eighteen study banks on eight reaches of various streams within the Little Arkansas River watershed were selected to develop a regional BANCS model, in an attempt to quantify and predict streambank erosion rates. Drainage areas for selected stream reaches vary from 79 to

3,334 sq. km. Rosgen stream classifications were obtained for each stream reach (Rosgen, 1996b). Stream classification worksheets can be found in Appendix A. The majority of the reaches classified as a C5/6c- stream type, or a meandering, low-gradient (c-), sand-bed (5) or clay-bed (6) stream that is slightly entrenched, with a riffle-pool sequence and a well-developed floodplain. Two stream reaches classified as an E5 stream type or a sinuous sand-bed stream with a flat gradient, very low bankfull width-to-bankfull mean depth ratios, a riffle-pool sequence, and a well-developed, connected floodplain. Another reach classified as a B5c or a sand-bed stream that is moderately entrenched with a flat gradient (c) and a narrow valley. The final reach classified as a G5c or an unstable, entrenched, sand-bed stream with a low gradient (c) and a low bankfull width-to-bankfull mean depth ratio with a high sediment detachment and transport capacity (Rosgen, 1996b). Streambank erosion data, through either bank profile surveys or bank pin measurements, were collected from each study bank for as many as ten years (2006-2016) to one year (2015-2016). A summary of study bank reach characteristics are provided in Table 4.1 below.

Table 4.1 Little Arkansas River Watershed, Stream Reach and Study Bank Characteristics

Stream Reach	HUC	Drainage Area (km^2)	Rosgen Stream Classification	# of Study Banks	Study Period
Upper Little Arkansas (ULA)	1103001201	868	E5	2	2015-2016
Middle Little Arkansas (MLA)	1103001203	1,922	E5	2	2015-2016
Lower Little Arkansas (LLA)	1103001204	3,334	C5c-	3	2015-2016
Dry Turkey (DT)	110300120206	98	C5c-	2	2006-2016
Running Turkey (RT)	110300120207	93	G5c	2	2006-2016
Upper West Emma (UWE)	110300120401	125	C5c-	3	2006-2016
Lower West Emma (LWE)	110300120402	223	B5c	2	2006-2016
Black Kettle (BK)	110300120302	78	C6c-	2	2006-2009*

* Bank pins and/or toe pins not found, unable to re-survey after 2009

Geology and soils vary throughout the Little Arkansas River watershed. The land surface is comprised of sedimentary rocks of the Permian, Cretaceous, and Quaternary age. Consolidated rocks include shale, limestone, sandstone, and siltstone. Unconsolidated rocks include fluvial-deposited and wind-deposited silt and sand. The southwest portion of the Little Arkansas River watershed consists of sand dunes; the remainder of the watershed is comprised of less permeable silt and sandy-silt materials and some deposits of clay (Albert & Stramel, 1966). Soil samples from each study bank were collected and analyzed using the hydrometer method (College of Agriculture and Life Sciences - University of Wisconsin, 2004) to characterize study bank soil textures. While soil textures throughout the profile of any given study bank ranged from sand to clay, the majority of study bank layers classified as loam, sandy loam, or silt loam. Stratified bank layers of sandy loam with clay and clay loam materials occurred on the Lower and Upper West Emma and Lower Little Arkansas stream reaches. Streambanks with moderate to high percentages of clay (> 30%) were found on the Lower and Upper West Emma, Middle Little Arkansas, Dry Turkey, and Black Kettle stream reaches while streams with high percentages of sand (> 60%) were found on the Upper and Lower Little Arkansas and Upper and Lower West Emma stream reaches. Soil texture analysis of study banks can be found in Appendix G.

The climate in this region is classified as hot summer continental (Dfa), with hot, humid summers and cold winters (Peel et al., 2007). The average precipitation occurring in this region ranges from 690 mm in the west to 860 mm in the east, with the majority of the precipitation falling in the spring and summer months (NRCS, 2007). During the study period, precipitation ranged from 540 mm in 2012 to 1,050 mm in 2007, averaged across six rain gauge locations within the watershed. Five years experienced above average precipitation, four years below average, and one year near average. Precipitation data is summarized in Table 4.2. Notably wet months that occurred during the study period were in the months of May 2007 (256 mm avg.), July 2013 (250 mm avg.), August 2013 (240 mm avg.), June 2014 (233 mm avg.), and May 2015 (215 mm avg.). Precipitation received during these months were, in most cases, more than double the monthly average.

Table 4.2 Precipitation Data for the Little Arkansas River Watershed (mm) over period of provisional BANCS Model Development (ACIS, 2016)

	Year									
Location	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Windom	603.8	992.4	810.0	785.6	682.0	537.0	553.0	1019.6	767.8	800.4
Inman	676.1	1200.9	899.4	787.7	814.3	-	562.1	1011.4	697.7	818.9
McPherson	644.4	1133.1	903.7	950.2	-	610.6	461.8	927.9	-	-
Hesston	-	-	951.7	905.3	792.5	-	-	1155.7	707.9	999.5
Goessel	573.8	1056.4	827.0	-	883.9	541.8	461.8	927.1	642.1	1036.1
Newton	-	851.9	980.4	-	795.8	506.5	643.9	1040.1	798.8	1033.5
Average	**624.5**	**1046.9**	**895.4**	**857.2**	**793.7**	**549.0**	**536.5**	**1013.6**	**722.9**	**937.7**

The reoccurrence interval of the bankfull discharge at the Alta Mills USGS stream gage (USGS 07143665) located on the Little Arkansas River near the middle of the watershed was determined to be 1.5-years based upon field indicators, regional curves (See Appendix C), and a Log-Pearson Type III Distribution flood frequency analysis. The 1.5-year reoccurrence interval discharge is 2,826 cfs for the Alta Mills reach. The flood frequency plot for the Alta Mills USGS gage, at which 42 years of annual peak flow data have been collected continuously since 1973, is shown in Figure 4.3. During the study period, daily peak flows ranged from 0 cfs in the drought years of 2011 and 2012 to 7,800 cfs (3.1-year return interval) during the wet year of 2007. Figure 4.4 through Figure 4.6 show the daily maximum recorded discharges at the Alta Mills USGS gage from January 2006 to April 2016 (USGS, 2016). Flows recorded over this 11-year period were near (>1.3-year return interval of 2,000 cfs), equal to or exceeded the 1.5-year return interval discharge twenty-five times. In August of 2013, flow exceeded 1,000 cfs for twenty-two days straight. In 2007, flows exceeded 2,000 cfs (>1.3-year return interval) seven times. Table 4.3 summarizes these discharges.

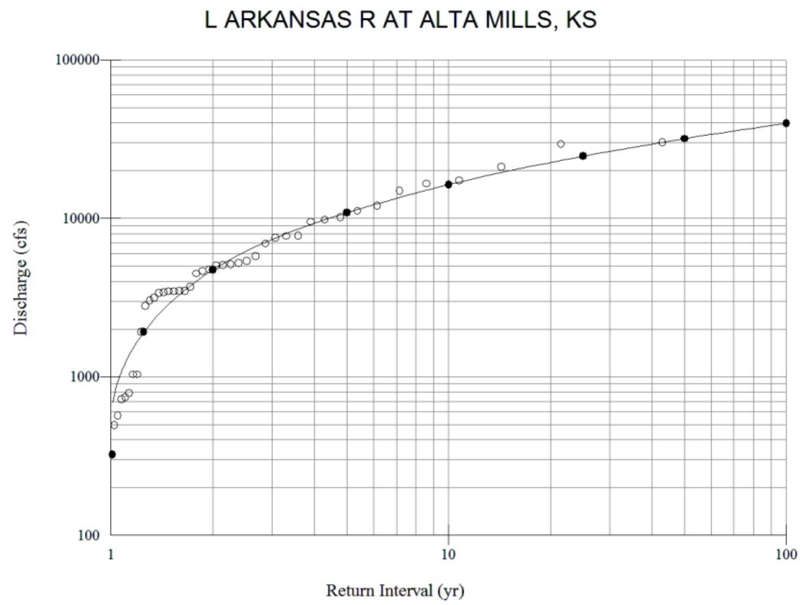


Figure 4.3 Log Pearson Type III Distribution Flood Frequency Analysis for Little Arkansas River at Alta Mills, KS (1973-2015)

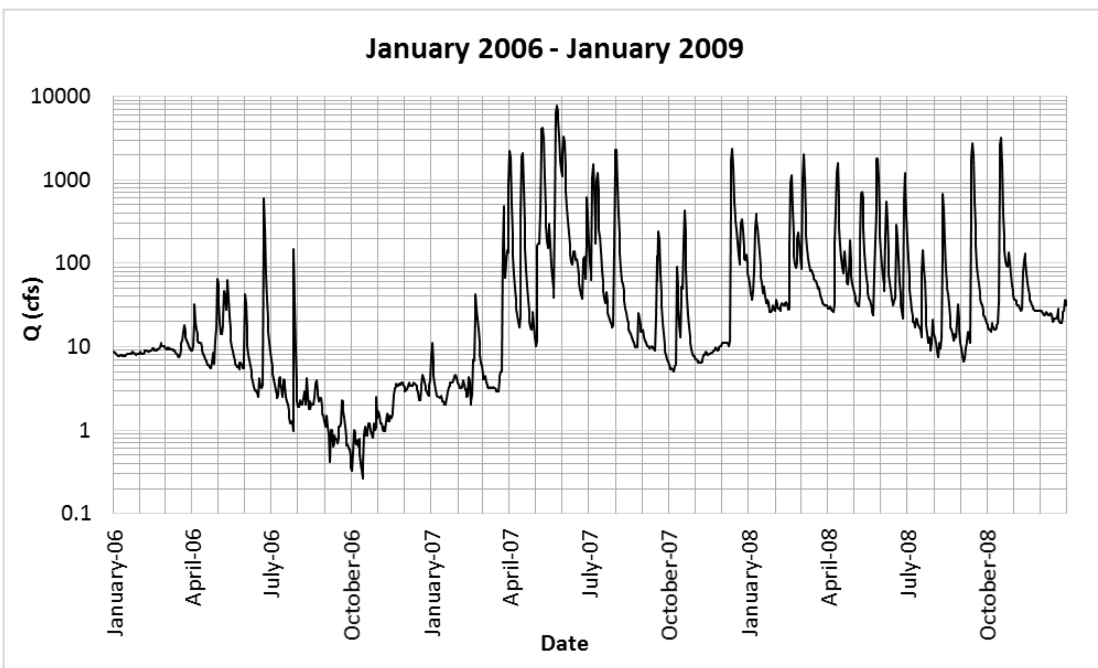


Figure 4.4 Daily Maximum Discharge (cfs) for January 2006 – January 2009 at the Alta Mills USGS Gage (USGS 07143665)

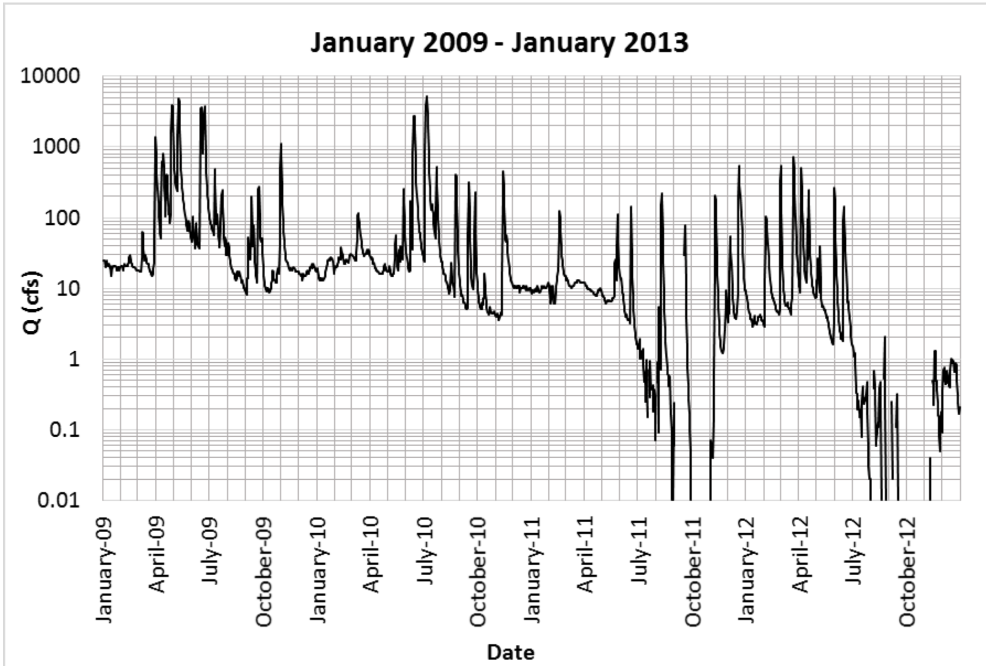


Figure 4.5 Daily Maximum Discharge (cfs) for January 2009 – January 2013 at the Alta Mills USGS Gage (USGS 07143665)

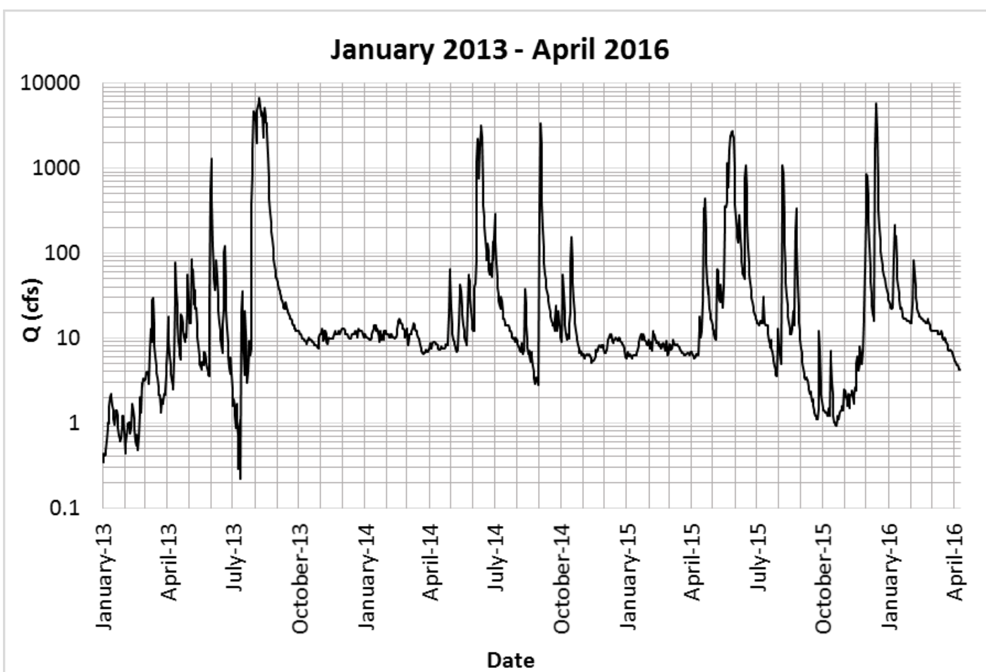


Figure 4.6 Daily Maximum Discharge (cfs) for January 2013 – April 2016 at the Alta Mills USGS Gage (USGS 07143665)

Table 4.3 Runoff Events At, Near[15] or Exceeding the 1.5-year Reoccurrence Interval Discharge (2,826 cfs) at the Alta Mills USGS Gage (USGS 07143665)

	Event	Maximum Discharge (cfs)	Return Interval (yr)
1	4/1/2007	2230	1.4
2	4/16/2007	2080	1.4
3	5/9/2007	4250	1.9
4	5/25/2007	7800	3.1
5	6/2/2007	3250	1.6
6	8/1/2007	2310	1.4
7	12/13/2007	2390	1.4
8	3/4/2008	2010	1.3
9	9/14/2008	2740	1.5
10	10/17/2008	3240	1.6
11	4/29/2009	3940	1.8
12	5/10/2009	4850	2
13	6/18/2009	3660	1.7
14	6/23/2009	3840	1.7
15	6/16/2010	2760	1.5
16	7/6/2010	5160	2.1
17	7/30/2013	4690	1.9
18	8/7/2013	6660	2.6
19	8/10/2013	4700	1.9
20	8/14/2013	5190	2.1
21	6/7/2014	2200	1.4
22	6/12/2014	3140	1.6
23	9/3/2014	3350	1.6
24	5/28/2015	2730	1.5
25	12/15/2015	5800	2.5

4.3 Methods

To create a BANCS model for the Central Great Plains Ecoregion, three items were collected at each study bank: (1) the Bank Erosion Hazard Index (BEHI), (2) the Near-Bank Stress (NBS) rating and, (3) measured annual bank erosion rates (unit length/year). The BEHI provides an adjective rating or scored ranking of bank erodibility based on visual and measured assessment of a streambank of interest (Rosgen, 2009). Seven variables comprise the BEHI method to develop an overall BEHI score and rating. These variables are defined as follows:

---

[15] >1.3-year return interval of 2,000 cfs

1) Study Bank Height-to-Bankfull Height Ratio (Ranking of 1 to 10 points): Height to the top of the bank divided by the bankfull height. This ratio adjusts for scale and identifies possible channel degradation which may result in accelerated bank erosion. The closer the ratio is to one, the more likely the channel is not degrading and the lower the risk of erosion.
2) Root Depth-to-Study Bank Height Ratio (Ranking of 1 to 10 points): Prevailing root depth divided by the height to the top of the bank. This measures streambank reinforcement from roots and may identify possible channel degradation. The closer the ratio is to one, the greater the stability of the streambank.
3) Weighted Root Density (Ranking of 1 to 10 points): Estimated percentage of root density multiplied by the root depth-to-study bank height ratio. Higher densities of root mass provide greater bank cohesion. Therefore the greater the density, the less risk to erosion.
4) Bank Angle (Ranking of 1 to 10 points): Measured in degrees. Greater bank angles result in a higher risk of bank instability caused by the gravitational force on the streambank.
5) Surface Protection (Ranking of 1 to 10 points): Percentage of streambank surface protected by vegetation, woody debris, large rock, etc. The greater the percentage of protection, the lower the risk of streambank erosion.
6) Bank Material Adjustment: Adjust the final BEHI score from the addition of rankings obtained from variables 1 through 5 by -20 points to +10 points based upon bank material. The presence of bedrock and boulder bank materials results in an automatic final BEHI score of 0-19.5 points which means that these banks have the lowest erosion potential. Points may be added to the score if the material in the bank is considered to be highly erodible, such as gravel or composite matrix and sand. Points may be subtracted from the score if the bank material is highly resistive to erosion such as medium to large cobble and banks with high amounts of clay.
7) Stratification of Bank Material: Adjust the final BEHI score from the addition of rankings obtained from variables 1 through 6 by up to +10 points based upon the presence and type of bank material layers that may be subject to piping or entrainment (Rosgen, 2009).

Point rankings obtained from variables 1 through 7 are summed to obtain a final BEHI score and then are converted to a BEHI rating. BEHI ratings of a particular streambank can be Very Low (0-9.5 points), Low (10-19.5 points), Moderate (20- 29.5 points), High (30-39.5 points), Very High (40-45 points), and Extreme (46-50 points), where the latter would represent a streambank highly susceptible to bank erosion due to streambank physical properties. A BEHI worksheet is available to assist in compiling measurement data, converting these measurements/ratios to BEHI scores, and obtaining a final BEHI rating. Figure 2.5 and Figure 2.6 provide a sample BEHI worksheet and the measurement/ratio conversion graphs necessary to obtain a BEHI score, respectively (Rosgen, 2009).

The NBS rating provides an adjective rating of the amount of fluvial force (or applied shear stress) induced by the outer one-third of the channel flow adjacent to the eroding bank of interest (Rosgen, 2009). NBS ratings can be divided into 6 categories ranging from Very Low to Extreme, where an "Extreme" NBS rating represents the greatest applied shear stress on a given bank. There are seven methods that can be used to determine the NBS rating and are ordered with increasing level of detail and resources needed to complete the method. They are as follows:

1) Presence of Transverse/Central Bars or Channel Pattern Changes
2) Radius of Curvature-to-Bankfull Width ratio
3) Pool Slope-to-Average Water Surface Slope ratio
4) Pool Slope-to-Riffle Slope ratio
5) Near-bank Maximum Depth-to-Bankfull Mean Depth ratio
6) Near-bank Shear Stress-to-Bankfull Shear Stress ratio
7) Velocity Isovels (Rosgen, 2009)

The field practitioner selects one or several of these methods that best represent the site conditions and then uses the highest (not the average) of these ratings as the dominant near-bank stress (Rosgen, 2009). A NBS worksheet is also available to assist in compiling measurements and converting methods into NBS ratings. The NBS worksheet is shown in Figure 2.12.

BEHI and NBS ratings of all study banks used in the Central Great Plains ecoregion BANCS model were obtained only once in 2015 or 2016. Based on the results obtained in Chapter 3, to reduce the subjectivity inherent to obtaining BEHI/NBS ratings, BEHI and NBS ratings were obtained by a minimum of two field personnel with at least one having Rosgen Level III training. Surveying equipment was used to accurately measure study bank height, the most sensitive BEHI parameter. Also, bank material uncertainty was decreased by obtaining soil samples along the profile at different bank layers. Bank materials were retrieved from the exposed surface of the bank with a hand trowel. These soil samples were analyzed in the lab using the hydrometer method to obtain soil texture (College of Agriculture and Life Sciences – University of Wisconsin, 2004). In addition to the adjustments for clay presented by Rosgen (2014) and suggested by Stantec (2013), if bank material was >30% clay along the majority of the bank profile, five points were subtracted from the final BEHI score. Bank material results are presented in Appendix G. To guarantee proper selection of NBS methods, most methods were utilized when determining NBS ratings, unless it was obvious that a given method was not representative of the site conditions. NBS Method 7 was not utilized due to lack of equipment available to obtain velocity measurements and the danger inherent to retrieving velocity measurements during high flow events.

The last item needed to create a BANCS model for the Central Great Plains ecoregion is average annual bank erosion rates of each study bank. Eleven of the eighteen study banks were installed in 2006 and measured, typically on an annual basis, until 2009 and then again in 2015 and 2016, if toe pins or bank pins were located. Of these eleven study banks, four were monitored utilizing bank pins to measure streambank erosion rates while the remaining seven were surveyed using the repeated cross profiling technique for short banks, hereon denoted as the "low bank" cross profiling technique. Both of these techniques are described below.

Bank pins installed along study banks in the Little Arkansas River watershed consisted of 1.3 cm diameter by 1.2 m long steel rebar pins hammered flush with the bank. After a given time period, the exposed portion of the bank pin was measured to obtain bank retreat rates. Once a pin has been measured and recorded, it could then be hammered flush with the study bank for future measurements. To increase accuracy of erosion rate measurements, at least two bank pins were installed per study bank where repeated bank profiles were not conducted (roughly 1 bank pin every 30 cm vertical). Average bank retreat rates using bank pin measurements were calculated using Equation 11.

$$Average\ Bank\ Retreat\ (m/yr) = \frac{Average\ Exposed\ Bank\ Pin\ Length\ (m)}{Time\ (yr)} \qquad \text{(Eq. 11)}$$

Repeated cross profiles, or bank profiles, require a permanent, monumented cross section, typically through installation of, at the minimum, a 1.3 cm x 1.2 m long rebar pin with a cap located at or near the toe of the study bank, also known as a toe pin. The low bank (2 m tall or less) cross profiling technique requires the installation of a toe pin. A survey rod is then placed plumb on the toe pin allowing the bank to be "profiled" by taking level, horizontal measurements to the study bank at regularly-spaced, vertical distances up the survey rod. Once a toe pin is installed, the study bank can be easily re-profiled in subsequent years. Figure 2.16 depicts the low bank cross profiling technique. Limitations and accuracy of both the bank pin measurements and the low bank cross profiling technique (also known as repeated cross profiles) are described in Table 2.3Table 2.2.

The remaining seven study banks were installed in 2015 and were profiled using total station surveying equipment, from heron denoted the "tall bank" (>2 m tall) repeated cross profiling technique. For these study banks, a toe pin and a pin at the top of the bank were installed to allow for a line to be strung between the two pins (see Figure 4.7). Total station surveying equipment can then be used to survey the bank along the line using a combination of the "break-of-slope" and "regularly-spaced interval" methods to obtain a bank profile (Lawler, 1993a). Care was taken not to walk along the line being surveyed, which could potentially increase bank erosion from "foot shear." For each of these surveys, at least two benchmarks of known coordinates and elevation were also installed to allow for repeated annual measurements. Measurements utilizing the tall bank cross profiling technique were taken within 0 to a maximum of 30 cm laterally from the line strung between the top and toe pins, with majority of survey shots between 0 to 15 cm. Elevations obtained were within 0 to a maximum of 2 cm, with majority of survey shots between 0 to 1 cm, based upon survey shots taken at the backsight.

Figure 4.7 Example of Tall Bank Profile Setup – Middle Little Arkansas #1 (Bigham, 2015)

Once at least two years of bank profiles were obtained utilizing either repeated cross profiling technique, bank profiles were then superimposed on one another to calculate bank retreat using Equation 12.

$$Average\ Bank\ Retreat\ (m/yr) = \frac{\Delta Area\ (m^2)}{Bank\ Height\ (m) * Time\ (yr)} \qquad \text{(Eq. 12)}$$

4.4 Results and Discussion

The BEHI and NBS ratings and calculated annual bank erosion rates obtained for all eighteen study banks are shown in Table 4.4. Appendix H provides the completed BEHI and NBS worksheets for all eighteen study banks. Twelve study banks were classified as a High BEHI rating, three as Moderate, two as Low, and one as Extreme. In terms of NBS ratings, five study banks obtained an Extreme NBS rating, five as High, five as Low, two as Moderate, and one as Very High. NBS methods 2, 3, 5 and 6 yielded the highest NBS ratings for the eighteen study banks. Appendices I, J, and K provide the bank pin measurements for four study banks, the low bank cross profiling technique measurements for seven study banks, and the tall bank cross profiling survey shots for seven study banks, respectively. Bank erosion rates varied from 0.01

m/yr to 0.603 m/yr with bank heights ranging from 0.6 m to 10.5 m tall. Figure 4.8 gives an example of bank retreat that occurred from 2015 to 2016 at Middle Little Arkansas Study Bank #1.

Table 4.4 Bank Erosion Hazard Index (BEHI), Near-Bank Stress (NBS) Ratings and Annual Bank Erosion Rates for Little Arkansas River Watershed Study Banks

Location♦	BEHI Rating	BEHI Score	NBS Rating	NBS Method	Bank Erosion Method*	Years Measured	Bank Height (m)	Average Retreat/Yr (m/yr)
ULA-1	High	31.3	Moderate	5	TCP	'15-'16	4.5	0.107
ULA-2	High (Moderate)	33.0 (28.0)	High	3	TCP	'15-'16	5.1	0.055
MLA-1	High	36.6	High	5	TCP	'15-'16	8.0	0.603
MLA-3	High	35.8	Extreme	2	TCP	'15-'16	10.5	0.347
LLA-1	High	36.6	Moderate	3	TCP	'15-'16	4.6	0.344
LLA-2	High	34.8	High	3	TCP	'15-'16	3.8	0.331
LLA-3	High	38.3	Very High	6	TCP	'15-'16	4.4	0.513
DT-BP	Moderate	25.8	Low	3	BP	'06-09', '16	1.7	0.020
DT-PXS	Moderate	26.5	Low	3, 5	LCP	'06-'07, '16	1.2	0.028
RT-LPXS	High	31.8	Low	5	LCP	'06-'07, '15†	2.2	0.065
RT-RPXS	High	37.4	Low	5	LCP	'06-'07, '09, '15-'16	2.2	0.131
UWE-SB	Moderate	26.9	Extreme	2	LCP	'06, '08-'09†	0.6	0.097
UWE-PXS	High	30.5	Low	5	LCP	'06-'07, '09, '15-'16	1.1	0.035
UWE-BP	Extreme	46.7	Extreme	2	BP	'06-'09†	2.1	0.028
LWE-PXS	High	30.2	Extreme	2	LCP	'06-'07, '09, '15-'16	2.1	0.129
LWE-ISCO	High	36.2	High	5	LCP	'06-'07, '15-'16	1.7	0.234
BK-PXS	Low	13.9	High	3	BP	'06-'07, '09†	0.6	0.030
BK-BP	Low	14.9	Extreme	3	BP	'06-'07, '09†	1.1	0.010

♦ULA-#: Upper Little Arkansas Study Bank #; MLA-#: Middle Little Arkansas Study Bank #; LLA-#: Lower Little Arkansas Study Bank #; DT: Dry Turkey; RT: Running Turkey; UWE: Upper West Emma; LWE: Lower West Emma; BK: Black Kettle; BP: Bank Pins; PXS: Pool Cross Section (L=Left Bank, R=Right Bank); SB: Study Bank; ISCO: ISCO Study Bank
* TCP: tall bank cross profiling technique; LCP: low bank cross profiling technique; BP: bank pin measurements
(BEHI) BEHI score/rating was modified to reflect research findings
† Could not re-measure in later years due to loss of toe pin or bank pins

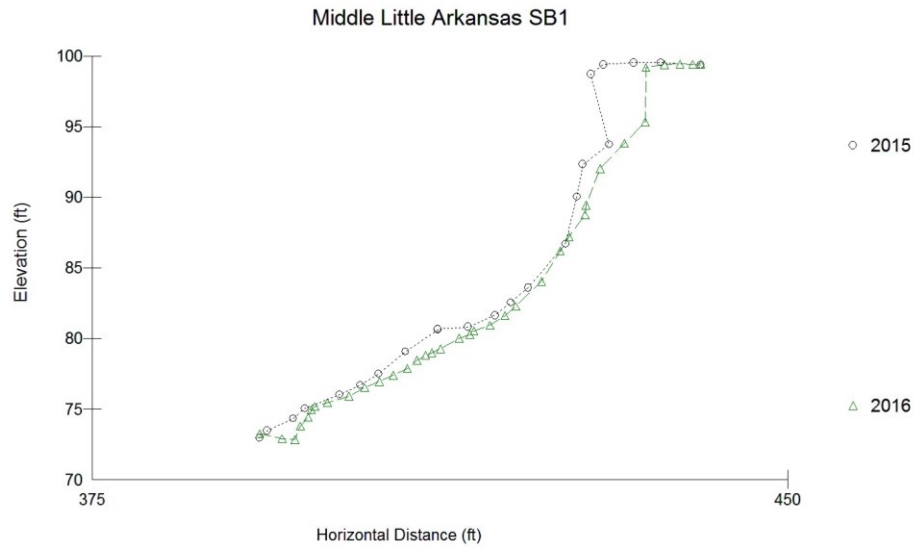


Figure 4.8 Middle Little Arkansas Study Bank #1 Bank Retreat, 2015-2016

A BANCS model was created for the Little Arkansas River watershed based on the data presented in Table 4.4. NBS rating was plotted on the X-axis, average bank retreat (m/yr) on the Y-axis, and BEHI rating was used as a grouping variable. These values were plotted with a log-lin scale and exponential regression equations were obtained.

The first assessment of all available data that could be used to create a provisional BANCS model for the Central Great Plains ecoregion is presented in Figure 4.9. As to be expected, erosion rates increase along any given BEHI exponential regression line when NBS rating increases. Also, study banks with High BEHI ratings had, on average, greater bank erosion rates than study banks with Moderate and Low BEHI ratings, when holding NBS rating constant. The exponential regression line characterizing the Moderate BEHI rating had the highest R^2 value (0.9603), but this category only had three observations, which explains this high correlation. The High BEHI rating regression line had an R^2 value of 0.2583 with twelve observations. The Extreme BEHI, Extreme NBS data point is an outlier. This study bank was measured using three 1.2 m long bank pins. During the wet year of 2007, these three bank pins were not found and therefore, average bank erosion rates could not be calculated. Loss of bank pins could mean that this specific study bank retreated at least 1.2 m during 2007, but without another form of survey, such as a repeated cross profile, this assumption could not be validated. Therefore, this observation was removed from the dataset.

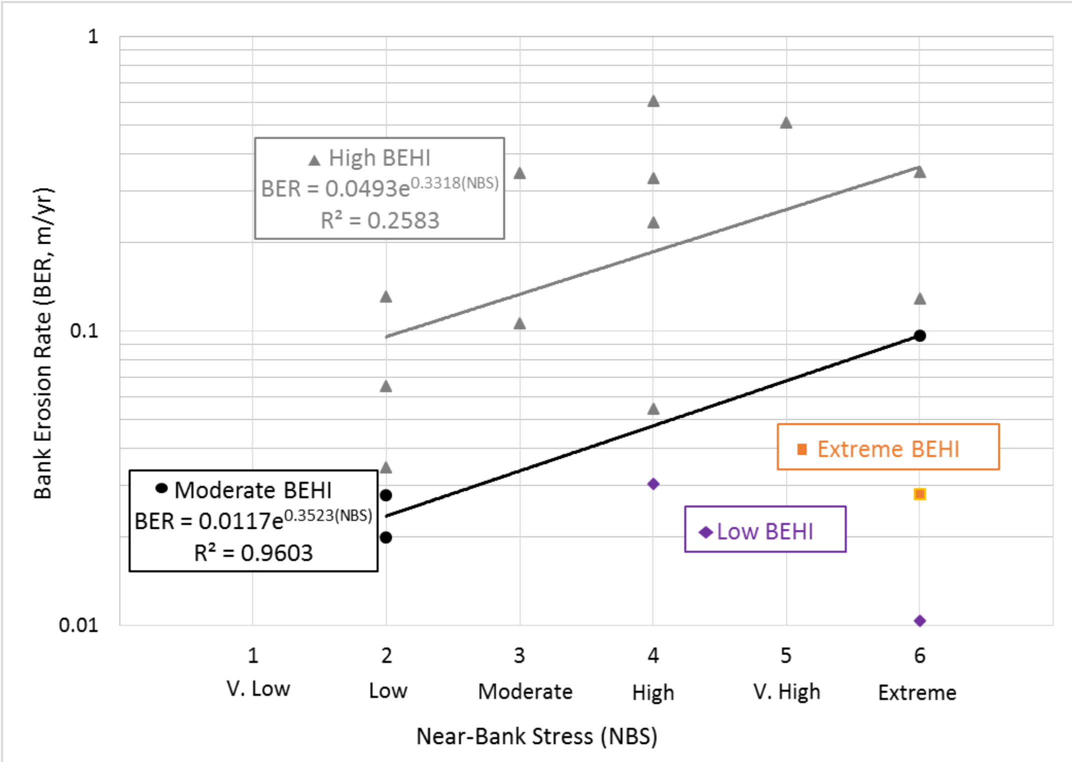


Figure 4.9 First Assessment of All Data that could be used to Create a Provisional Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model for the Central Great Plains Ecoregion

Three study banks marked as a High BEHI rating follow the Moderate BEHI regression line closely. These three points represent BEHI/NBS ratings and average annual erosion rates for UWE-PXS, ULA-2, and LWE-PXS. Each of these study banks had an adjusted BEHI score due to the presence of sand, either through the bank material or stratification adjustment, increasing the final score by +5 to +10 points. If these adjustments were not made, a Moderate BEHI rating may have resulted. This might indicate that although the soil samples obtained from the bank were comprised of sand, given that these study banks were all on sand-bed streams and samples were taken via a hand trowel rather than a soil sampling auger, the material sampled could have been deposited on the bank. This supposition was confirmed for ULA-2 by comparing the 2015 bank profile to the 2016 bank profile, shown in Figure 4.11, and through field observation of deposition on the streambank. During this year, ULA-2 eroded near the bottom and at the top but middle sections of the bank received sand deposition following high flows. The BEHI score was modified to reflect this finding by adjusting the BEHI score by +5 points instead of +10 points resulting in a lower BEHI rating of Moderate. When comparing the annual bank profiles for

UWE-PXS and LWE-PXS, this observation could not be validated as no deposition was recorded or observed in the field. But, it is noted that both banks were very close to the threshold from High BEHI rating to Moderate BEHI rating (upper limit 29.5 points), where UWE-PXS and LWE-PXS received BEHI ratings of 30.5 and 30.2 points, respectively. This suggests that a change in any of the BEHI parameters might result in a lower BEHI category. Since evidence of deposition could not be confirmed, though, High BEHI ratings were maintained for both UWE-PXS and LWE-PXS. Based on the removal of the Extreme BEHI, Extreme NBS data point and the adjustment made to the ULA-2 BEHI rating, a final, yet still provisional, BANCS model is presented in Figure 4.10. The R^2 value for High BEHI exponential regression line improved from 0.2583 to 0.3313 while the R^2 Moderate BEHI regression line decreased slightly from 0.9603 to 0.9542.

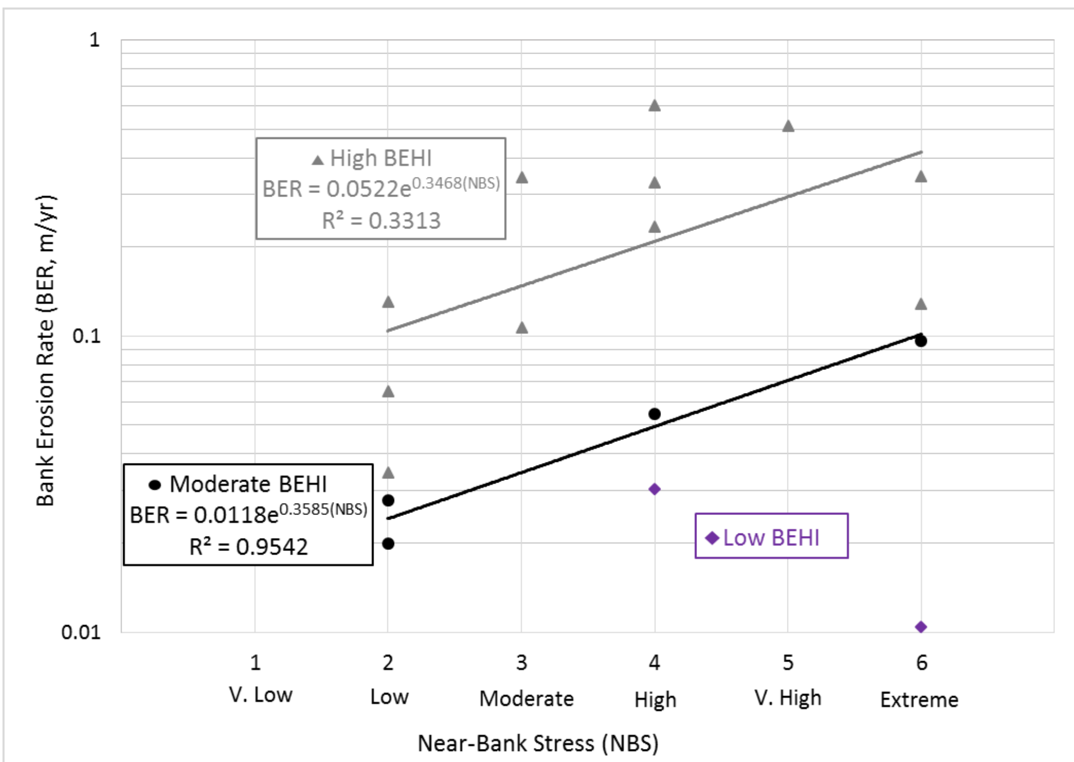
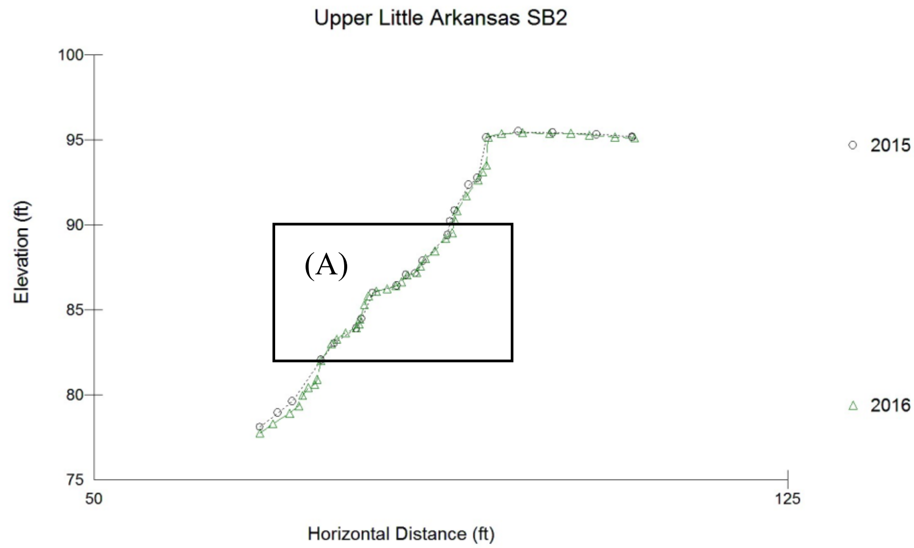


Figure 4.10 ***Provisional*** **Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model for the Central Great Plains Ecoregion**[16]

[16] Based on the removal of the Extreme BEHI, Extreme NBS data point and the lowering of the BEHI category from High to Moderate at Upper Little Arkansas Study Bank #2



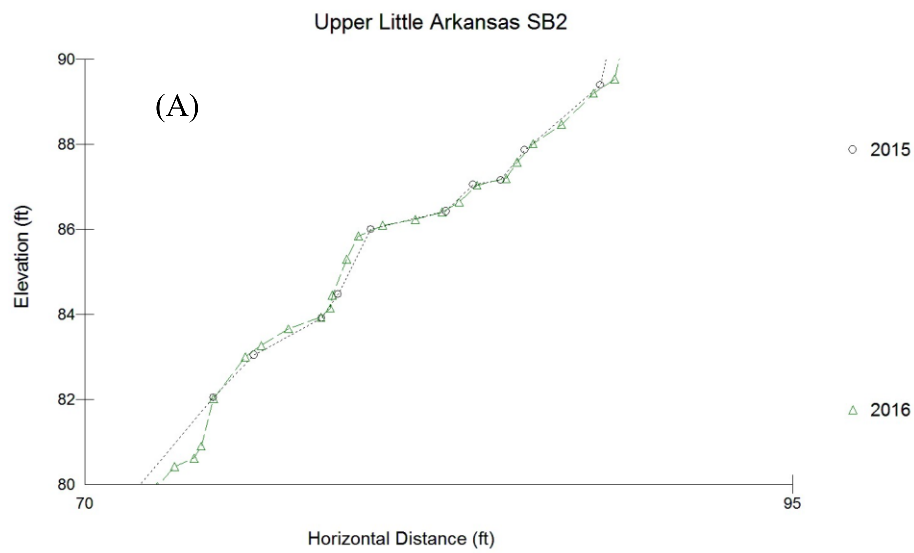


Figure 4.11 Upper Little Arkansas Study Bank #2 (2015-2016) - Deposition occurring in the box labeled (A)

Model fit of the provisional BANCS model is similar to but shows more variability than that of the Colorado, Wyoming (Rosgen, 1996b; Rosgen, 2001; Rosgen, 2009), Arkansas (Van Eps et al., 2004), and California (Kwan & Swanson, 2014) curves. There are several potential explanations of this observed dispersion. It was assumed that the BEHI and NBS rating obtained during 2015 or 2016 for study banks on DT, RT, UWE, LWE and BK was, in fact, the BEHI/NBS rating for that bank over the last ten years, which may or may not have been the case. Another reason for greater model dispersion could be due to the small sample size. Only eighteen study banks were installed and monitored with seventeen of these being included in the provisional BANCS model shown in Figure 4.10. This sample size is less than any of the four curves created in Colorado, Wyoming, Arkansas, and California, limiting the dataset's regression analysis. An insufficient number of study banks could explain the atypical fit of the Kansas (Sass & Keane, 2012) curve, where BEHI regression lines crossed, and the low R^2 values of the BEHI and NBS regression lines of the New York (Coryat, 2011; Markowitz & Newton, 2011) curves. Furthermore, streambank erosion data was collected sporadically, not annually, as shown in Table 4.4, and bank erosion rates were averaged over a 1 to up to a 10-year period, rather than over just a 1-year period, as was done in the Colorado, Wyoming, Arkansas, and California curves. Figure 4.12 illustrates the years in which study banks were surveyed that were used in the provisional BANCS model for the Central Great Plains ecoregion. As shown in Figure 4.4 through Figure 4.6, there were a wide range of flow events that were captured during this 10-year study period, from drought (2006, 2011-2012) to a flood of magnitude 2.8-times greater than the bankfull discharge (2007). This range of events and the bank erosion data that may or may not have captured those events varied throughout the dataset, which could explain the variability observed in the provisional BANCS model for the Central Great Plains ecoregion. Alternatively, this wide range of flows may have instead decreased variability of this curve, as flood years could have resulted in the greatest bank erosion rates while drought years could have had the least bank erosion, buffering the rates obtained during the flood years. Finally, streambank erosion rates were measured by three different techniques: bank pin measurements (BP), low bank repeated cross profiling (LCP), and tall bank repeated cross profiling (TCP), as shown in Figure 4.13. Each technique has different erosion rate measurement accuracy and limitations, resulting in variable bank erosion rate estimates and potentially causing greater dispersion in the dataset.

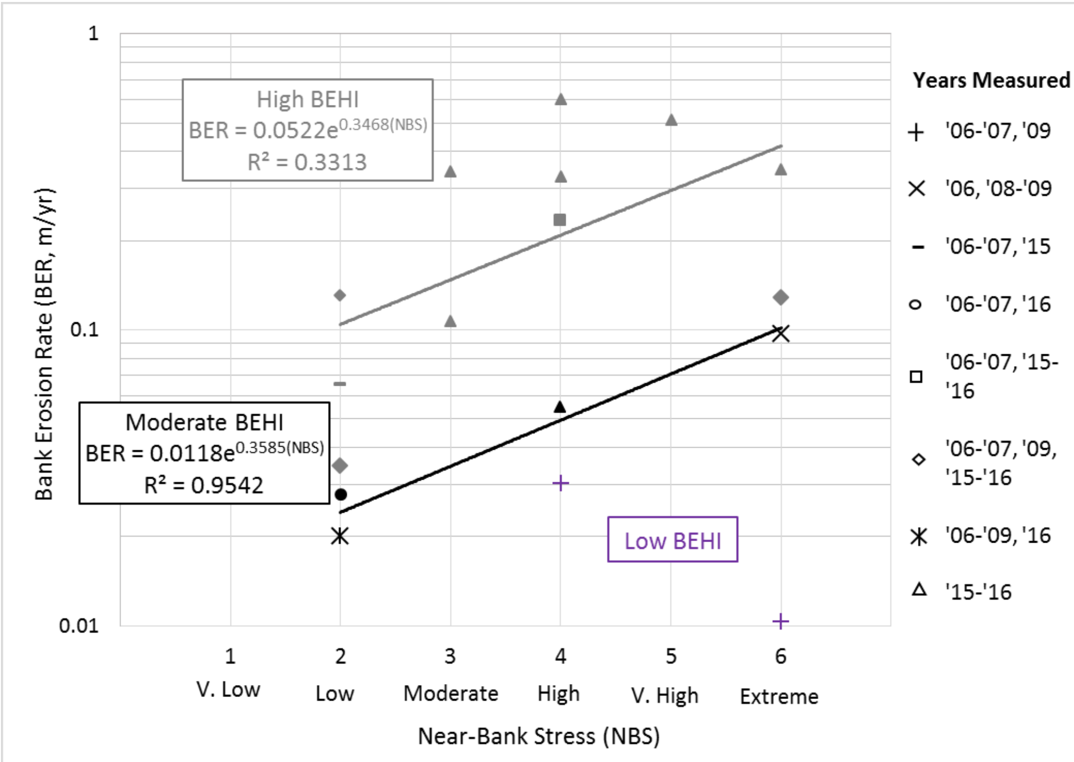


Figure 4.12 ***Provisional*** **Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model for the Central Great Plains Ecoregion with Years of Streambank Erosion Data Collected**

This is the first BANCS model that has been created that takes into account the clay content adjustment that followed after observations made during Kansas (Sass & Keane, 2012) and New York (Markowitz & Newton, 2011) curve development. Seven study banks (MLA-3, DT-BP, UWE-SB, LWE-PXS, LWE-ISCO, BK-PXS, and BK-BP) had a clay adjustment. Five of these study banks would have obtained a higher category rating without the clay adjustment, which would have resulted in three Moderate BEHI-rated study banks and two Very High BEHI category study banks. The R^2 for the High BEHI exponential regression line would have decreased from 0.3313 to 0.214. Additionally, the Moderate BEHI regression line would have a negative correlation and a reduced R^2 of 0.3487 from 0.9542. The provisional BANCS model without the clay adjustment is shown in Figure 4.14.

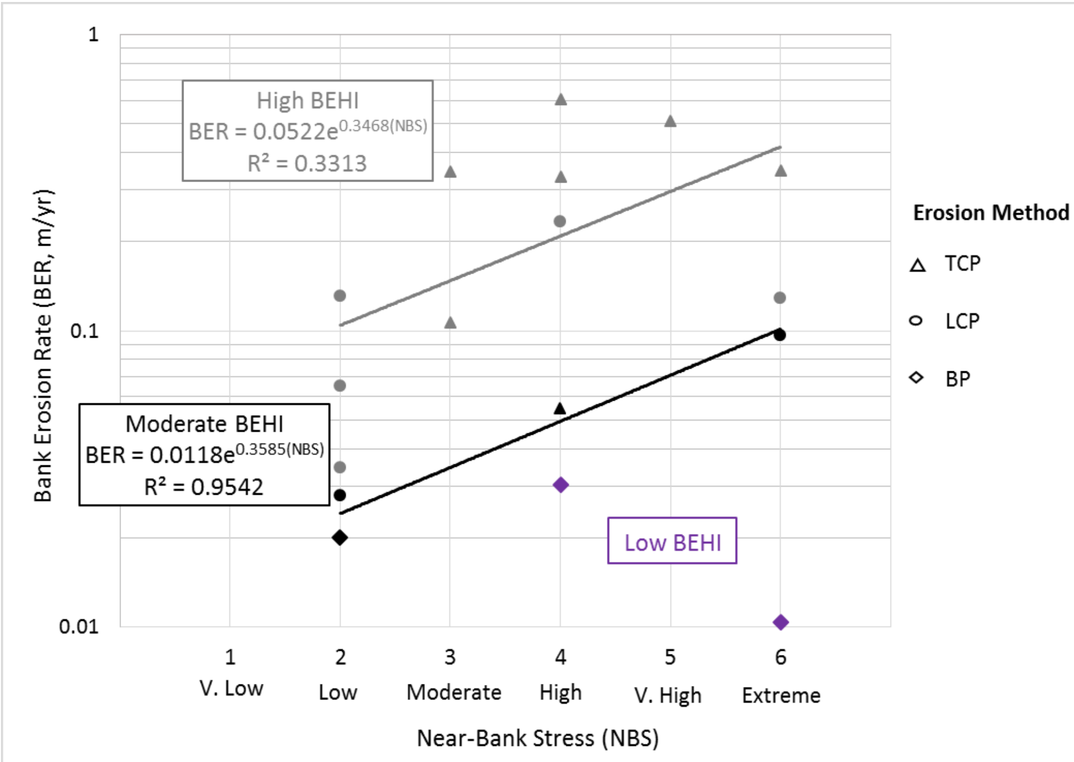


Figure 4.13 *Provisional* Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model for the Central Great Plains Ecoregion with Streambank Erosion Rate Measurement Technique[17]

Model fit and application of the provisional BANCS model presented in Figure 4.10 could have potentially been improved if BEHI/NBS ratings were obtained every year at each study bank and average annual streambank erosion rates were averaged over just one-year (e.g. Kwan & Swanson, 2014; Rosgen, 1996b; Rosgen, 2001; Rosgen, 2009; Van Eps et. al., 2004), and not multiple years (e.g. this study; Coryat, 2011; Sass & Keane, 2012). This kind of data collection could have resulted in 107 annual streambank erosion observations that could then be separated into three annual hydrologic event categories: drought (2006, 2011-2012), flood (2007, 2010, 2013, 2015), and bankfull (2008, 2009, 2014). Three streambank erosion rate prediction curves, rather than one, could have been created based on each hydrologic event category, as recommended by Rosgen (2015). Flood events that occurred during model creation might explain the wide variability obtained in studies where flow events exceeded 4-times the bankfull discharge (e.g. Coryat, 2011; Harmel et al., 1999; Markowitz & Newton, 2011), further

[17] TCP: Tall Bank Cross Profiling Technique; LCP: Low Bank Cross Profiling Technique; BP: Bank Pins

supporting the need for flow-dependent curves. By collecting streambank erosion data in this fashion, masking of the spatiotemporal variability of streambank erosion inherent to averaging bank erosion rates would be decreased.

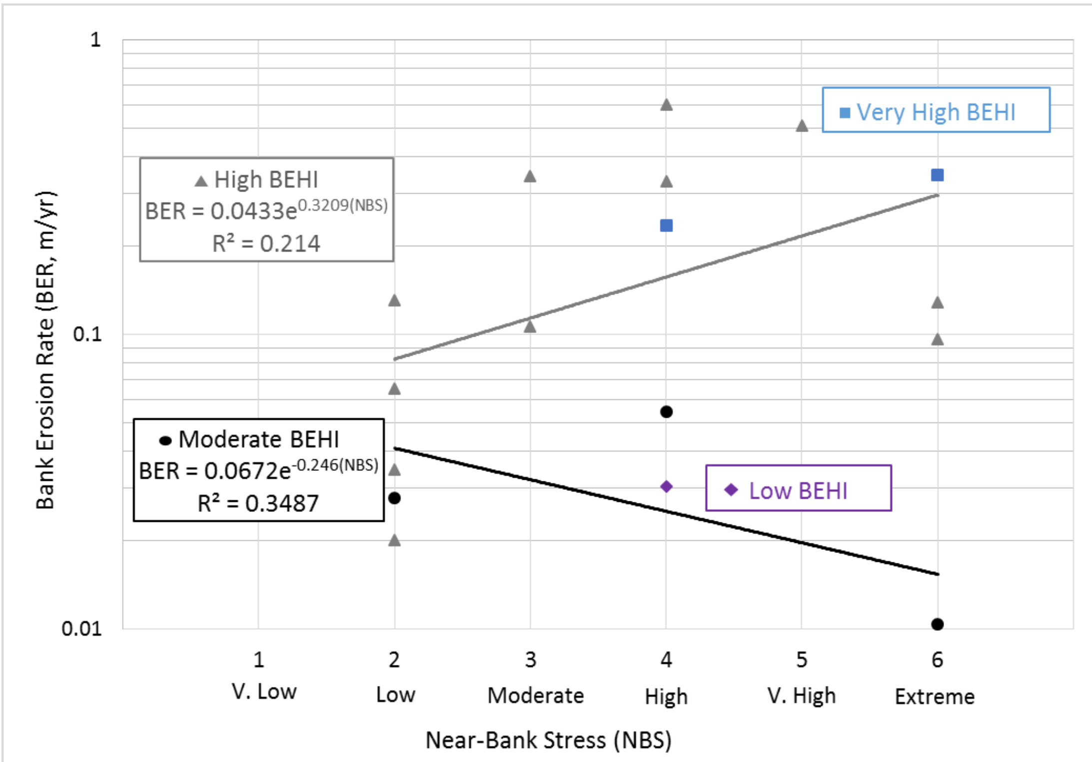


Figure 4.14 *Provisional* Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model <u>without</u> a Clay Adjustment, Provides Evidence that Clay Adjustment improved Model Fit

Finally, the model could have been further improved if repeated cross profiles were conducted annually on all banks, rather than measuring bank pin exposure on some banks. Although each streambank erosion measurement technique has its limitations, the risk of losing bank pins is much greater than losing toe pins or other monumented cross section points, resulting in loss of data (e.g., loss of the Extreme BEHI, Extreme NBS data point in this study). In addition to the risk of losing pins, the use of bank pins:

- May not reflect the spatial variability of bank erosion if not enough pins are installed,
- May be affected by bank material properties (i.e. shrink/swell clay), and
- May unintentionally increase or decrease bank erosion rates (Lawler, 1993a).

The use of bank pin erosion measurement rather than repeated cross profiles could potentially improve the R^2 of BEHI regression lines of the North Carolina (Jennings & Harman, 2001; Patterson et al., 1999) and Oklahoma (Harmel et al., 1999) curves.

4.5 Conclusions

A provisional BANCS model was created for the Central Great Plains ecoregion from BEHI/NBS ratings and streambank erosion data collected sporadically over a ten-year period along reaches found within the sediment-impaired Little Arkansas River watershed, located in south-central Kansas. This model's fit is similar to but exhibits more variability than that of more successful curves, such as the Colorado, Wyoming (Rosgen, 1996b; Rosgen, 2001; Rosgen, 2009), Arkansas (Van Eps et al., 2004), and California (Kwan & Swanson, 2014) BANCS models. The relatively high variability observed in this model could be caused by:

- Not obtaining study bank BEHI and NBS ratings every year,
- Not having a large enough sample size,
- Obtaining streambank erosion data sporadically over a 10-year period with variable streamflows, and
- Utilizing three streambank erosion rate measurement techniques rather than one reliable and accurate method, such as repeated cross profiles.

Based upon the examination of the BANCS model developmental process, it is recommended that a BANCS model creation procedure should be established and should include:

- Accurate measurement of study bank heights, which was determined to be the most sensitive BEHI parameter;
- A soil texture analysis of streambanks with silt/clay banks to obtain percentage of clay and to reduce uncertainty in adjusting for bank material;
- Multiple assessments by at least two trained stream professionals to obtain precise BEHI/NBS ratings;
- Utilization of as many NBS methods as possible that best represent the site conditions; and
- Measurement of streambank erosion rates through repeated bank profiles only.

Although determination of soil texture within layers is useful for estimating percentage of clay, creators of future BANCS models should obtain soil samples further into the bank profile so samples reflect actual bank material properties and not material that has been deposited on the bank. This could be accomplished by using a handheld soil sample auger instead of a hand trowel. Furthermore, creators of future models should consider obtaining BEHI/NBS ratings annually, in addition to streambank erosion measurements, over multiple years to capture all types of flow events, such as drought, flood, and bankfull events. This type of data collection would also result in a larger sample size. Streambank erosion data could then be separated by flow categories to create segregated streambank erosion rate prediction curves. Doing so would enable prediction of erosion rates for all types of flow events (Rosgen, 2015). Given the similar fit of the curve presented in this study relative to other successful curves, such as the Colorado, Wyoming, Arkansas and California BANCS models, it is recommended that, in addition to these flow-dependent curves, one prediction curve with average streambank erosion rates over the entire study period should also be created, for comparison purposes. These curve creation recommendations may generate BANCS models with increased statistical fit and significance, resulting in more accurate prediction of streambank erosion rates when the curve is properly implemented, and may also improve the overall understanding of streambank erosion processes across a range of flow events.

Chapter 5 - Recommended Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model Creation Procedure

5.1 Introduction

Excess sediment is the second leading cause of stream impairment in the United States (U.S. EPA, 2016), resulting in poor water quality, damage to aquatic ecosystems, and sedimentation of downstream waterbodies, such as federal reservoirs. Sediment is a non-point source pollutant, but several case studies have identified accelerated stream degradation and streambank erosion as the main contributor of sediment in some impaired watersheds (Belmont et al., 2011; Bull, 1997; Kronvang et al., 1997; Mukundan et al., 2010; Rondeau et al., 2000; Trimble, 1997; Wilson et al., 2008).

Although streambank erosion is natural and an essential component to aquatic ecosystems (Florsheim et al., 2008), drastic changes in regional climate and watershed land use, type, and/or management can create stream instability that results in both physical and biological degradation. Stream instability causes accelerated bank erosion and channel degradation and/or aggradation, as the stream works to change its dimensions, pattern, and profile to reach a dynamic equilibrium under new discharge and/or sediment conditions. Therefore, it is essential to identify, quantify, and reduce streambank erosion in sediment-impaired watersheds, especially those that have been influenced by extreme natural events and anthropogenic processes, such as the conversion of land for agricultural purposes or urban development.

One method that can be utilized to estimate streambank erosion rates is through the development of an empirically-derived "Bank Assessment for Non-Point Source Consequences of Sediment" (BANCS) model (Rosgen, 2001). A BANCS model is a process-integrated streambank erosion rate prediction curve that, once developed for a specific hydrophysiographic region of interest, allows rapid estimation of annual streambank erosion rates, in units of length per year. A curve is created solely on empirical relationships among streambank physical properties and estimated localized shear stress, as reflected by the two model parameters: (1) the Bank Erosion Hazard Index (BEHI), and (2) the Near-Bank Stress (NBS) rating. The BEHI provides an adjective rating of bank erodibility based on visual and measured assessment of a streambank of interest, while the NBS rating provides an adjective rating of the amount of applied shear stress induced by the outer one-third of the channel flow adjacent to the eroding bank of interest (Rosgen, 2009). More information on how to assess streambanks for BEHI and NBS can be found in Rosgen (2014).

Ten BANCS models have been developed and published, with varying degrees of success, across numerous hydrophysiographic or ecoregions in the United States (see Figure 2.17) and eastern India. An existing BANCS model must be validated or a new curve created before it can be used to predict streambank erosion rates in a different hydrophysiographic region (Rosgen, 2001; Rosgen, 1996; Rosgen, 2009).

In addition to being limited to the hydrophysiographic region in which it was developed, a BANCS model is also limited to the streamflows that occurred during the curve development stage (Van Eps et al., 2004). For example, if BEHI, NBS, and bank erosion rates were collected over a one-year period and streamflow exceeded the bankfull stage, then that curve will only be good for predicting bank erosion rates during flood years (Rosgen, 2001; Rosgen, 2015). A BANCS model may also be limited to the accuracy of the erosion rate measurement technique utilized to create the model (Lawler, 1993a). BANCS models have been created using various streambank erosion measurement methods, such as repeated cross profiles or bank profiles, repeated cross sections, and/or bank pin measurements. Differences between created models, such as streamflows experienced over the development period and streambank erosion measurement methods utilized, are summarized in Table 2.2.

Like any other empirically-derived model that attempts to explain and estimate natural processes, the BANCS model has also been criticized. Criticisms of the BANCS model include:

- Creation is time-consuming (Rosgen, 2009);
- Implementation may be subjective, such as bankfull identification (Coryat, 2011; Johnson & Heil, 1996; Juracek & Fitzpatrick, 2003; Markowitz & Newton, 2011; Rathbun, 2011; Roper et al., 2008; Simon et al., 2007; Williams, 1978); and
- Implementation and prediction of streambank sediment loss as an average length per year masks the spatiotemporal variability of streambank erosion (Lawler et al., 1999).

Furthermore, it seems that lack of a detailed procedure for developing new curves could explain the wide variability of results. As depicted in Table 2.2, methods and factors that vary amongst developed BANCS models include:

- Number of streambank sites employed;

- Number of years streambank erosion data is collected;
- Streamflows experienced;
- NBS method(s) applied; and
- Streambank erosion measurement method implemented.

Although the lack of a detailed procedure to develop a BANCS model has never been directly criticized, several creators of curves identified some or all of these unknown methods and/or factors as a primary cause of the high variability that they observed in their results (e.g. Coryat, 2011; Harmel et al., 1999; Jennings & Harman, 2001; Markowitz & Newton, 2011; Patterson et al., 1999).

In an effort to reduce variability in BANCS models associated with user uncertainty in model development methods, the objective of this chapter is to present a detailed BANCS model creation procedure. This procedure is based upon results obtained from this thesis, as well as results from other published BANCS models.

5.2 Recommended Bank Assessment for Non-Point Source Consequences of Sediment (BANCS) Model Creation Procedure

Based on the results of this study and from the literature, the following BANCS model creation procedure is recommended to create future, region-dependent BANCS models.

1) **Select representative streambanks for BANCS model development.** Select, at the minimum, five study banks per BEHI rating of Very Low to Extreme (for a minimum total of 30 study banks, if all 6 BEHI categories are represented), where BEHI is obtained based on a rapid, visually-based assessment of the streambank. To guarantee that streambanks utilized in the creation of the model have varying NBS ratings, NBS rating should also be estimated and recorded for each bank. This minimum sample size is based on results from a provisional BANCS model created for the Central Great Plains ecoregion (see Chapter 4) and an Ozark Highlands BANCS model created by Van Eps et al. (2004), where an average of five streambanks were utilized per BEHI exponential regression line in both models. Each curve had low sample sizes of 17 and 24 for the Central Great Plains and Ozark Highlands curve, respectively, but both obtained proper model fit, where bank erosion rates increased with increasing BEHI and NBS ratings. To

ensure that a wide range of streambanks are employed in model creation, recommendations for study bank selection include:

a. Select stream reaches and study banks that represent the variety of stream size and classifications found within the hydrophysiographic region.
b. Utilize no more than five study banks from each stream reach, where a reach is equal to 20 times the bankfull width or 2 meander wavelengths (Rosgen, 1996b), for a minimum total of 6 stream reaches, in the development of the BANCS model.

2) **Determine bankfull elevation.** Calibrate bankfull discharge elevation at all of the study reaches, through gage flood-frequency analysis and/or the use of regional curves (Rosgen, 1996b). This elevation can be corroborated with bankfull field indicators present within study reaches, giving model creators greater confidence in their estimates of bankfull height as required for BANCS model creation and application.
3) **Establish repeatable bank profile stations at study streambanks.** Both Rosgen (2015) and Patterson et al. (1999) suggest implementing repeated cross profiles (also known as bank profiles) over bank pin measurements, as they tend to provide more reliable estimates of lateral bank retreat. This suggestion was supported by the results obtained from this study while developing a provisional BANCS model for the Central Great Plains ecoregion. Erosion data was lost following a flood year on a streambank where only bank pins were installed, as it was expected that the pins had washed out. Therefore, it is recommended that bank profiles be utilized to calculate annual bank erosion rates. To establish bank profile and cross section stations at a streambank of interest, install two 1.3 cm x 1.2 m rebar top pins with plastic survey caps at the study bank. Place one pin several feet back from the top of the eroding bank of interest and the other at the top of the opposite bank, at or above the bankfull elevation. Lawler (1993a) recommends placing pins at least one channel width from the top edge of the eroding streambank. String a taut line, such as a tape measure or cam-line, between the two pins and make sure the line is perpendicular to flow. Place one 1.3 cm x 1.2 m rebar toe pin with plastic survey cap into the streambed at the toe of the study bank. Hammer the toe pin far enough into the streambed to reduce snags but high enough to allow for deposition. In addition to these pins, it is also recommended to install 1.3 cm x 1.2 m bank pin(s) into

the eroding bank to serve as a quick, visual estimate of bank erosion rates and to indicate when the study bank should be re-profiled.

4) **Characterize channel slope and geometry for NBS inputs.** Survey the stream reach that is at least 20 times the bankfull width or 2 meander wavelengths in length (Rosgen, 1996b). Be sure to obtain, at the minimum, thalweg, bankfull, and water surface (or water depth) shots and distance between shots to create a longitudinal profile, as well as at least one cross section through a representative riffle. In addition to these shots, survey the top-of-bank and toe pins installed at selected study banks. It is recommended that at least two benchmarks also be installed to allow for repeated measurements.

5) **Measure study bank profiles.** Obtain bank profiles on installed study banks using either the low bank cross profiling technique (bank height ≤ 2 meters) or the tall bank cross profiling technique (bank height > 2 meters). The low bank cross profiling technique involves placing a survey rod plumb on the toe pin allowing the bank to be "profiled" by taking level, horizontal measurements to the study bank at regularly-spaced, vertical distances up the survey rod (see Figure 2.16). The tall bank cross profiling technique involves stringing a taut line between the top and the toe pin of the bank (see Figure 4.7) and then utilizing surveying equipment such as a total station or survey-grade GPS to survey the bank along the line using a combination of the "break-of-slope" and "regularly-spaced interval" methods to obtain a bank profile (Lawler, 1993a). In addition to the bank profile, survey the cross section from the left to the right top pin, utilizing the taut line between the top-of-bank pins to guide measurement. Survey shots should be taken based upon the "break-of-slope" technique. Care should be taken when obtaining measurements along the eroding streambank in interest to prevent erosion caused by the survey.

6) **Obtain BEHI and NBS ratings for study banks.** Assess each study bank using the current BANCS methodology, as described in Rosgen (2014). Recommendations to improve the precision of BEHI/NBS ratings include:
    a. Accurately measure study bank height and root depth using surveying equipment and bank angle using an inclinometer or a pitch and angle, as these were identified as sensitive BEHI parameters, meaning that they have the greatest influence on the final BEHI rating.

b. The sensitivity analysis conducted on BEHI parameters indicated that the bank material adjustment was the most uncertain BEHI parameter. To reduce uncertainty, obtain soil samples of study bank layers at or below bankfull on streambanks comprised of silt and clay using a handheld soil sampling auger. Make sure sample contains actual bank materials and not deposited material. Classify soil texture utilizing a soil texture analysis procedure, such as the hydrometer method. Based on suggestions from Rosgen (2014) and Stantec Consulting Services (2013), the following adjustments to the BEHI score based on percent of clay present are proposed:

   i. <30% clay – no adjustment
   ii. 30% to 50% clay – subtract 5 BEHI points
   iii. 50% to 70% clay – subtract 10 BEHI points
   iv. >70% clay – subtract 20 BEHI points

   Additional research should evaluate and revise, if necessary, these proposed adjustments.

c. Utilize as many NBS methods as reasonably possible, based on site conditions, as NBS method selection is a sensitive BANCS model parameter. NBS methodologies are detailed in Rosgen (2014).

d. Obtain BEHI/NBS assessments from a minimum of 2 trained stream professionals, preferably 4, and finalize the rating based on the central tendency of all observations. For example, the final BEHI rating could be taken as the group's median value and the final NBS rating could be taken as the group's mode value (or maximum value). The recommendation for multiple raters is based on findings from a repeatability study of the BEHI and NBS methodologies, in which, despite variability among individual bank raters, the central tendency of raters tended to the assumed BEHI and NBS rating values, thereby increasing rating precision and reducing the subjectivity inherent to BEHI and NBS assessments.

7) **Determine streambank erosion rates.** Obtain multiple years of streambank erosion data, reassessing BEHI/NBS every year if it appears that conditions have changed (i.e. following a bankfull or flood event). This approach was taken by Kwan and Swanson

(2014) in the development of a BANCS model for the Sierra Nevada ecoregion of California. The purpose of this is to minimize masking the spatiotemporal variability of streambank erosion. It is also recommended to collect data during the same season every year to ensure similar visual streambank characteristics. Once at least two years of bank profiles are obtained, profiles can then superimposed on one another to calculate streambank retreat using Equation 12.

$$Average\ Bank\ Retreat\ (m/yr) = \frac{\Delta Area\ (m^2)}{Bank\ Height\ (m) * Time\ (yr)} \qquad \text{(Eq. 12)}$$

8) **Account for inter-annual flow variability.** Segregate BEHI/NBS and calculated annual streambank erosion rates based on flow events that occurred during the year of observation, as recommended by Rosgen (2015). For example, separate into three categories:
    a. Drought (annual peak flow <50% of bankfull)
    b. Bankfull (annual peak flow 50-150% of bankfull)
    c. Flood (annual peak flow >150% of bankfull)

    Category limits are suggestions based on results and model fit obtained from previous created models. Subsequent research should test and adjust these limits, if necessary.
9) **Develop BANCS curves.** Based on flow segregations selected in Step 8, create flow-dependent annual bank erosion prediction curves, as recommended by Rosgen (2015). In addition to these curves, create one streambank erosion rate prediction curve for bank retreat rates as averaged over the entire study period, for comparison purposes.

5.3 Conclusion

A process-integrated, empirically-derived BANCS model is one method that can be utilized to estimate streambank erosion rates in sediment-impaired watersheds. An existing BANCS model must be validated before it can be used in a different hydrophysiographic region. If it cannot be validated, a new curve must be developed. This chapter provides a step-by-step BANCS model creation procedure. This study addresses the apparent need to provide model creators with additional guidance regarding BANCS curve development, and may also improve future models' statistical fit and significance. This procedure is intended for model *creation*, as many of the added recommendations and suggestions will increase the time needed to develop a streambank erosion rate prediction curve. This extra time is warranted though, as improving model accuracy in prediction will greatly improve its application, provided streambanks are properly assessed for BEHI/NBS. These recommendations and suggestions should be considered and utilized when assessing streambanks for BEHI and NBS and/or applying a created BANCS model to obtain a sediment yield, if time and resources allow.

Subsequent studies should implement this procedure in several different hydrophysiographic regions to validate and/or improve the methodology as a whole. The suggestions provided in this procedure, such as the clay content adjustments and the flow categories, should be scientifically evaluated and adjusted as needed. Furthermore, it may be beneficial to develop a field assessment procedure to identify and properly adjust for bank materials, such as a soil ribbon protocol, to reduce the time and resources needed to collect soil samples and analyze for soil texture in a lab. The MDEQ (2008) has begun this discussion, but this in-situ assessment could be further improved. Finally, subsequent research should investigate the effect of seasons on BEHI/NBS ratings in temperate regions of the globe, especially regions with deciduous riparian forests. Step 7 of the procedure recommends obtaining BEHI/NBS ratings at the same time every year to ensure that visual characteristics of a streambank are similar, but assessing streambanks the same time every year may not always be possible. This kind of analysis would examine whether time of year has an effect on BEHI and NBS ratings.

Chapter 6 - Conclusions

Estimating yields from all possible sources of sediment in watersheds is the only way to effectively identify problem areas, mitigate erosion, and reduce sediment in impaired streams. Numerous case studies have determined that streambank erosion can be the main contributor of sediment in impaired watersheds. Therefore, it is vital that existing predictive streambank erosion rate models be improved or new models be developed to more accurately and efficiently quantify streambank erosion rates. Just as Bull (1997), Lawler et al. (1999) and Couper (2004) point out, the spatiotemporal variability of streambank erosion, caused by changing boundary conditions and applied hydraulic and gravitational forces, makes it extraordinarily difficult to model and predict streambank erosion. But with continued research of streambank erosion processes and application of predictive models, the uncertainty of bank erosion rates can certainly be reduced.

An empirically-derived, regionally-based BANCS model is just one of many channel erosion models that has been developed to predict streambank erosion rates. A review of ten published BANCS models provided evidence that model methodology could be improved in some way, as shown by the varying coefficients of determinations (R^2) of the exponential regression lines of each model. In an effort to improve model application, this study examined the repeatability of the BANCS model methodology and the sensitivity of model parameters. In addition, the developmental process of BANCS models was analyzed through the creation of a provisional streambank erosion rate prediction curve for the Central Great Plains ecoregion.

This study found that the BANCS model methodology is subject to user bias, which could be caused by inaccurate measurement of identified sensitive and uncertain BEHI/NBS parameters. Furthermore, the BANCS model that was created for the Central Great Plains ecoregion could have been improved if a model creation methodology had been in place prior to streambank erosion data collection, as the lack of a procedure may explain the wide variability of results of previously developed BANCS models, among which curve development methods varied. Based on the results from this research and the results of others, a detailed procedure was outlined to reduce the variability and uncertainty of the BANCS model developmental process, with the intent of potentially improving the statistical fit and significance of future streambank erosion rate prediction curves. Recommendations that were provided based upon the results of this thesis include:

- Accurate measurement of study bank height and root depth using surveying equipment and bank angle using an inclinometer or a pitch and angle, as these were identified as sensitive BEHI parameters;
- Accurate identification and adjustment for bank material, especially banks comprised of silt and clay, as the bank material adjustment was found to be the most uncertain BEHI parameter;
- Utilizing as many NBS methods as reasonably possible, based on site conditions, as NBS method selection is a sensitive BANCS model parameter;
- Obtaining multiple assessments by at least two trained stream professionals, preferably four, to finalize BEHI/NBS ratings based on a measure of central tendency of ratings to ensure precision and reduce the subjectivity inherent to BEHI and NBS assessment; and
- Utilizing repeated cross profiles only to measure streambank erosion rates to improve measurement accuracy and reduce the risk of losing streambank erosion data overtime.

6.1 Future Research

Additional research needs to be administered to inform and improve the suggested procedure provided in Chapter 5. The bank materials adjustment for clay is quite vague, as Rosgen (2014) does not provide a clear definition of what "primarily clay" actually means. In attempt to further define this parameter, Stantec (2013) and the author provide threshold clay content percentages, as described in 6(b) of the procedure provided in Section 5.2. Based on the acceptable fit of the BANCS model created for Central Great Plains ecoregion, where bank erosion rates generally increased with increasing BEHI and NBS ratings, it seems that the threshold clay content percentage of 30-50% clay, resulting in an adjustment of -5 BEHI points, may be acceptable. It is noted though that none of the banks utilized in the study had a clay content >50%, so adjustments of less than -5 points were not tested. Additional research should further investigate and define these threshold percentages to more accurately adjust the final BEHI score.

One of the original benefits of the use of a created BANCS model is its practicality and efficiency in extrapolating annual bank erosion rates. The efficiency of this rapid assessment may be reduced in regions dominated by silt/clay banks, as it may be difficult to field estimate percentage of clay in bank materials, necessitating the collection of soil samples to properly classify soil texture in the lab. Additionally, some users of created BANCS models may not have access to the equipment and space necessary to administer soil texture analysis procedures. Therefore, additional research should investigate ways to rapidly assess bank materials in the field, such as developing a soil ribbon protocol. The MDEQ (2008) has begun this discussion, but this in-situ assessment could be further improved.

In addition to improving the clay adjustment of the BEHI, future studies should investigate the effect of seasons on BEHI/NBS ratings in temperate regions of the globe, especially regions with deciduous riparian forests. Step 7 of the procedure presented in Section 5.2 recommends obtaining BEHI/NBS ratings at the same time every year to ensure that visual characteristics of a streambank are similar, but assessing streambanks the same time every year may not always be possible. This kind of analysis would examine whether time of year has an effect on BEHI and NBS ratings.

A thorough sensitivity and uncertainty analysis of the BEHI methodology was completed in this study for the Central Great Plains ecoregion. This type of analysis should be replicated in other hydrophysiographic regions to determine if other BEHI parameters are more sensitive and/or uncertain in those regions. In addition to a replicated BEHI sensitivity analysis, it is recommended that a sensitivity analysis of independent variables within each site-specific, user-selected NBS method should also be evaluated based on data obtained by a several individual raters and/or groups of raters, as this type of analysis was not completed in this study. Furthermore, NBS assessment procedure and methods are rarely ever questioned as a potential cause of observed variability of existing BANCS models. Subsequent research should investigate and confirm that current NBS methods can be utilized as valid tools to predict near-bank stress or if alternative methods should be utilized to estimate localized shear stress.

Finally, Rosgen (2015) recommends creating several curves based on annual flow conditions but does not specify how to segregate flow events. To better define flow segregation categories, the author provides three flow delineation categories as part of the model creation procedure presented in Section 5.2 based on results and model fit obtained from previous created models. In order to determine whether or not these delineation categories are acceptable, additional BANCS models will need to be created over multiple years to validate and/or improve the limits of these categories.

6.2 Summary

The BANCS model methodology is one procedure that can be utilized to predict sediment yields from streambank erosion. The work documented in this thesis evaluated the BANCS model's repeatability and sensitivity, as well as the model developmental process through the creation of a provisional streambank erosion rate prediction curve for the Central Great Plains ecoregion. Based on the results of this study and others, a detailed procedure for creating future BANCS models was suggested that addresses several model limitations and criticisms and may also improve future models' statistical fit and significance. Subsequent research will enhance the procedure, improve the overall understanding of streambank erosion processes, and increase the predictive power of future BANCS models.

References

Albert, C. D., & Stramel, G. J. (1966). *Fluvial sediment in the Little Arkansas River basin Kansas.* (No. 1798-B). Washington, D.C.: United States Government Printing Office.

ACIS (Applied Climate Information System). (2016). *NOWData - NOAA online weather data* NOAA.

Bandyopadhyay, S., Saha, S., Ghosh, K., & De, S. N. (2013). Validation of BEHI model through field generated data for assessing bank erosion along the River Haora, west Tripura, India. *Earth Science India, 6*(3), 126-135.

Belmont, P., Gran, K. B., Schottler, S. P., Wilcook, P. R., Day, S. S., Jennings, C., . . . Parker, G. (2011). Large shift in source of fine sediment in the upper Mississippi River. *Environmental Science & Technology, 45*(20), 8804-8810.

Bull, L. J. (1997). Magnitude and variation in the contribution of bank erosion to the suspended sediment load of the River Severn, UK. *Earth Surface Processes and Landforms, 22*, 1109-1123.

Casagli, N., Rinaldi, M., Gargini, A., & Curini, A. (1999). Pore water pressure and streambank stability: Results from a monitoring site on the Sieve River, Italy. *Earth Surface Processes and Landforms, 24*, 1095-1114.

Chapman, S. S., Omernik, J. M., Freeouf, J. A., Huggins, D. G., McCauley, J. R., Freeman, C. C., . . . Schlepp, R. L. (2010). *Ecoregions of Nebraska and Kansas.* Reston, Virginia: U.S. Geological Survey.

College of Agriculture and Life Sciences – University of Wisconsin. (2004). In John Peters (Ed.), *Lab procedures and methods*. Madison: University of Wisconsin-Extension-Madison.

Connell, B. A. (2012). GIS-based streambank video mapping to determine erosion susceptible areas (Master's Thesis, University of Tennessee).

Coryat, M. (2011). Analysis of the bank assessment for non-point source consequences of sediment (BANCS) approach for the prediction of streambank stability and erosion along Stony Clove Creek in the Catskills (Master of Science, Syracuse University).

Couper, P. R. (2004). Space and time in river bank erosion research: A review. *Area, 36.4*, 387-403.

Couper, P. R., & Maddock, I. P. (2001). Subaerial river bank processes and their interaction with other bank erosion mechanisms on the River Arrow, Warwickshire, UK. *Earth Surface Processes and Landforms, 26*, 631-646.

Davis, S. L., & Starr, R. R. (2008). *Moores Run, Baltimore City, Maryland 2007 abbreviated geomorphic condition and channel stability resurvey.* (No. CFBO-SO8-02). Annapolis, MD: United States Fish and Wildlife Service.

Downing, D. J., Gardner, R. H., & Hoffman, F. O. (1985). An examination of response-surface methodologies for uncertainty analysis in assessment models. *Technometrics, 27*(2), 151-163.

Doyle, M. W., & Harbor, J. M. (2000). Discussion of "Evaluation of Rosgen's streambank erosion potential assessment in northeast Oklahoma," by R. Daren Harmel, C.T. Haan, and Russell C. Dutnell. *Journal of American Water Resources Association, 36*(5), 1191-1192.

Dunne, T., & Leopold, L. B. (1978). *Water in environmental planning*. New York: W.H. Freeman and Company.

Emmert, B., & Hase, K. (2001). Geomorphic assessment and classification of Kansas riparian systems. (No. CD 997520-01). U.S. EPA.

Eng, C. K., Fleming, K. M., & Starr, R. R. (2007). *Stony Run, Baltimore City, Maryland geomorphic baseline survey.* (No. CFBO-SO6-03). Annapolis, MD: United States Fish and Wildlife Service.

Evans, D. J., Gibson, C. E., & Rossell, R. S. (2006). Sediment loads and sources in heavily modified Irish catchments: A move towards informed management strategies. *Geomorphology, 79*, 93-113.

Fitzpatrick, F. A., Knox, J. C., & Whitman, H. E. (1999). *Effects of historical land-cover changes on flooding and sedimentation, North Fish Creek, Wisconsin.* (Water-Resources Investigations Report No. 99-4083). Middleton, WI: U.S. Geological Survey.

Florsheim, J. L., Mount, J. F., & Chin, A. (2008). Bank erosion as a desirable attribute of rivers. *BioScience, 58*(6), 519-529.

Fox, G. A., Wilson, G. V., Simon, A., Langendoen, E. J., Akay, O., & Fuchs, J. W. (2007). Measuring streambank erosion due to ground water seepage: Correlation to bank pore water pressure, precipitation and stream stage. *Earth Surface Processes and Landforms, 32*, 1558-1573.

Ghosh, K. G., Pal, S., & Mukhopadhyay, S. (2016). Validation of BANCS model for assessing stream bank erosion hazard potential (SBEHP) in Bakreshwar River of Rarh region, eastern India. *Modeling Earth Systems and Environment, 2*(95), 1-15.

Goudie, A. S. (2006). Global warming and fluvial geomorphology. *Geomorphology, 79*, 384-394.

Graf, W. L. (2006). Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology, 79*, 336-360.

Gurnell, A. (1997). The hydrological and geomorphological significance of forested floodplains. *Global Ecology and Biogeography Letters, 6*, 219-229.

Hagerty, D. J. (1991). Piping/sapping erosion. I: Basic considerations. *Journal of Hydraulic Engineering, 117*(8), 991-1008.

Hamby, D. M. (1994). A review of techniques for parameter sensitivity analysis of environmental models. *Environmental Monitoring and Assessment, 32*, 135-154.

Harmel, R. D., Haan, C. T., & Dutnell, R. C. (1999). Evaluation of Rosgen's streambank erosion potential assessment in northeast Oklahoma. *Journal of American Water Resources Association, 35*(1), 113-121.

Hensley, K. J. (2014). Estimating streambank erosion using GPS-based watershed-scale video mapping and USEPA BANCS for development of sediment TMDLs (Master's Thesis, University of Tennessee).

Jennings, G. D., & Harman, W. A. (2001). Measurement and stabilization of streambank erosion in North Carolina. *Soil Erosion Research for the 21st Century, Proc. Int. Symp.* Honolulu, HI. 537-540.

Johnson, P. A., & Heil, T. M. (1996). Uncertainty in estimating bankfull conditions. *Water Resources Bulletin, 32*(6), 1283-1291.

Juracek, K. E., & Fitzpatrick, F. A. (2003). Limitations and implications of stream classification. *Journal of American Water Resources Association, 39*(3), 659-670.

KDHE (Kansas Department of Health and Environment). (2014). Lower Arkansas basin total maximum daily load - waterbody/ assessment unit: Little Arkansas river watershed, water quality impairment: Total suspended solids (TSS). Topeka: Kansas Department of Health and Environment.

Kronvang, B., Grant, R., & Laubel, A. L. (1997). Sediment and phosphorus export from a lowland catchment: Quantification of sources. *Water, Air and Soil Pollution, 99*, 465-476.

Kwan, H., & Swanson, S. (2014). Prediction of annual streambank erosion for Sequoia National Forest, California. *Journal of American Water Resources Association, 50*(6), 1439-1447.

Lane, E. W. (1955). The importance of fluvial morphology in hydraulic engineering. *American Society of Civil Engineering, 81* 1-17.

Lawler, D. M. (1993a). The measurement of river bank erosion and lateral channel change: A review. *Earth Surface Processes and Landforms, 18*, 777-821.

Lawler, D. M. (1993b). Needle ice processes and sediment mobilization on river banks: The River Ilston, West Glamorgan, UK. *Journal of Hydrology, 150*, 81-114.

Lawler, D. M., Grove, J. R., Couperthwaite, J. S., & Leeks, G. J. L. (1999). Downstream change in river bank erosion rates in the Swale-Ouse system, northern England. *Hydrological Processes, 13*, 977-992.

Legendre, P. (2010). Coefficient of concordance. *Encyclopedia of research design, vol. 1* (N.J. Salkind ed., pp. 164-169). Los Angeles: SAGE Publications, Inc.

Lenth, R. V. (2009). Java applets for power and sample size [computer software]. Retrieved from http://homepage.stat.uiowa.edu/~rlenth/Power/

Leopold, L. B., Wolman, M. G., & Miller, J. P. (1964). *Fluvial processes in geomorphology*. New York: Dover Publications, Inc.

Markowitz, G., & Newton, S. (2011). Using bank assessment for non-point source consequences of sediment (BANCS) model to prioritize potential stream bank erosion on Birch Creek, Shandaken, New York. Phoenicia, NY: Ashokan Watershed Stream Management Program.

MDEQ (Michigan Department of Environmental Quality). (2008). *Stream stability assessment guidelines for NPS grant applicants.* Unpublished manuscript.

Minitab, I. (2016). Using kappa statistics and Kendall's coefficients. Retrieved from http://support.minitab.com/en-us/minitab/17/topic-library/basic-statistics-and-graphs/tables/other-statistics-and-tests/using-kappa-statistics-and-kendall-s-coefficients/

Mukundan, R., Radcliffe, D. E., Ritchie, J. C., Risse, L. M., & McKinley, R. A. (2010). Sediment fingerprinting to determine the source of suspended sediment in a southern Piedmont stream. *Journal of Environmental Quality, 39*, 1328-1337.

NRCS (Natural Resources Conservation Service). (2007). *Kansas annual precipitation*. Salina, KS: United States Department of Agriculture.

Newton, S. E., & Drenten, D. M. (2015). Modifying the bank erosion hazard index (BEHI) protocol for rapid assessment of streambank erosion in northeastern Ohio. *Journal of Visualized Experiments, 96*, e52330.

Omernik, J. M. (1987). Ecoregions of the conterminous United States. *Annals of the Association of American Geographers, 77*(1), 118-125.

Parker, C., Simon, A., & Thorne, C. R. (2008). The effects of variability in bank material properties on riverbank stability: Goodwin Creek, Mississippi. *Geomorphology, 101*, 533-543.

Patterson, J. M., Clinton, D. R., Harman, W. A., Jennings, G. D., & Slate, L. O. (1999). Development of streambank erodibility relationships for North Carolina streams. *Journal of American Water Resources Association, June/July*, 117-123.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences, 11*, 1633-1644.

Rathbun, J. (2011). *Assessing bank erosion potential using a modified version of Rosgen's bank erosion hazard index (BEHI).* (Standard Operating Procedure). Lansing: Michigan Department of Environmental Quality.

Rondeau, B., Cossa, D., Gagnon, P., & Bilodeau, L. (2000). Budget and sources of suspended sediment transported in the St. Lawrence River, Canada. *Hydrological Processes, 14*, 21-36.

Roper, B. P., Buffington, J. M., Archer, E., Moyer, C., & Ward, M. (2008). The role of observer variation in determining Rosgen stream types in northeastern Oregon mountain streams. *Journal of American Water Resources Association, 44*(2), 417-427.

Rosgen, D. (1996a). *Applied river morphology* (First ed.). Pagosa Springs: Wildland Hydrology.

Rosgen, D. (1996b). *Applied river morphology* (Second ed.). Pagosa Springs: Wildland Hydrology.

Rosgen, D. (2001). A practical method of computing streambank erosion rates. *Proceedings of the Seventh Federal Interagency Sedimentation Conference, 2*(2) 9-15.

Rosgen, D. (2006). *Watershed assessment of river stability and sediment supply (WARSSS)* (First ed.). Fort Collins: Wildland Hydrology.

Rosgen, D. (2008). Discussion "Critical evaluation of how the Rosgen classification and associated 'natural channel design' methods fail to integrate and quantify fluvial processes and channel responses" by A. Simon, M. Doyle, M. Kondolf, F.D. Shields Jr., B. Rhoads, and M. McPhillips. *Journal of American Water Resources Association, 44*(3), 782-792.

Rosgen, D. (2009). *Watershed assessment of river stability and sediment supply (WARSSS)* (Second ed.). Fort Collins: Wildland Hydrology.

Rosgen, D. (2014). *River stability field guide* (Second ed.). Fort Collins: Wildland Hydrology.

Rosgen, D. (2015). Discussion "Prediction of annual streambank erosion for Sequoia National Forest, California" by Hilda Kwan and Sherman Swanson. *Journal of American Water Resources Association, 51*(2), 567.

Sass, C. K. (2011). Evaluation and development of predictive streambank erosion curves for northeast Kansas using Rosgen's "BANCS" methodology (Doctor of Philosophy, Kansas State University).

Sass, C. K., & Keane, T. D. (2012). Application of Rosgen's BANCS model for NE Kansas and the development of predictive streambank erosion curves. *Journal of the American Water Resources Association, 48*(4), 774-787.

Schumm, S. A., Harvey, M. D., & Watson, C. C. (1984). *Incised channels, morphology, dynamics and control*. Littleton: Water Resources Publications.

Sekely, A. C., Mulla, D. J., & Bauer, D. W. (2002). Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation, 57*(5), 243-250.

Simon, A. (1989). A model of channel response in disturbed alluvial channels. *Earth Surface Processes and Landforms, 14*, 11-26.

Simon, A. (1994). *Gradation processes and channel evolution in modified west Tennessee streams: Process, response, and form.* (U.S. Geological Survey Professional Paper No. 1470). Washington, D.C.: United States Government Printing Office.

Simon, A., & Collison, A. J. C. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms, 27*, 527-546.

Simon, A., Curini, A., Darby, S. E., & Langendoen, E. J. (2000). Bank and near-bank processes in an incised channel. *Geomorphology, 35*, 193-217.

Simon, A., Doyle, M., Kondolf, M., Shields Jr., F.D., Rhoads, B., & McPhillips, M. (2007). Critical evaluation of how the Rosgen classification and associated "natural channel design" methods fail to integrate and quantify fluvial processes and channel response. *Journal of American Water Resources Association, 43*(5), 1117-1131.

Simon, A., & Hupp, C. R. (1987). Geomorphic and vegetative recovery processes along modified Tennessee streams: An interdisciplinary approach to distributed fluvial systems. *Forest Hydrology and Watershed Management - Proceedings of the Vancouver Symposium,* Vancouver. (167) 251-262.

Simpson, A., Turner, I., Brantley, E., & Helms, B. (2014). Bank erosion hazard index as an indicator of near-bank aquatic habitat and community structure in a southeastern Piedmont stream. *Ecological Indicators, 43*, 19-28.

Stantec Consulting Services, I. (2013). *RIVERMorph 5.2.0* (Professional ed.) Stantec Consulting Services, Inc.

Thorne, C. R., & Tovey, K. (1981). Stability of composite river banks. *Earth Surface Processes and Landforms, 6*, 469-484.

Trimble, S. W. (1997). Contribution of stream channel erosion to sediment yield from an urbanizing watershed. *Science, 278*, 1442-1444.

U.S. EPA. (2012). 5.8 total solids. Retrieved from http://water.epa.gov/type/rsl/monitoring/vms58.cfm

U.S. EPA. (2016). Water quality assessment and TMDL information. Retrieved from http://ofmpub.epa.gov/waters10/attains_nation_cy.control

USGS. (2014). Boundary descriptions and names of regions, sub regions, accounting units and cataloging units. Retrieved from http://water.usgs.gov/GIS/huc_name.html#Region11

USGS. (2016). USGS 07143665 L Arkansas R at Alta Mills, KS. Retrieved from http://waterdata.usgs.gov/ks/nwis/uv?site_no=07143665

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. *Self-Sustaining Solutions for Streams, Wetlands, and Watersheds,* St. Paul, Minnesota. 125-132.

Warren, D. R., Blain, G. T., Shorney, F. L., & Klein, L. J. (1995). IRP: A case study from Kansas. *American Water Works Association, 87*(6), 57-71.

Wildland Hydrology. (2015). Short course schedule. Retrieved from http://www.wildlandhydrology.com/html/courses.htm

Williams, G. P. (1978). Bank-full discharge of rivers. *Water Resources Research, 14*(6), 1141-1154.

Wilson, C. G., Kuhnle, R. A., Bosch, D. D., Steiner, J. L., Starks, P. J., Tomer, M. D., & Wilson, G. V. (2008). Quantifying relative contributions from sediment sources in conservation effects assessment project watersheds. *Journal of Soil and Water Conservation, 63*(6), 523-532.

Ziegler, A. (2014). Equus Beds groundwater recharge project. Retrieved from http://ks.water.usgs.gov/equus-beds-recharge

Appendix A - Study Stream Reach Classification Worksheets

Stream: **Black Kettle Creek**				
Basin:	Drainage Area: **19264** acres	**30.1**	mi^2	
Location:				
Twp.&Rge: **;**	Sec.&Qtr.: **;**			
Cross-Section Monuments (Lat./Long.): **38.072242 Lat / -97.553625 Long**			Date: **03/24/06**	
Observers: **Keane, Barnes, Neel**			Valley Type: U-AL-FD	

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**35.38**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**1.74**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**61.39**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**20.33**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**2.63**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**75.88**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**2.14**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.062**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00066**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.45**	

Stream Type	**B 6c**	(See **Figure 2-14**)

Stream: **Dry Turkey Creek**	
Basin: Drainage Area: **24256** acres **37.9** mi^2	
Location:	
Twp.&Rge: **;**	Sec.&Qtr.: **;**
Cross-Section Monuments (Lat./Long.): **38.289659 Lat / -97.610023 Long**	Date: **05/19/09**
Observers: **Keane, Barnes, Morrow, Moss**	Valley Type: U-AL-FD

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**30.72**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**2.35**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**72.29**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**13.07**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**3.35**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**68.85**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**2.24**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.07**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00052**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.1**	

Stream Type **C 5c-** (See **Figure 2-14**)

Stream: **Lower Little Arkansas River**	
Basin:	Drainage Area: **823808** acres **1287.2** mi^2
Location:	
Twp.&Rge: **;**	Sec.&Qtr.: **;**
Cross-Section Monuments (Lat./Long.): **37.860637 Lat / 97.408547 Long**	Date: **03/16/15**
Observers: **Bigham, Zortman, Moore, Cleve**	Valley Type: U-AL-FD

Parameter	Value	Units
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**159.61**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**8.09**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**1291.47**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**19.73**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**10.61**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**790**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**4.95**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**1.1**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00034**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.4**	

Stream Type → **C 5c-** ← (See **Figure 2-14**)

Stream: **Middle Little Arkansas River**	
Basin:	Drainage Area: **435840** acres **681** mi^2
Location:	
Twp.&Rge: **;**	Sec.&Qtr.: **;**
Cross-Section Monuments (Lat./Long.): **38.112326 Lat / -97.592048 Long**	Date: **03/17/15**
Observers: **Bigham, Moore, Cleve, Zortman**	Valley Type: U-AL-FD

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**97.1**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**10.23**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**993.21**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**9.49**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**15.93**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**1000**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**10.3**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.21**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00028**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**2.13**	

Stream Type **E 5** (See **Figure 2-14**)

Stream: **Upper Little Arkansas River**			
Basin:	Drainage Area: **214464** acres	**335.1**	mi^2
Location:			
Twp.&Rge: **;**	Sec.&Qtr.: **;**		
Cross-Section Monuments (Lat./Long.): **38.105227 Lat / -97.684083 Long**		Date: **03/18/15**	
Observers: **Bigham, Moore, Cleve, Zortman**		Valley Type: U-AL-FD	

Parameter	Value	Unit
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**63.25**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**6.15**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**389.18**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**10.28**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**8.99**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**350**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**5.53**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.14**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00346**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.83**	

Stream Type **E 5** (See **Figure 2-14**)

Stream: **Running Turkey Creek**				
Basin:	Drainage Area: **23040** acres	**36**	mi^2	
Location:				
Twp.&Rge: **;**	Sec.&Qtr.: **;**			
Cross-Section Monuments (Lat./Long.): **38.290662 Lat / -97.593065 Long**		Date: **08/08/07**		
Observers: **Neel, Dale**		Valley Type: U-AL-FD		

Parameter	Value	Unit
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**23.07**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**2.21**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**51**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**10.44**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**3.25**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**28.23**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**1.22**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.32**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00109**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.1**	

Stream Type **G5c** (See **Figure 2-14**)

Stream: **Lower West Emma**			
Basin:	Drainage Area: **55168** acres	**86.2**	mi^2
Location:			
Twp.&Rge: **;**	Sec.&Qtr.: **;**		
Cross-Section Monuments (Lat./Long.): **38.086728 Lat / -97.471674 Long**		Date: **05/27/09**	
Observers: **Keane, Barnes, Morrow, Moss**		Valley Type: U-AL-FD	

Parameter	Value	Units
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**64.4**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**2.06**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**132.63**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**31.26**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**4.47**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**92**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**1.43**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.2**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00018**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.14**	

Stream Type **B 5c** (See **Figure 2-14**)

Stream:	**Upper West Emma Creek**
Basin:	Drainage Area: **30912** acres **48.3** mi^2
Location:	
Twp.&Rge: **;**	Sec.&Qtr.: **;**
Cross-Section Monuments (Lat./Long.): **38.231991 Lat / -97.441849 Long**	Date: **05/26/09**
Observers: **Keane, Barnes, Moss, Morrow**	Valley Type: U-AL-FD

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**59.02**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**1.07**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**63.39**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**55.16**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**2.59**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**160**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**2.71**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**0.72**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00094**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.2**	

Stream Type **C 5c-** (See **Figure 2-14**)

Appendix B - Research Involving Human Subjects – IRB #7733

KANSAS STATE UNIVERSITY | University Research Compliance Office

TO: Trisha Moore
Biological & Ag Engineering
153 Seaton

Proposal Number: 7733

FROM: Rick Scheidt, Chair
Committee on Research Involving Human Subjects

DATE: 04/30/15

RE: Proposal Entitled, "Evaluation & Application of the BANCS Model to Predict Annual Streambank Erosion Rates in South-Central Kansas Watershed"

The Committee on Research Involving Human Subjects / Institutional Review Board (IRB) for Kansas State University has reviewed the proposal identified above and has determined that it is EXEMPT from further IRB review. This exemption applies only to the proposal - as written – and currently on file with the IRB. Any change potentially affecting human subjects must be approved by the IRB prior to implementation and may disqualify the proposal from exemption.

Based upon information provided to the IRB, this activity is exempt under the criteria set forth in the Federal Policy for the Protection of Human Subjects, **45 CFR §46.101, paragraph b, category: 2, subsection: ii.**

Certain research is exempt from the requirements of HHS/OHRP regulations. A determination that research is exempt does not imply that investigators have no ethical responsibilities to subjects in such research; it means only that the regulatory requirements related to IRB review, informed consent, and assurance of compliance do not apply to the research.

Any unanticipated problems involving risk to subjects or to others must be reported immediately to the Chair of the Committee on Research Involving Human Subjects, the University Research Compliance Office, and if the subjects are KSU students, to the Director of the Student Health Center.

203 Fairchild Hall, Lower Mezzanine, Manhattan, KS 66506-1103 | 785-532-3224 | fax: 785-532-3278 | k-state.edu/research/comply | comply@ksu.edu

Appendix C - Rater Packet Example

Instructions

BANCS Assessment #1 – Little Arkansas River Watershed – Tuesday, June 30, 2015

Tentative Schedule

10:00 am – Arrive at Lower West Emma Site

10-10:15 am – Introduction - Hand-out forms/info

10:15 am – Training 1: Provided by Tim Keane

11:15 am – Individual assessment on 3 study banks on Lower West Emma Creek

12:15 pm – Leave for Training 2 at Middle Little Arkansas River Training Site

12:30 pm – Lunch at Middle Little Arkansas River Training Site

1:00 pm –Training 2: Provided by Tim Keane

2:00 pm – Leave for Middle Little Arkansas Assessment Site

2:10 pm – Individual assessment on 3 study banks on Middle Little Arkansas River

3:10 pm – Gather Data/Depart

Instructions for Individual Assessment

1. **Divide into groups of 3-4 people**, each group starts at 1 of the 3 study streambanks.

2. **Assess the study bank using BEHI** (Worksheet 3-11) based on what you learned from the training and your own experience.

- Make sure to **fill out worksheet 3-11** provided in handout. One worksheet should be filled out for each study bank.
- Make sure to **write down which study bank you are on and your name** at the top of each worksheet.
- **Write down what instrument you used** to measure bank height, bankfull height, and root depth.
- **Tools/Items available to you:**
    - Rangefinder
    - Survey Rods
    - Pitch & Angle
    - 100' Tape Measure
    - Pocket Rod
    - Regional Curves for South-Central Kansas (in handouts)

    - Scaled, Aerial Maps w/ Drainage Area (in handouts)
    - Hard copy of the River Stability Field Guide
    - Please **ask the group leader if you are missing something** for measurement.
- **Notes:**
    - Do your best not to disturb the streambanks to **prevent "foot shear."**
    - There should be **no communication** between individuals during the assessment related to the measurements.
    - Please do your best **not to watch others while they are taking measurements** to prevent bias.

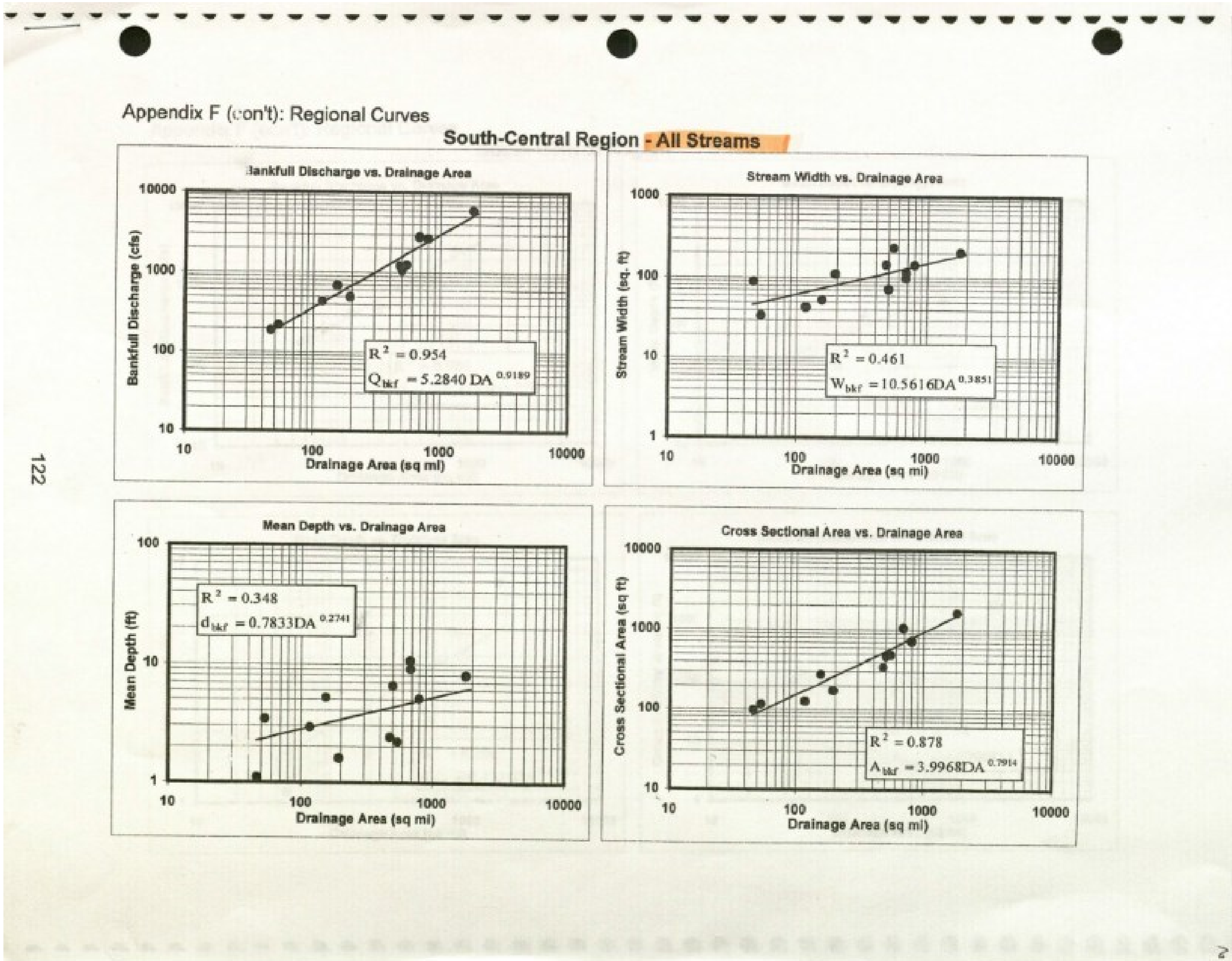
3. **Assess the study bank using NBS** (Worksheet 3-12) based on what you learned from the training and from your own experience.

- Since no real data is given to you to calculate ratios, **select what method(s) you would use** to measure NBS for this specific study streambank. Assume that **Method 7 is not a feasible option**.
- **Circle what method(s) you would use on Worksheet 3-12**. One worksheet should be filled out for each study bank.
- Make sure to **write down which study bank you are on and your name** at the top of each worksheet.
- **Tools/Items available to you:**
    - Survey Rods
    - Pitch & Angle
    - 100' Tape Measure
    - Pocket Rod
    - Regional Curves for South-Central Kansas (in handouts)
    - Scaled, Aerial Maps w/ Drainage Area (in handouts)
    - Hard copy of the River Stability Field Guide
    - Please **ask the group leader if you are missing something** for measurement.
- **Notes:**
    - Do your best not to disturb the streambanks to **prevent "foot shear."**
    - There should be **no communication** between individuals during the assessment related to the measurements and assessment.
    - Please do your best **not to watch others while they are taking measurements** to prevent bias.

4. When your group is done, **proceed to the next study streambank**. If the group prior to you is not done, wait until that group has completed their assessment. Do not watch them take measurements to prevent bias.

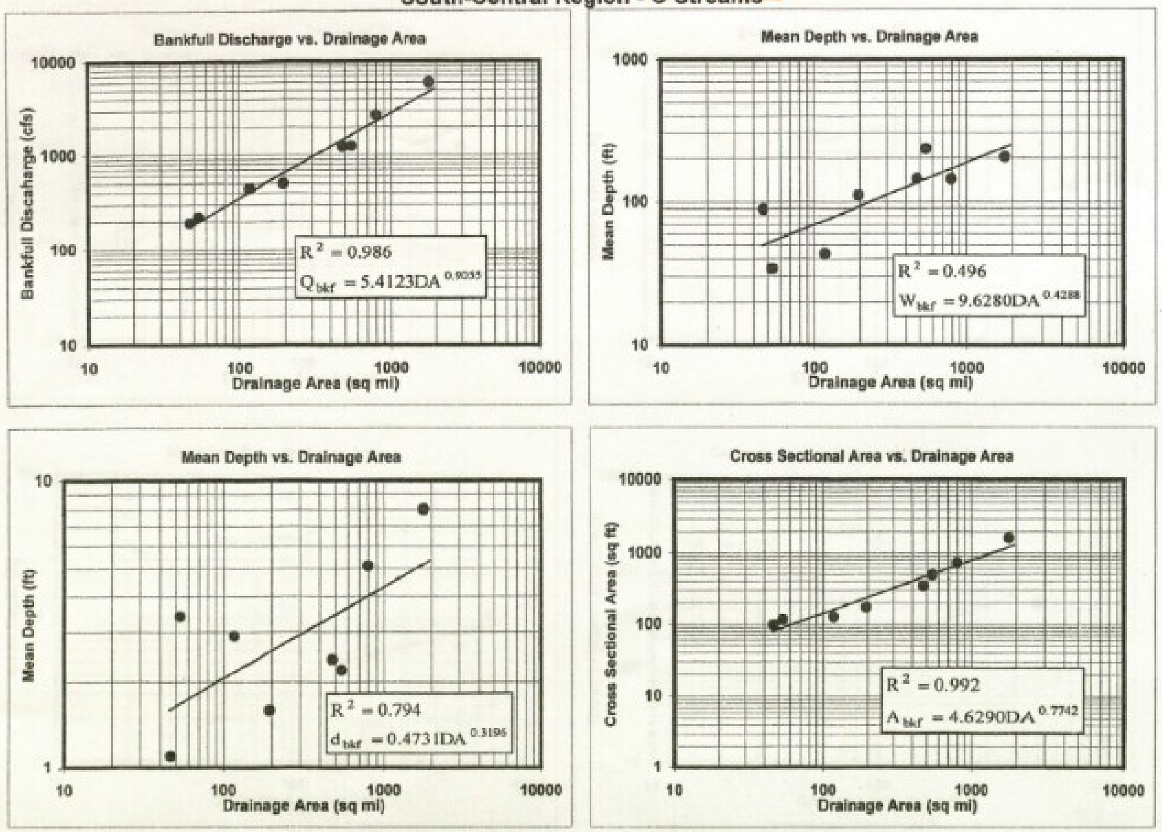
5. When you have completed all 3 study streambanks, **please hand in all worksheets to Kari Bigham.** At the end of the day, please hand in all materials/equipment. This includes regional curves, maps, anything that was handed to you at the beginning of the day. You may keep these items after the 2^{nd} assessment in August. Also**, please do not discuss what you got for ratings with group members following the assessment** until after the 2^{nd} assessment is over with in August to prevent bias during the 2^{nd} assessment.

Regional Curves for South-Central Kansas (Emmert & Hase, 2001)



Appendix F (con't): Regional Curves

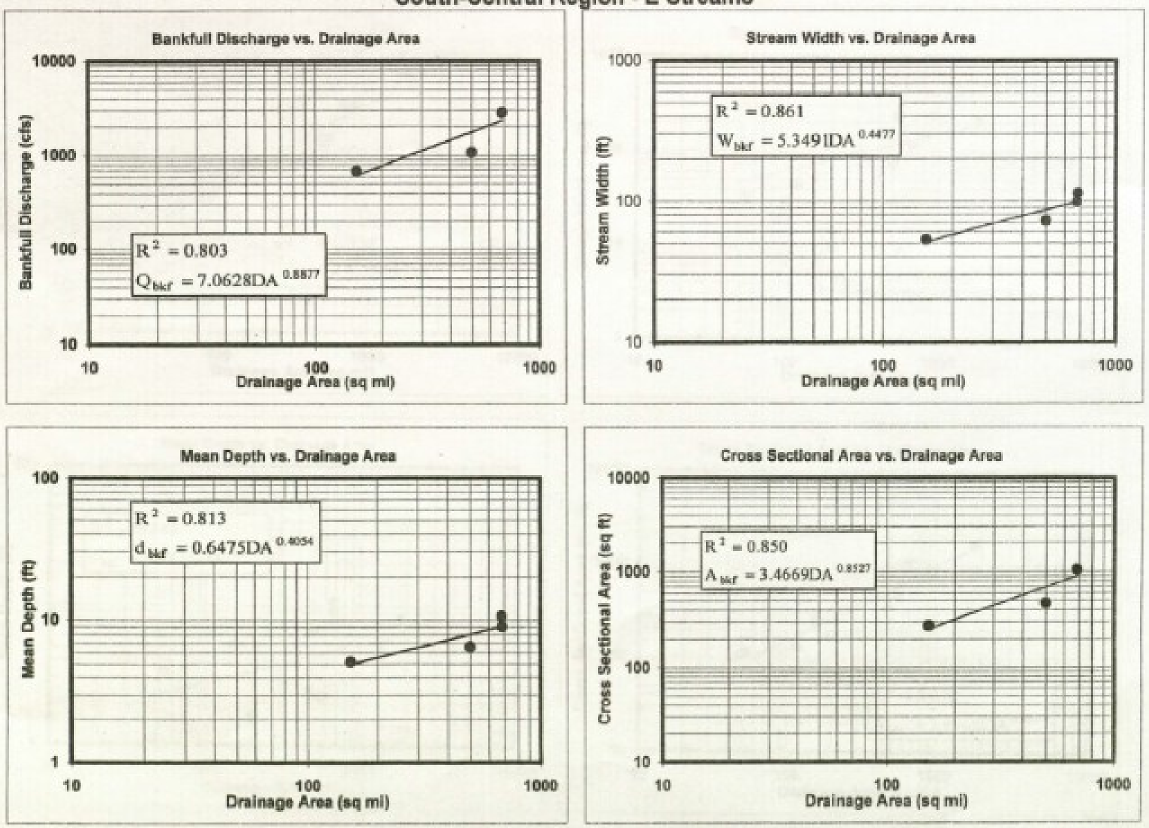
South-Central Region - C Streams



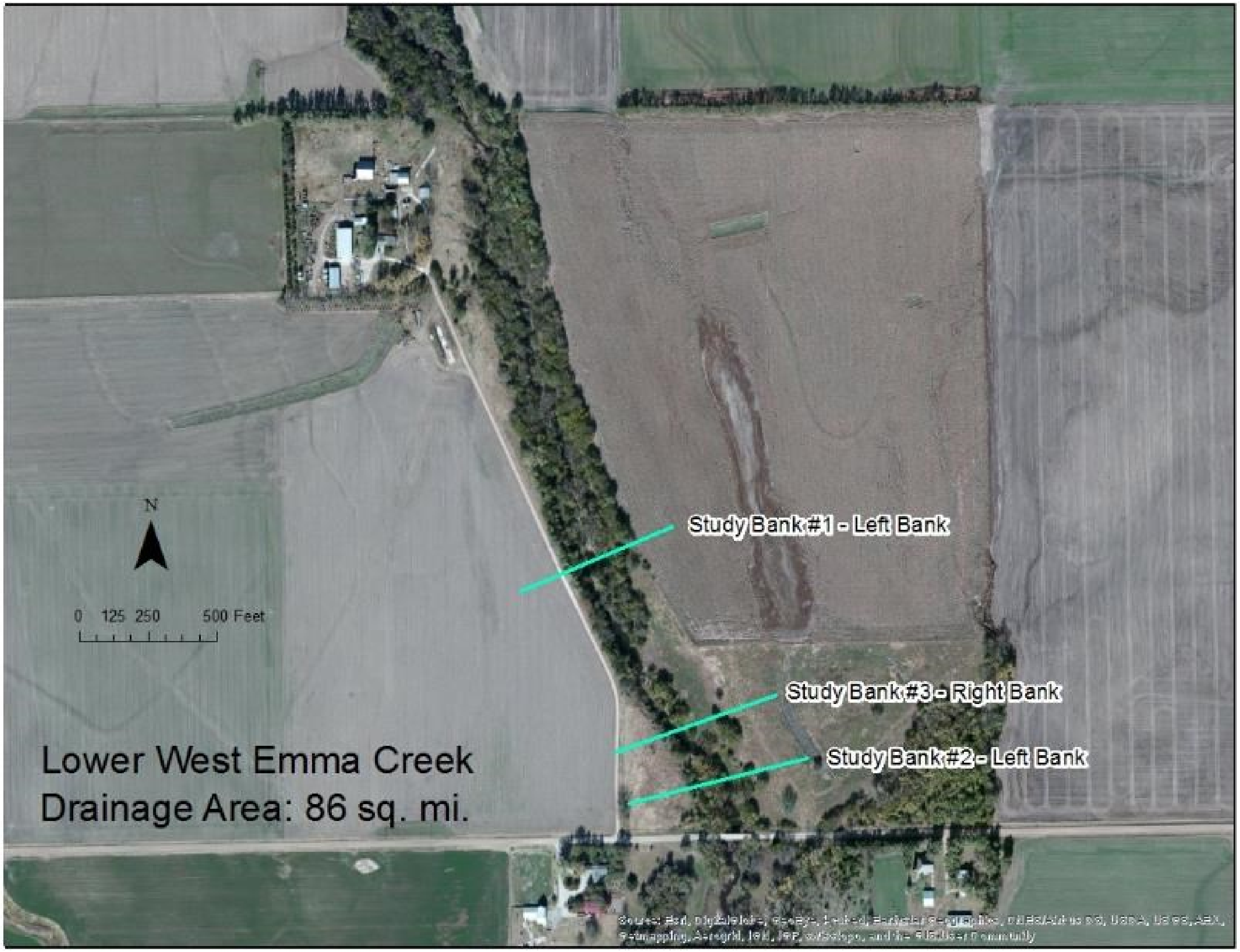
123

Appendix F (con't): Regional Curves

South-Central Region - E Streams



Site Maps


Study Bank #1 - Left Bank
Study Bank #3 - Right Bank
Study Bank #2 - Left Bank
N
0 125 250 500 Feet
Lower West Emma Creek
Drainage Area: 86 sq. mi.


Study Bank #1 - Right Bank
Study Bank #2 - Left Bank
Study Bank #3 - Left Bank
N
0 125 250 500 Feet
Middle Little Arkansas River
Drainage Area: 681 sq. mi.

Bank Erosion Hazard Index (BEHI) & Near-Bank Stress (NBS) Worksheets

(Rosgen, 2009)

Name ______________________________

Worksheet 5-16. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-15** with BEHI variables to determine BEHI score.

Stream:		Location:
Station:		Observers:
Date:	Stream Type:	Valley Type:

SBH Measurement Tool: ______

BkfHeight Measurement Tool: ______

Study Bank Height / Bankfull Height (C) — **BEHI Score (Fig. 5-15)**

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)	

Root Depth Measurement Tool: ______

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)	

Weighted Root Density (G)

Root Density as % =	(F)	(F) x (E) =	(G)	

Bank Angle (H)

Bank Angle as Degrees =	(H)	

Note: Silt/Clay adjustment → No adjustment unless primarily clay, then subtract 20 points (From Rosgen, 2014)

Surface Protection (I)

Surface Protection as % =	(I)	

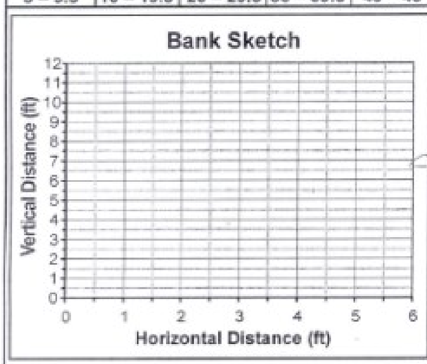
Bank Material Adjustment:

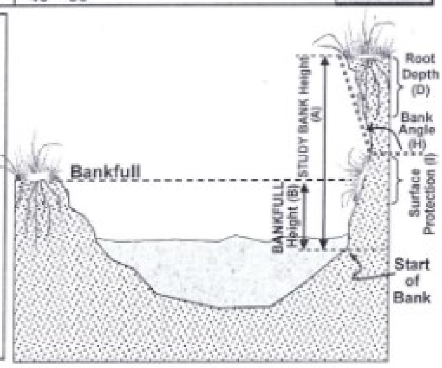
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform med. to large cobble)
Gravel or Composite Matrix (Add 5-10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay ~~(No adjustment)~~ See Note

Bank Material Adjustment →

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	





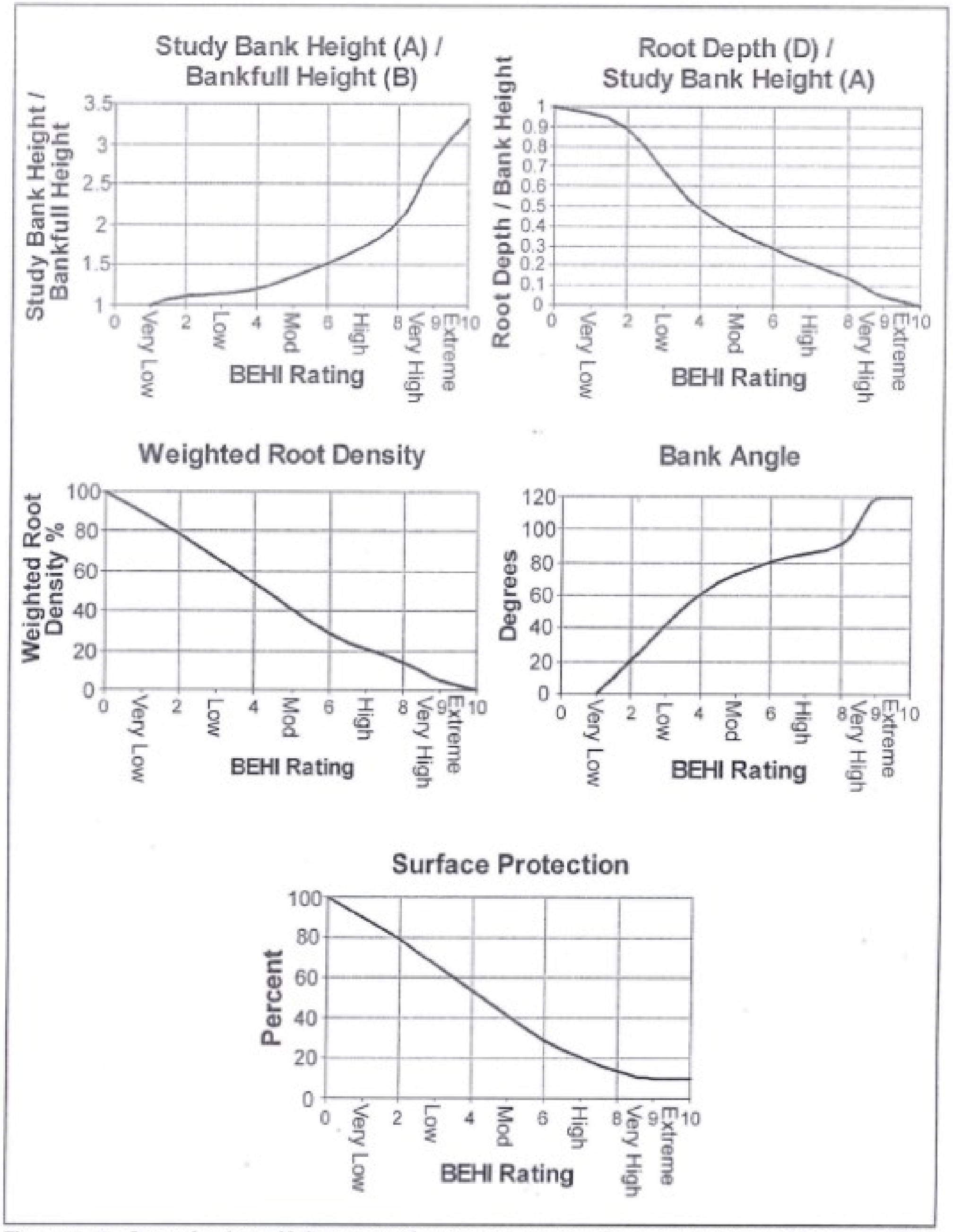


Figure 5-15. Streambank erodibility criteria showing conversion of measured ratios and bank variables to a BEHI rating (Rosgen, 1996, 2001a). Use **Worksheet 5-16** variables to determine BEHI score.

Name

Worksheet 5-17. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream:	Location:	
Station:	Stream Type:	Valley Type:
Observers:		Date:

Methods for Estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General Prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)	Level II	General Prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General Prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed Prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed Prediction
(7) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous ......NBS = High / Very High
	Extensive deposition (continuous, cross-channel) ......NBS = Extreme
	Chute cutoffs, down-valley meander migration, converging flow ......NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)				

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)				

Dominant Near-Bank Stress

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)				

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)		

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) Ratings	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) Rating	

Appendix D – Minitab/SAS/JMP Input and Results

Overall Rater Agreement Analysis

Minitab Input

BEHI[18]

Rater,Sample,BEHI

1,1,4

1,1,4

2,1,5

2,1,4

3,1,4

3,1,5

5,1,5

5,1,4

6,1,4

6,1,5

7,1,3

7,1,3

8,1,6

8,1,5

10,1,5

10,1,5

1,2,3

1,2,4

2,2,5

2,2,5

3,2,4

[18] Sample 1 = LWE1; Sample 2 = LWE2; Sample 3 = LWE3; Sample 4 = MLA1; Sample 5 = MLA2; Sample 6 = MLA3; BEHI = 1 = Very Low; BEHI = 2 = Low; BEHI = 3 = Moderate; BEHI = 4 = High; BEHI = 5 = Very High; BEHI = 6 = Extreme

3,2,5

5,2,4

5,2,4

6,2,4

6,2,4

7,2,2

7,2,5

8,2,4

8,2,6

10,2,5

10,2,5

1,3,3

1,3,3

2,3,3

2,3,4

3,3,3

3,3,3

5,3,5

5,3,4

6,3,3

6,3,3

7,3,1

7,3,3

8,3,3

8,3,3

10,3,3

10,3,4

1,4,6

1,4,3

2,4,4

2,4,3

3,4,5

3,4,5

5,4,3

5,4,4

6,4,3

6,4,2

7,4,4

7,4,5

8,4,6

8,4,6

10,4,4

10,4,3

1,5,2

1,5,3

2,5,2

2,5,2

3,5,2

3,5,3

5,5,2

5,5,3

6,5,2

6,5,2

7,5,1

7,5,1

8,5,2

8,5,2

10,5,3

10,5,2

1,6,4

1,6,4

2,6,4

2,6,3

3,6,5

3,6,5

5,6,4

5,6,5

6,6,3

6,6,4

7,6,4

7,6,4

8,6,6

8,6,4

10,6,4

10,6,3

NBS[19]

Rater,Sample,NBS

1,1,5

1,1,6

2,1,2

2,1,2

3,1,6

3,1,6

5,1,6

5,1,6

6,1,6

6,1,6

7,1,5

[19] Sample 1 = LWE1; Sample 2 = LWE2; Sample 3 = LWE3; Sample 4 = MLA1; Sample 5 = MLA2; Sample 6 = MLA3; NBS = 1 = Very Low; NBS = 2 = Low; NBS = 3 = Moderate; NBS = 4 = High; NBS = 5 = Very High; NBS = 6 = Extreme

7,1,6

8,1,6

8,1,6

10,1,2

10,1,6

1,2,4

1,2,4

2,2,4

2,2,4

3,2,4

3,2,4

5,2,4

5,2,4

6,2,4

6,2,4

7,2,1

7,2,2

8,2,4

8,2,2

10,2,4

10,2,4

1,3,6

1,3,6

2,3,3

2,3,3

3,3,3

3,3,3

5,3,1

5,3,3

6,3,6

6,3,6

7,3,6

7,3,6

8,3,6

8,3,6

10,3,3

10,3,3

1,4,4

1,4,4

2,4,4

2,4,4

3,4,4

3,4,4

5,4,4

5,4,4

6,4,4

6,4,4

7,4,1

7,4,4

8,4,4

8,4,4

10,4,1

10,4,4

1,5,6

1,5,6

2,5,2

2,5,2

3,5,5

3,5,5

5,5,5

5,5,2

6,5,6

6,5,6

7,5,6

7,5,3

8,5,5

8,5,6

10,5,6

10,5,4

1,6,6

1,6,6

2,6,3

2,6,3

3,6,6

3,6,6

5,6,6

5,6,6

6,6,6

6,6,6

7,6,6

7,6,6

8,6,6

8,6,6

10,6,6

10,6,6

Results

BEHI

Within Appraisers

```
Assessment Agreement

Appraiser  # Inspected  # Matched  Percent      95% CI
1                   6          3    50.00  (11.81, 88.19)
2                   6          2    33.33  ( 4.33, 77.72)
```

3	6	3	50.00	(11.81, 88.19)
5	6	1	16.67	(0.42, 64.12)
6	6	3	50.00	(11.81, 88.19)
7	6	3	50.00	(11.81, 88.19)
8	6	3	50.00	(11.81, 88.19)
10	6	2	33.33	(4.33, 77.72)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	1	*	*	*	*
	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.02857	0.408248	-0.06999	0.5279
	4	0.65714	0.408248	1.60966	0.0537
	5	*	*	*	*
	6	-0.09091	0.408248	-0.22268	0.5881
	Overall	0.21739	0.285658	0.76102	0.2233
2	1	*	*	*	*
	2	1.00000	0.408248	2.44949	0.0072
	3	-0.33333	0.408248	-0.81650	0.7929
	4	-0.50000	0.408248	-1.22474	0.8897
	5	0.55556	0.408248	1.36083	0.0868
	6	*	*	*	*
	Overall	0.09434	0.240273	0.39264	0.3473
3	1	*	*	*	*
	2	-0.09091	0.408248	-0.22268	0.5881
	3	0.55556	0.408248	1.36083	0.0868
	4	-0.20000	0.408248	-0.48990	0.6879
	5	0.33333	0.408248	0.81650	0.2071
	6	*	*	*	*
	Overall	0.23404	0.262459	0.89173	0.1863
5	1	*	*	*	*
	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.20000	0.408248	-0.48990	0.6879
	4	-0.33333	0.408248	-0.81650	0.7929
	5	-0.33333	0.408248	-0.81650	0.7929
	6	*	*	*	*
	Overall	-0.27660	0.262459	-1.05386	0.8540
6	1	*	*	*	*
	2	0.55556	0.408248	1.36083	0.0868
	3	0.25000	0.408248	0.61237	0.2701
	4	0.25000	0.408248	0.61237	0.2701
	5	-0.09091	0.408248	-0.22268	0.5881
	6	*	*	*	*
	Overall	0.29412	0.255279	1.15214	0.1246
7	1	0.55556	0.408248	1.36083	0.0868
	2	-0.09091	0.408248	-0.22268	0.5881
	3	0.55556	0.408248	1.36083	0.0868
	4	0.55556	0.408248	1.36083	0.0868
	5	-0.20000	0.408248	-0.48990	0.6879
	6	*	*	*	*
	Overall	0.35714	0.214781	1.66282	0.0482
8	1	*	*	*	*
	2	1.00000	0.408248	2.44949	0.0072
	3	1.00000	0.408248	2.44949	0.0072
	4	-0.20000	0.408248	-0.48990	0.6879
	5	-0.09091	0.408248	-0.22268	0.5881
	6	-0.02857	0.408248	-0.06999	0.5279
	Overall	0.32075	0.221782	1.44626	0.0741
10	1	*	*	*	*

2	-0.09091	0.408248	-0.22268	0.5881
3	-0.50000	0.408248	-1.22474	0.8897
4	-0.33333	0.408248	-0.81650	0.7929
5	1.00000	0.408248	2.44949	0.0072
6	*	*	*	*
Overall	0.05882	0.255279	0.23043	0.4089

* When no or all responses across trials equal the value, kappa cannot be computed.

Kendall's Coefficient of Concordance

Appraiser	Coef	Chi - Sq	DF	P
1	0.600000	6.00000	5	0.3062
2	0.856061	8.56061	5	0.1279
3	0.921053	9.21053	5	0.1010
5	0.715517	7.15517	5	0.2094
6	0.904762	9.04762	5	0.1072
7	0.818182	8.18182	5	0.1465
8	0.823077	8.23077	5	0.1440
10	0.869231	8.69231	5	0.1220

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
6	0	0.00	(0.00, 39.30)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
1	0.013620	0.0372678	0.3655	0.3574
2	0.428571	0.0372678	11.4998	0.0000
3	0.156044	0.0372678	4.1871	0.0000
4	0.100772	0.0372678	2.7040	0.0034
5	0.090526	0.0372678	2.4291	0.0076
6	0.004444	0.0372678	0.1193	0.4525
Overall	0.148467	0.0195227	7.6048	0.0000

Kendall's Coefficient of Concordance

Coef	Chi - Sq	DF	P
0.566625	45.33	5	0.0000

Attribute Agreement Analysis

W Significance

BEHI	
W	0.566625
M	16
n	6
F	**19.61206**
v1	4.875
v2	73.125
alpha	0.05
Fcv	**2.36**
	Reject H_0

NBS

Within Appraisers

```
Assessment Agreement

Appraiser  # Inspected  # Matched  Percent       95% CI
1                    6          5    83.33  (35.88,  99.58)
2                    6          6   100.00  (60.70, 100.00)
3                    6          6   100.00  (60.70, 100.00)
5                    6          4    66.67  (22.28,  95.67)
6                    6          6   100.00  (60.70, 100.00)
7                    6          2    33.33  ( 4.33,  77.72)
8                    6          4    66.67  (22.28,  95.67)
10                   6          3    50.00  (11.81,  88.19)

# Matched: Appraiser agrees with him/herself across trials.


Fleiss' Kappa Statistics

Appraiser  Response     Kappa  SE Kappa         Z  P(vs > 0)
1          1                *         *         *          *
           2                *         *         *          *
           3                *         *         *          *
           4          1.00000  0.408248   2.44949     0.0072
           5         -0.09091  0.408248  -0.22268     0.5881
           6          0.65714  0.408248   1.60966     0.0537
           Overall    0.69231  0.333826   2.07386     0.0190
2          1                *         *         *          *
           2          1.00000  0.408248   2.44949     0.0072
           3          1.00000  0.408248   2.44949     0.0072
           4          1.00000  0.408248   2.44949     0.0072
           5                *         *         *          *
           6                *         *         *          *
           Overall    1.00000  0.288675   3.46410     0.0003
3          1                *         *         *          *
           2                *         *         *          *
           3          1.00000  0.408248   2.44949     0.0072
           4          1.00000  0.408248   2.44949     0.0072
           5          1.00000  0.408248   2.44949     0.0072
           6          1.00000  0.408248   2.44949     0.0072
```

	Overall	1.00000	0.245271	4.07713	0.0000
5	1	-0.09091	0.408248	-0.22268	0.5881
	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.09091	0.408248	-0.22268	0.5881
	4	1.00000	0.408248	2.44949	0.0072
	5	-0.09091	0.408248	-0.22268	0.5881
	6	1.00000	0.408248	2.44949	0.0072
	Overall	0.55556	0.217543	2.55377	0.0053
6	1	*	*	*	*
	2	*	*	*	*
	3	*	*	*	*
	4	1.00000	0.408248	2.44949	0.0072
	5	*	*	*	*
	6	1.00000	0.408248	2.44949	0.0072
	Overall	1.00000	0.408248	2.44949	0.0072
7	1	-0.20000	0.408248	-0.48990	0.6879
	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.09091	0.408248	-0.22268	0.5881
	4	-0.09091	0.408248	-0.22268	0.5881
	5	-0.09091	0.408248	-0.22268	0.5881
	6	0.33333	0.408248	0.81650	0.2071
	Overall	0.04000	0.216025	0.18516	0.4266
8	1	*	*	*	*
	2	-0.09091	0.408248	-0.22268	0.5881
	3	*	*	*	*
	4	0.55556	0.408248	1.36083	0.0868
	5	-0.09091	0.408248	-0.22268	0.5881
	6	0.65714	0.408248	1.60966	0.0537
	Overall	0.42857	0.279699	1.53226	0.0627
10	1	-0.09091	0.408248	-0.22268	0.5881
	2	-0.09091	0.408248	-0.22268	0.5881
	3	1.00000	0.408248	2.44949	0.0072
	4	0.25000	0.408248	0.61237	0.2701
	5	*	*	*	*
	6	0.25000	0.408248	0.61237	0.2701
	Overall	0.32075	0.231212	1.38727	0.0827

* When no or all responses across trials equal the value, kappa cannot be computed.

Kendall’s Coefficient of Concordance

Appraiser	Coef	Chi - Sq	DF	P
1	0.94444	9.4444	5	0.0926
2	1.00000	10.0000	5	0.0752
3	1.00000	10.0000	5	0.0752
5	0.81818	8.1818	5	0.1465
6	1.00000	10.0000	5	0.0752
7	0.74590	7.4590	5	0.1887
8	0.93636	9.3636	5	0.0954
10	0.57031	5.7031	5	0.3362

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
6	0	0.00	(0.00, 39.30)

Matched: All appraisers’ assessments agree with each other.

```
Fleiss' Kappa Statistics

Response       Kappa   SE Kappa         Z  P(vs > 0)
1          -0.008696  0.0372678  -0.2333     0.5922
2           0.036364  0.0372678   0.9757     0.1646
3           0.211163  0.0372678   5.6661     0.0000
4           0.724370  0.0372678  19.4369     0.0000
5           0.099259  0.0372678   2.6634     0.0039
6           0.400000  0.0372678  10.7331     0.0000
Overall     0.382830  0.0209822  18.2454     0.0000


Kendall's Coefficient of Concordance

    Coef  Chi - Sq  DF       P
0.290926   23.2741   5  0.0003
```

Attribute Agreement Analysis

W Significance

NBS	
W	0.29
M	16
n	6
F	**6.126761**
v1	4.875
v2	73.125
alpha	0.05
Fcv	**2.36**
	Reject H_0

Training Group A Agreement Analysis

Minitab Input

BEHI[20]

Rater,Sample,BEHI

100,1,4

100,1,4

200,1,5

200,1,4

300,1,4

300,1,5

400,1,5

400,1,4

500,1,4

500,1,5

100,2,3

100,2,4

200,2,5

200,2,5

300,2,4

300,2,5

400,2,4

400,2,4

500,2,4

500,2,4

100,3,3

100,3,3

[20] Rater re-numbered in an effort not to reveal identity; Sample 1 = LWE1; Sample 2 = LWE2; Sample 3 = LWE3; Sample 4 = MLA1; Sample 5 = MLA2; Sample 6 = MLA3; BEHI = 1 = Very Low; BEHI = 2 = Low; BEHI = 3 = Moderate; BEHI = 4 = High; BEHI = 5 = Very High; BEHI = 6 = Extreme

200,3,3

200,3,4

300,3,3

300,3,3

400,3,5

400,3,4

500,3,3

500,3,3

100,4,6

100,4,3

200,4,4

200,4,3

300,4,5

300,4,5

400,4,3

400,4,4

500,4,3

500,4,2

100,5,2

100,5,3

200,5,2

200,5,2

300,5,2

300,5,3

400,5,2

400,5,3

500,5,2

500,5,2

100,6,4

100,6,4

200,6,4

200,6,3

300,6,5

300,6,5

400,6,4

400,6,5

500,6,3

500,6,4

NBS[21]

Rater,Sample,NBS

100,1,5

100,1,6

200,1,2

200,1,2

300,1,6

300,1,6

400,1,6

400,1,6

500,1,6

500,1,6

100,2,4

100,2,4

200,2,4

200,2,4

300,2,4

300,2,4

400,2,4

[21] Rater re-numbered in an effort not to reveal identity; Sample 1 = LWE1; Sample 2 = LWE2; Sample 3 = LWE3; Sample 4 = MLA1; Sample 5 = MLA2; Sample 6 = MLA3; NBS = 1 = Very Low; NBS = 2 = Low; NBS = 3 = Moderate; NBS = 4 = High; NBS = 5 = Very High; NBS = 6 = Extreme

400,2,4

500,2,4

500,2,4

100,3,6

100,3,6

200,3,3

200,3,3

300,3,3

300,3,3

400,3,1

400,3,3

500,3,6

500,3,6

100,4,4

100,4,4

200,4,4

200,4,4

300,4,4

300,4,4

400,4,4

400,4,4

500,4,4

500,4,4

100,5,6

100,5,6

200,5,2

200,5,2

300,5,5

300,5,5

400,5,5

400,5,2

500,5,6

500,5,6

100,6,6

100,6,6

200,6,3

200,6,3

300,6,6

300,6,6

400,6,6

400,6,6

500,6,6

500,6,6

Results

BEHI

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
100	6	3	50.00	(11.81, 88.19)
200	6	2	33.33	(4.33, 77.72)
300	6	3	50.00	(11.81, 88.19)
400	6	1	16.67	(0.42, 64.12)
500	6	3	50.00	(11.81, 88.19)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
100	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.02857	0.408248	-0.06999	0.5279
	4	0.65714	0.408248	1.60966	0.0537
	5	*	*	*	*
	6	-0.09091	0.408248	-0.22268	0.5881
	Overall	0.21739	0.285658	0.76102	0.2233
200	2	1.00000	0.408248	2.44949	0.0072
	3	-0.33333	0.408248	-0.81650	0.7929
	4	-0.50000	0.408248	-1.22474	0.8897
	5	0.55556	0.408248	1.36083	0.0868
	6	*	*	*	*
	Overall	0.09434	0.240273	0.39264	0.3473
300	2	-0.09091	0.408248	-0.22268	0.5881
	3	0.55556	0.408248	1.36083	0.0868
	4	-0.20000	0.408248	-0.48990	0.6879

	5	0.33333	0.408248	0.81650	0.2071
	6	*	*	*	*
	Overall	0.23404	0.262459	0.89173	0.1863
400	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.20000	0.408248	-0.48990	0.6879
	4	-0.33333	0.408248	-0.81650	0.7929
	5	-0.33333	0.408248	-0.81650	0.7929
	6	*	*	*	*
	Overall	-0.27660	0.262459	-1.05386	0.8540
500	2	0.55556	0.408248	1.36083	0.0868
	3	0.25000	0.408248	0.61237	0.2701
	4	0.25000	0.408248	0.61237	0.2701
	5	-0.09091	0.408248	-0.22268	0.5881
	6	*	*	*	*
	Overall	0.29412	0.255279	1.15214	0.1246

* When no or all responses across trials equal the value, kappa cannot be computed.

Kendall’s Coefficient of Concordance

Appraiser	Coef	Chi - Sq	DF	P
100	0.600000	6.00000	5	0.3062
200	0.856061	8.56061	5	0.1279
300	0.921053	9.21053	5	0.1010
400	0.715517	7.15517	5	0.2094
500	0.904762	9.04762	5	0.1072

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
6	0	0.00	(0.00, 39.30)

Matched: All appraisers’ assessments agree with each other.

Fleiss’ Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
2	0.519231	0.0608581	8.53183	0.0000
3	0.170087	0.0608581	2.79481	0.0026
4	0.145299	0.0608581	2.38751	0.0085
5	0.007092	0.0608581	0.11654	0.4536
6	-0.016949	0.0608581	-0.27850	0.6097
Overall	0.175518	0.0355695	4.93452	0.0000

Kendall’s Coefficient of Concordance

Coef	Chi - Sq	DF	P
0.570066	28.5033	5	0.0000

Attribute Agreement Analysis

W Significance

Training Group A - BEHI		
W	0.570066	
M	10	
n	6	
F	**11.93345**	
v1	4.8	
v2	43.2	
alpha	0.05	
Fcv	**2.46**	
	Reject H_0	

NBS

Within Appraisers

```
Assessment Agreement

Appraiser  # Inspected  # Matched  Percent       95% CI
100                  6          5    83.33  (35.88,  99.58)
200                  6          6   100.00  (60.70, 100.00)
300                  6          6   100.00  (60.70, 100.00)
400                  6          4    66.67  (22.28,  95.67)
500                  6          6   100.00  (60.70, 100.00)

# Matched: Appraiser agrees with him/herself across trials.


Fleiss' Kappa Statistics

Appraiser  Response     Kappa  SE Kappa         Z  P(vs > 0)
100        1                *         *         *          *
           2                *         *         *          *
           3                *         *         *          *
           4          1.00000  0.408248   2.44949     0.0072
           5         -0.09091  0.408248  -0.22268     0.5881
           6          0.65714  0.408248   1.60966     0.0537
           Overall    0.69231  0.333826   2.07386     0.0190
200        1                *         *         *          *
           2          1.00000  0.408248   2.44949     0.0072
           3          1.00000  0.408248   2.44949     0.0072
           4          1.00000  0.408248   2.44949     0.0072
           5                *         *         *          *
           6                *         *         *          *
           Overall    1.00000  0.288675   3.46410     0.0003
300        1                *         *         *          *
           2                *         *         *          *
           3          1.00000  0.408248   2.44949     0.0072
           4          1.00000  0.408248   2.44949     0.0072
           5          1.00000  0.408248   2.44949     0.0072
           6          1.00000  0.408248   2.44949     0.0072
           Overall    1.00000  0.245271   4.07713     0.0000
400        1         -0.09091  0.408248  -0.22268     0.5881
           2         -0.09091  0.408248  -0.22268     0.5881
           3         -0.09091  0.408248  -0.22268     0.5881
```

	4	1.00000	0.408248	2.44949	0.0072
	5	-0.09091	0.408248	-0.22268	0.5881
	6	1.00000	0.408248	2.44949	0.0072
	Overall	0.55556	0.217543	2.55377	0.0053
500	1	*	*	*	*
	2	*	*	*	*
	3	*	*	*	*
	4	1.00000	0.408248	2.44949	0.0072
	5	*	*	*	*
	6	1.00000	0.408248	2.44949	0.0072
	Overall	1.00000	0.408248	2.44949	0.0072

* When no or all responses across trials equal the value, kappa cannot be computed.

Kendall's Coefficient of Concordance

Appraiser	Coef	Chi - Sq	DF	P
100	0.94444	9.4444	5	0.0926
200	1.00000	10.0000	5	0.0752
300	1.00000	10.0000	5	0.0752
400	0.81818	8.1818	5	0.1465
500	1.00000	10.0000	5	0.0752

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
6	2	33.33	(4.33, 77.72)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
1	-0.01695	0.0608581	-0.2785	0.6097
2	0.10303	0.0608581	1.6930	0.0452
3	0.26325	0.0608581	4.3257	0.0000
4	1.00000	0.0608581	16.4317	0.0000
5	0.10714	0.0608581	1.7605	0.0392
6	0.33412	0.0608581	5.4901	0.0000
Overall	0.47804	0.0352123	13.5758	0.0000

Kendall's Coefficient of Concordance

Coef	Chi - Sq	DF	P
0.212752	10.6376	5	0.0591

Attribute Agreement Analysis

W Significance

Training Group A - NBS		
W	0.212752	
M	10	
n	6	
F	**2.43223**	
v1	4.8	
v2	43.2	
alpha	0.05	
Fcv	**2.46**	
Fail to Reject H_0		

Training Group B Agreement Analysis

Minitab Input

BEHI[22]

Rater,Sample,BEHI

600,1,3

600,1,3

700,1,6

700,1,5

800,1,5

800,1,5

600,2,2

600,2,5

700,2,4

700,2,6

800,2,5

800,2,5

600,3,1

600,3,3

700,3,3

700,3,3

800,3,3

800,3,4

600,4,4

600,4,5

700,4,6

700,4,6

[22] Rater re-numbered in an effort not to reveal identity; Sample 1 = LWE1; Sample 2 = LWE2; Sample 3 = LWE3; Sample 4 = MLA1; Sample 5 = MLA2; Sample 6 = MLA3; BEHI = 1 = Very Low; BEHI = 2 = Low; BEHI = 3 = Moderate; BEHI = 4 = High; BEHI = 5 = Very High; BEHI = 6 = Extreme

800,4,4

800,4,3

600,5,1

600,5,1

700,5,2

700,5,2

800,5,3

800,5,2

600,6,4

600,6,4

700,6,6

700,6,4

800,6,4

800,6,3

NBS[23]

Rater,Sample,NBS

600,1,5

600,1,6

700,1,6

700,1,6

800,1,2

800,1,6

600,2,1

600,2,2

700,2,4

700,2,2

[23] Rater re-numbered in an effort not to reveal identity; Sample 1 = LWE1; Sample 2 = LWE2; Sample 3 = LWE3; Sample 4 = MLA1; Sample 5 = MLA2; Sample 6 = MLA3; NBS = 1 = Very Low; NBS = 2 = Low; NBS = 3 = Moderate; NBS = 4 = High; NBS = 5 = Very High; NBS = 6 = Extreme

800,2,4

800,2,4

600,3,6

600,3,6

700,3,6

700,3,6

800,3,3

800,3,3

600,4,1

600,4,4

700,4,4

700,4,4

800,4,1

800,4,4

600,5,6

600,5,3

700,5,5

700,5,6

800,5,6

800,5,4

600,6,6

600,6,6

700,6,6

700,6,6

800,6,6

800,6,6

Results

BEHI

Within Appraisers

```
Assessment Agreement
```

Appraiser	# Inspected	# Matched	Percent	95% CI
600	6	3	50.00	(11.81, 88.19)
700	6	3	50.00	(11.81, 88.19)
800	6	2	33.33	(4.33, 77.72)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
600	1	0.55556	0.408248	1.36083	0.0868
	2	-0.09091	0.408248	-0.22268	0.5881
	3	0.55556	0.408248	1.36083	0.0868
	4	0.55556	0.408248	1.36083	0.0868
	5	-0.20000	0.408248	-0.48990	0.6879
	6	*	*	*	*
	Overall	0.35714	0.214781	1.66282	0.0482
700	1	*	*	*	*
	2	1.00000	0.408248	2.44949	0.0072
	3	1.00000	0.408248	2.44949	0.0072
	4	-0.20000	0.408248	-0.48990	0.6879
	5	-0.09091	0.408248	-0.22268	0.5881
	6	-0.02857	0.408248	-0.06999	0.5279
	Overall	0.32075	0.221782	1.44626	0.0741
800	1	*	*	*	*
	2	-0.09091	0.408248	-0.22268	0.5881
	3	-0.50000	0.408248	-1.22474	0.8897
	4	-0.33333	0.408248	-0.81650	0.7929
	5	1.00000	0.408248	2.44949	0.0072
	6	*	*	*	*
	Overall	0.05882	0.255279	0.23043	0.4089

* When no or all responses across trials equal the value, kappa cannot be computed.

Kendall's Coefficient of Concordance

Appraiser	Coef	Chi - Sq	DF	P
600	0.818182	8.18182	5	0.1465
700	0.823077	8.23077	5	0.1440
800	0.869231	8.69231	5	0.1220

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
6	0	0.00	(0.00, 39.30)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
1	0.054545	0.105409	0.51746	0.3024
2	0.212500	0.105409	2.01595	0.0219
3	0.081481	0.105409	0.77300	0.2198
4	0.164286	0.105409	1.55855	0.0596
5	0.184236	0.105409	1.74782	0.0402

```
6          -0.068387  0.105409  -0.64878     0.7418
Overall     0.110266  0.049713   2.21805     0.0133
```

```
Kendall's Coefficient of Concordance

    Coef  Chi - Sq  DF       P
0.646259   19.3878   5  0.0016
```

Attribute Agreement Analysis

W Significance

Training Group B- BEHI		
W	0.646259	
M	6	
n	6	
F	**9.134635**	
v1	4.666667	
v2	23.33333	
alpha	0.05	
Fcv	**2.68**	
	Reject H_0	

NBS

Within Appraisers

```
Assessment Agreement

Appraiser  # Inspected  # Matched  Percent      95% CI
600                  6          2    33.33  ( 4.33, 77.72)
700                  6          4    66.67  (22.28, 95.67)
800                  6          3    50.00  (11.81, 88.19)

# Matched: Appraiser agrees with him/herself across trials.
```

```
Fleiss' Kappa Statistics

Appraiser  Response     Kappa  SE Kappa         Z  P(vs > 0)
600        1         -0.20000  0.408248  -0.48990     0.6879
           2         -0.09091  0.408248  -0.22268     0.5881
           3         -0.09091  0.408248  -0.22268     0.5881
           4         -0.09091  0.408248  -0.22268     0.5881
           5         -0.09091  0.408248  -0.22268     0.5881
           6          0.33333  0.408248   0.81650     0.2071
           Overall    0.04000  0.216025   0.18516     0.4266
700        1                *         *         *          *
           2         -0.09091  0.408248  -0.22268     0.5881
           3                *         *         *          *
           4          0.55556  0.408248   1.36083     0.0868
           5         -0.09091  0.408248  -0.22268     0.5881
```

	6	0.65714	0.408248	1.60966	0.0537
	Overall	0.42857	0.279699	1.53226	0.0627
800	1	-0.09091	0.408248	-0.22268	0.5881
	2	-0.09091	0.408248	-0.22268	0.5881
	3	1.00000	0.408248	2.44949	0.0072
	4	0.25000	0.408248	0.61237	0.2701
	5	*	*	*	*
	6	0.25000	0.408248	0.61237	0.2701
	Overall	0.32075	0.231212	1.38727	0.0827

* When no or all responses across trials equal the value, kappa cannot be computed.

Kendall's Coefficient of Concordance

Appraiser	Coef	Chi - Sq	DF	P
600	0.745902	7.45902	5	0.1887
700	0.936364	9.36364	5	0.0954
800	0.570313	5.70313	5	0.3362

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
6	1	16.67	(0.42, 64.12)

Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
1	0.054545	0.105409	0.51746	0.3024
2	0.054545	0.105409	0.51746	0.3024
3	0.054545	0.105409	0.51746	0.3024
4	0.292857	0.105409	2.77829	0.0027
5	-0.058824	0.105409	-0.55805	0.7116
6	0.442724	0.105409	4.20005	0.0000
Overall	0.242105	0.057572	4.20529	0.0000

Kendall's Coefficient of Concordance

Coef	Chi - Sq	DF	P
0.515741	15.4722	5	0.0085

Attribute Agreement Analysis

W Significance

Training Group B- NBS		
W	0.515741	
M	6	
n	6	
F	**5.325053**	
v1	4.666667	
v2	23.33333	
alpha	0.05	
Fcv	**2.68**	
	Reject H_0	

Testing for Difference in Mean and Variance of BEHI score between Training Groups A and B

SAS Code

```
PROC IMPORT OUT= WORK.BEHI
        DATAFILE=
"C:\Users\Chris\Documents\KSUConsulting\Kari_Bigham\BEHI.csv"
        DBMS=CSV REPLACE;
    GETNAMES=YES;
    DATAROW=2;
RUN;

PROC IMPORT OUT= WORK.NBS
        DATAFILE=
"C:\Users\Chris\Documents\KSUConsulting\Kari_Bigham\NBS.csv"
        DBMS=CSV REPLACE;
    GETNAMES=YES;
    DATAROW=2;
RUN;

ods rtf
file='C:\Users\Chris\Documents\KSUConsulting\Kari_Bigham\BEHI_output_v2.rtf';
proc glimmix data=BEHI;
  class training date streambank;
  model behi_score= training/ ddfm=KR;
  covtest homogeneity;
  random streambank*date;
  random _residual_ /group=training;
  lsmeans training/pdiff cl alpha=0.1;
run;
ods rtf close;
```

Results

The GLIMMIX Procedure

Model Information	
Data Set	WORK.BEHI
Response Variable	BEHI_Score
Response Distribution	Gaussian
Link Function	Identity
Variance Function	Default
Variance Matrix	Not blocked
Estimation Technique	Restricted Maximum Likelihood
Degrees of Freedom Method	Kenward-Roger
Fixed Effects SE Adjustment	Kenward-Roger

Class Level Information		
Class	**Levels**	**Values**
Training	2	a b
Date	2	a j
Streambank	6	a1 a2 a3 e1 e2 e3

Number of Observations Read	120
Number of Observations Used	108

Dimensions	
G-side Cov. Parameters	1
R-side Cov. Parameters	2
Columns in X	3
Columns in Z	12
Subjects (Blocks in V)	1
Max Obs per Subject	108

Optimization Information	
Optimization Technique	Dual Quasi-Newton
Parameters in Optimization	3
Lower Boundaries	3
Upper Boundaries	0
Fixed Effects	Profiled
Starting From	Data

Iteration History					
Iteration	**Restarts**	**Evaluations**	**Objective Function**	**Change**	**Max Gradient**
0	**0**	4	766.53289574	.	0.939716
1	**0**	6	762.02846051	4.50443523	0.10966
2	**0**	4	761.84655271	0.18190781	0.045291
3	**0**	4	761.74068939	0.10586332	0.054674
4	**0**	4	761.40995	0.33073939	0.010162
5	**0**	2	761.39841544	0.01153456	0.002456
6	**0**	3	761.39776019	0.00065525	0.001626
7	**0**	3	761.39770466	0.00005553	0.00125
8	**0**	4	761.39726933	0.00043533	0.000508
9	**0**	3	761.39726514	0.00000419	4.34E-6

Convergence criterion (GCONV=1E-8) satisfied.

Fit Statistics	
-2 Res Log Likelihood	761.40
AIC (smaller is better)	767.40
AICC (smaller is better)	767.63
BIC (smaller is better)	768.85
CAIC (smaller is better)	771.85
HQIC (smaller is better)	766.86
Generalized Chi-Square	106.00
Gener. Chi-Square / DF	1.00

Covariance Parameter Estimates			
Cov Parm	Group	Estimate	Standard Error
Date*Streambank		52.1515	24.7390
Residual (VC)	Training a	40.3538	7.6193
Residual (VC)	Training b	95.7066	22.4565

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Training	1	56.52	0.79	0.3785

Training Least Squares Means								
Training	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
a	31.4164	2.2274	11.53	14.10	<.0001	0.1	27.4330	35.3998
b	32.9258	2.5757	20.02	12.78	<.0001	0.1	28.4837	37.3679

Differences of Training Least Squares Means									
Training	_Training	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
a	b	-1.5094	1.7004	56.52	-0.89	0.3785	0.1	-4.3529	1.3342

Tests of Covariance Parameters Based on the Restricted Likelihood					
Label	DF	-2 Res Log Like	ChiSq	Pr > ChiSq	Note
Homogeneity	1	769.37	7.97	0.0048	DF

DF: P-value based on a chi-square with DF degrees of freedom.

Testing for Significant Difference between Sensitivity Rankings of BEHI Parameters

JMP Input

BEHI_Var,Bank,R1,R2,Ravg[24]

Bank_Height,LWE1,1,1,1

Bankfull_Height,LWE1,4,4,4

Root_Depth,LWE1,3,3,3

Root_Density,LWE1,,,

Bank_Angle,LWE1,2,2,2

Surface_Prot,LWE1,7,6,6.5

Bank_Mat,LWE1,5,7,6

Stratification,LWE1,6,5,5.5

Bank_Height,LWE2,1,1,1

Bankfull_Height,LWE2,2,2,2

Root_Depth,LWE2,3,4,3.5

Root_Density,LWE2,,,

Bank_Angle,LWE2,4,3,3.5

Surface_Prot,LWE2,6,5,5.5

Bank_Mat,LWE2,5,6,5.5

Stratification,LWE2,7,7,7

Bank_Height,LWE3,1,2,1.5

Bankfull_Height,LWE3,2,3,2.5

Root_Depth,LWE3,3,1,2

Root_Density,LWE3,6,7,6.5

Bank_Angle,LWE3,4,4,4

Surface_Prot,LWE3,5,6,5.5

Bank_Mat,LWE3,7,8,7.5

Stratification,LWE3,8,5,6.5

[24] BEHI_Var: BEHI Parameter; Bank: Study Bank (LWE#: Lower West Emma Study Bank #; MLA#: Middle Little Arkansas River Study Bank #); R1: BEHI parameter ranking based on a minimum change in BEHI parameter that resulted in a change in BEHI category; R2: BEHI parameter ranking based on the summation of positive percent change of BEHI parameter when BEHI category change occurs or a maximum is reached and negative percent change of BEHI parameter when BEHI category change occurs or a minimum is reached; Ravg: Average ranking

Bank_Height,MLA1,1,5,3

Bankfull_Height,MLA1,5,4,4.5

Root_Depth,MLA1,6,6,6

Root_Density,MLA1,,,

Bank_Angle,MLA1,2,2,2

Surface_Prot,MLA1,,,

Bank_Mat,MLA1,3,1,2

Stratification,MLA1,4,3,3.5

Bank_Height,MLA2,1,3,2

Bankfull_Height,MLA2,5,6,5.5

Root_Depth,MLA2,2,2,2

Root_Density,MLA2,6,4,5

Bank_Angle,MLA2,4,5,4.5

Surface_Prot,MLA2,3,1,2

Bank_Mat,MLA2,7,7,7

Stratification,MLA2,8,8,8

Bank_Height,MLA3,4,1,2.5

Bankfull_Height,MLA3,6,6,6

Root_Depth,MLA3,3,5,4

Root_Density,MLA3,,,

Bank_Angle,MLA3,1,2,1.5

Surface_Prot,MLA3,,,

Bank_Mat,MLA3,2,4,3

Stratification,MLA3,5,3,4

Results

Kruskal-Wallis Tests (Rank Sums)					
BEHI_Var	N	Sum	Mean	(Mean-Mean0/Std0)	
Bank_Angle	6	87.5	14.5833	-1.482	
Bank_Height	6	44.5	7.4167	-3.036	
Bank_Mat	6	169	28.1667	1.428	
Bankfull_Height	6	134	22.3333	0.163	
Root_Density	2	64	32	1.217	
Root_Depth	6	108.5	18.0833	-0.723	
Stratification	6	190	31.6667	2.187	
Surface_Prot	4	105.5	26.375	0.819	
Overall	42				
ChiSquare=18.499	DF=7	P=0.0099			

Tukey HSD - Ravg					
Level			Mean		
Root_Density	A	B	5.75		
Stratification	A		5.75		
Bank_Mat	A		5.1666667		
Surface_Prot	A	B	4.875		
Bankfull_Height	A	B	4.0833333		
Root_Depth	A	B	3.4166667		
Bank_Angle	A	B	2.9166667		
Bank_Height		**B**	**1.8333333**		
Levels not connected by same letter are significantly different.					

Testing for Significant Difference between Uncertainty Rankings of BEHI Parameters

JMP Input

BEHI_Var,Bank,U,U_rank[25]

Bank_Height,LWE1,3.6,7

Bankfull_Height,LWE1,4.5,6

Root_Depth,LWE1,10.4,2

Root_Density,LWE1,1.7,8

Bank_Angle,LWE1,5.3,4.5

Surface_Prot,LWE1,5.3,4.5

Bank_Mat,LWE1,19,1

Stratification,LWE1,7,3

Bank_Height,LWE2,7.3,3

Bankfull_Height,LWE2,5.8,5

Root_Depth,LWE2,10.9,2

Root_Density,LWE2,2.2,8

Bank_Angle,LWE2,5.2,6

Surface_Prot,LWE2,6,4

Bank_Mat,LWE2,17,1

Stratification,LWE2,5,7

Bank_Height,LWE3,6.3,3

Bankfull_Height,LWE3,7.1,2

Root_Depth,LWE3,3.9,8

Root_Density,LWE3,5.1,6

Bank_Angle,LWE3,6,5

[25] BEHI_Var: BEHI Parameter; Bank: Study Bank (LWE#: Lower West Emma Study Bank #; MLA#: Middle Little Arkansas River Study Bank #); U: Uncertainty Measure equal to the difference of the maximum BEHI score (pts) when BEHI parameter base-case scenario is adjusted by +2 BEHI parameter standard deviations and the minimum BEHI score (pts) when BEHI parameter base-case scenario is adjusted by -2 BEHI parameter standard deviations; U_rank: Rank based upon U where ranking of 1 represents the largest U

Surface_Prot,LWE3,6.2,4
Bank_Mat,LWE3,19,1
Stratification,LWE3,4,7
Bank_Height,MLA1,11.2,2
Bankfull_Height,MLA1,5,6
Root_Depth,MLA1,8,4
Root_Density,MLA1,1.1,8
Bank_Angle,MLA1,7,5
Surface_Prot,MLA1,2.5,7
Bank_Mat,MLA1,29,1
Stratification,MLA1,10,3
Bank_Height,MLA2,13.5,3
Bankfull_Height,MLA2,8.3,4
Root_Depth,MLA2,15.3,2
Root_Density,MLA2,8,5
Bank_Angle,MLA2,2.2,6
Surface_Prot,MLA2,1.3,8
Bank_Mat,MLA2,24,1
Stratification,MLA2,2,7
Bank_Height,MLA3,6.3,4
Bankfull_Height,MLA3,2.8,7
Root_Depth,MLA3,8.8,2
Root_Density,MLA3,1.5,8
Bank_Angle,MLA3,3.9,6
Surface_Prot,MLA3,4.3,5
Bank_Mat,MLA3,27,1
Stratification,MLA3,8,3

Results

Kruskal-Wallis	Test	on	U_rank	
BEHI_Var	N	Median	Ave	Rank
Bank_Angle	6	5.5	30.2	1.06
Bank_Height	6	3	19.4	-0.95
Bank_Mat	6	1	3.5	-3.93
Bankfull_Height	6	5.5	27.5	0.56
Root_Density	6	8	40.6	3.01
Root_Depth	6	2	17.4	-1.32
Stratification	6	5	27.5	0.56
Surface_Prot	6	4.75	29.9	1.01
Overall	48	24.5		
H=26.18	DF=7	P=0.000		
H=26.54	DF=7	P=0.000		

Tukey HSD					
BEHI_Var	N	Mean	Grouping		
Root_Density	6	7.167	A		
Surface_Prot	6	5.417	A	B	
Bank_Angle	6	5.417	A	B	
Stratification	6	5	A	B	
Bankfull_Height	6	5	A	B	
Bank_Height	6	3.667		B	C
Root_Depth	6	3.333		B	C
Bank_Mat	6	1			C
Means that do not share a letter are significantly different.					

Appendix E - Individual Rater Bank Assessment for Non-Point Sources Consequences of Sediment (BANCS) Assessment Results

Lower West Emma Study Bank #1

BANCS Rater	BEHI Rating (Score) June	BEHI Rating (Score) August	NBS Rating (Method) June	NBS Rating (Method) August
1	High (30.4)	High (30)	Very High (3)	Extreme (2)
2	Very High (40.7)	High (33.9)	Low (5)	Low (5)
3	High (33.8)	Very High (43.2)	Extreme (2)	Extreme (2)
4	High (34.5)	*N/A*	Low (5)	*N/A*
5	Very High (41.4)	High (37.3)	Extreme (2)	Extreme (2)
6	High (38.9)	Very High (41)	Extreme (1)	Extreme (1)
7	Moderate (21)	Moderate (26.8)	Very High (3)	Extreme (2)
8	Extreme (49.5)	Very High (42.2)	Extreme (2)	Extreme (2)
9	Very High (42.4)	*N/A*	Very High (3)	*N/A*
10	Very High (45.2)	Very High (41.1)	Low (5)	Extreme (2)
	Overall Mean	High (37.41)	**Overall Mode**	Extreme (2)

Lower West Emma Study Bank #2

BANCS Rater	BEHI Rating (Score) June	BEHI Rating (Score) August	NBS Rating (Method) June	NBS Rating (Method) August
1	Moderate (27.1)	High (32.5)	High (5)	High (5)
2	Very High (42.7)	Very High (44.9)	High (5)	High (5)
3	High (38.4)	Very High (44)	High (5)	High (5)
4	High (34.7)	*N/A*	High (5)	*N/A*
5	High (37.2)	High (34.4)	High (5)	High (5)
6	High (35.7)	High (38.3)	High (5)	High (5)
7	Low (19.8)	Very High (40.3)	Very Low (3, 4)	Low (2)
8	High (32.4)	Extreme (48.1)	High (5)	Low (2)
9	Moderate (24.3)	*N/A*	Low (2)	*N/A*
10	Very High (43.2)	Very High (42.6)	High (5)	High (5)
	Overall Mean	High (37.75)	**Overall Mode**	High (5)

Lower West Emma Study Bank #3

BANCS Rater	BEHI Rating (Score) June	BEHI Rating (Score) August	NBS Rating (Method) June	NBS Rating (Method) August
1	Moderate (22.9)	Moderate (24)	Extreme (3)	Extreme (3)
2	Moderate (28.3)	High (39.6)	Moderate (5)	Moderate (5)
3	Moderate (23.2)	Moderate (26.2)	Moderate (5)	Moderate (5)
4	High (31.6)	*N/A*	Moderate (5)	*N/A*
5	Very High (42.6)	High (32.6)	Very Low (2)	Moderate (5)
6	Moderate (29.5)	Moderate (27.7)	Extreme (3)	Extreme (3,6)
7	Very Low (8.4)	Moderate (26.1)	Extreme (3)	Extreme (3)
8	Moderate (24.4)	Moderate (28.7)	Extreme (3)	Extreme (3)
9	High (37.1)	*N/A*	Extreme (3)	*N/A*
10	Moderate (27)	High (38.8)	Moderate (5)	Moderate (5)
	Overall Mean	Moderate (28.82)	**Overall Mode**	Extreme (3)

Middle Little Ark Study Bank #1

BANCS Rater	BEHI Rating (Score) June	BEHI Rating (Score) August	NBS Rating (Method) June	NBS Rating (Method) August
1	Extreme (46.5)	Moderate (26.5)	High (5)	High (5)
2	High (35.7)	Moderate (21.1)	High (5)	High (5)
3	Very High (40.8)	Very High (44.6)	High (5)	High (5)
4	High (31.6)	*N/A*	High (5)	*N/A*
5	Moderate (26.5)	High (33.8)	High (5)	High (5)
6	Moderate (23.5)	Low (19.5)	High (5)	High (5)
7	High (33.8)	Very High (42.8)	Very Low (2)	High (5)
8	Extreme (57.2)	Extreme (48.1)	High (5)	High (5)
9	High (36.6)	*N/A*	Very Low (2-4)	*N/A*
10	High (39.6)	Moderate (24.3)	Very Low (2)	High (5)
	Overall Mean	High (35.14)	**Overall Mode**	High (5)

Middle Little Ark Study Bank #2

BANCS Rater	BEHI Rating (Score) June	BEHI Rating (Score) August	NBS Rating (Method) June	NBS Rating (Method) August
1	Low (16.1)	Moderate (24.6)	Extreme (3)	Extreme (3)
2	Low (19.6)	Low (17.3)	Low (5)	Low (5)
3	Low (16.4)	Moderate (22.4)	Very High (2)	Very High (2)
4	Very Low (4.9)	*N/A*	Low (5)	*N/A*
5	Low (15.5)	Moderate (22)	Very High (1)	Low (5)
6	Low (15.3)	Low (18.5)	Extreme (3)	Extreme (3, 6)
7	Very Low (5.1)	Very Low (8.6)	Extreme (3)	Moderate (4)
8	Low (12.3)	Low (14.4)	Very High (1)	Extreme (3)
9	Moderate (20.7)	*N/A*	Extreme (3)	*N/A*
10	Moderate (25.8)	Low (16.7)	Extreme (6)	High (1)
	Overall Mean	Low (16.46)	**Overall Mode**	Extreme (3)

Middle Little Ark Study Bank #3

BANCS Rater	BEHI Rating (Score) June	BEHI Rating (Score) August	NBS Rating (Method) June	NBS Rating (Method) August
1	High (29.6)	High (36.9)	Extreme (2)	Extreme (2)
2	High (31)	Moderate (27.5)	Moderate (5)	Moderate (5)
3	Very High (43.3)	Very High (41.5)	Extreme (2)	Extreme (2)
4	High (31.6)	*N/A*	Extreme (2)	*N/A*
5	High (36.5)	Very High (45.9)	Extreme (2)	Extreme (2)
6	Moderate (28.8)	High (31.8)	Extreme (2)	Extreme (1)
7	High (38)	High (39.7)	Extreme (1)	Extreme (2)
8	Extreme (53.4)	High (39.9)	Extreme (2)	Extreme (2)
9	Extreme (47.8)	*N/A*	Extreme (2)	*N/A*
10	High (38.7)	Moderate (26.8)	Extreme (2)	Extreme (2)
	Overall Median	High (37.15)	**Overall Mode**	Extreme (2)

Appendix F - Rater Bank Erosion Hazard Index (BEHI) Parameter Variability and Mean

Lower West Emma Study Bank #1

BEHI Parameter	Standard Deviation	Base-Case Scenario (Mean)
Study Bank Height	0.2 m	2.5 m
Bankfull Height	0.3 m	1.1 m
Root Depth	0.9 m	1.5 m
Root Density	5.6 %	8.8 %
Bank Angle	14.0°	63.5°
Surface Protection	12.2 %	21.1%
Bank Material Adjustment	5.3 points	+2 points
Stratification Adjustment	2.7 points	+1.8 points
BEHI Score	--	36 points (High)

Lower West Emma Study Bank #2

BEHI Parameter	Standard Deviation	Base-Case Scenario (Mean)
Study Bank Height	0.3 m	2.0 m
Bankfull Height	0.2 m	1.1 m
Root Depth	0.7 m	0.8 m
Root Density	12.4 %	12.6 %
Bank Angle	14.3°	60.5°
Surface Protection	17.4 %	18.4 %
Bank Material Adjustment	4.6 points	+1.8 points
Stratification Adjustment	2.1 points	+1.1 points
BEHI Score	--	34.8 points (High)

Lower West Emma Study Bank #3

BEHI Parameter	Standard Deviation	Base-Case Scenario (Mean)
Study Bank Height	0.2 m	1.8 m
Bankfull Height	0.2 m	1.1 m
Root Depth	0.4 m	1.7 m
Root Density	14.7 %	16.3 %
Bank Angle	18.0°	65°
Surface Protection	19.2 %	16.8 %
Bank Material Adjustment	5.1 points	-0.8 point
Stratification Adjustment	1.7 points	0.7 point
BEHI Score	--	27.9 points (Moderate)

Middle Little Arkansas Study Bank #1

BEHI Parameter	Standard Deviation	Base-Case Scenario (Mean)
Study Bank Height	2.0 m	7.7 m
Bankfull Height	1.2 m	3.3 m
Root Depth	1.6 m	2.1 m
Root Density	7.1 %	8 %
Bank Angle	23.6°	60.6°
Surface Protection	6.2 %	5.8 %
Bank Material Adjustment	8.4 points	-7.2 points
Stratification Adjustment	3.4 points	+3.7 points
BEHI Score	--	35.6 points (High)

Middle Little Arkansas Study Bank #2

BEHI Parameter	Standard Deviation	Base-Case Scenario (Mean)
Study Bank Height	1.4 m	5.9 m
Bankfull Height	1.2 m	3.1 m
Root Depth	2.7 m	4.6 m
Root Density	38.3 %	57.9 %
Bank Angle	8.8 °	51.3 °
Surface Protection	7.2 %	89.7 %
Bank Material Adjustment	5.9 points	-4.4 points
Stratification Adjustment	1.2 points	+0.3 points
BEHI Score	--	15.7 points (Low)

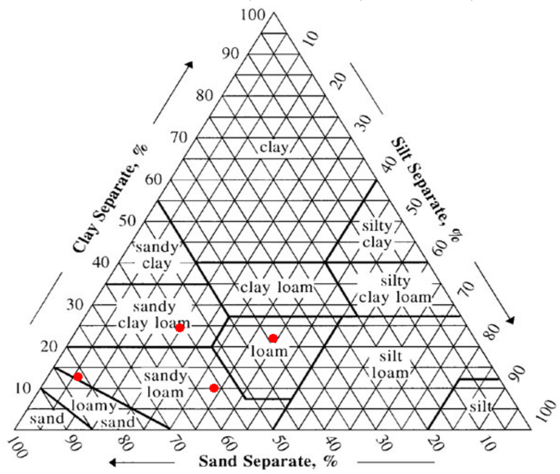
Middle Little Arkansas Study Bank #3

BEHI Parameter	Standard Deviation	Base-Case Scenario (Mean)
Study Bank Height	2.2 m	10.4 m
Bankfull Height	1.3 m	3.0 m
Root Depth	2.5 m	3.0 m
Root Density	11.4 %	10.3 %
Bank Angle	11.1 °	62.8 °
Surface Protection	11.4 %	9.7 %
Bank Material Adjustment	6.7 pts	-4 pts
Stratification Adjustment	2.8 pts	+2.1 pts
BEHI Score	--	38.2 points (High)

Appendix G – Study Bank Soil Texture Analysis

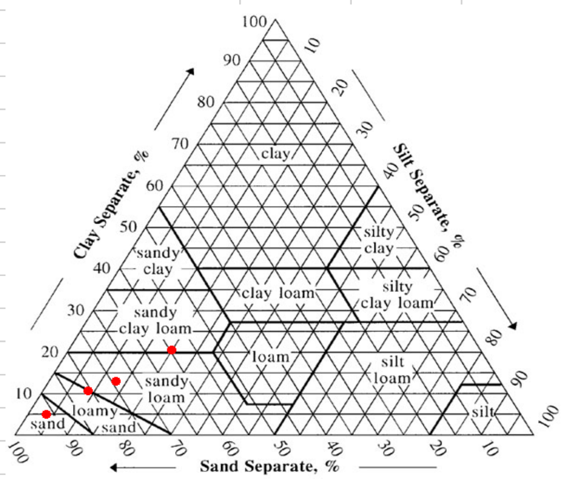
Upper Little Arkansas

Study Bank #1	*% clay*	*% silt*	*% sand*	*Soil Texture*
2.78' V	24.00932	19.03652	56.95416	Sandy Clay Loam
4.78' V	12.22111	5.306533	82.47236	Loamy Sand
7.71' V	9.469097	33.00317	57.52773	Sandy Loam
11.64' V	21.4646	38.49102	40.04438	Loam



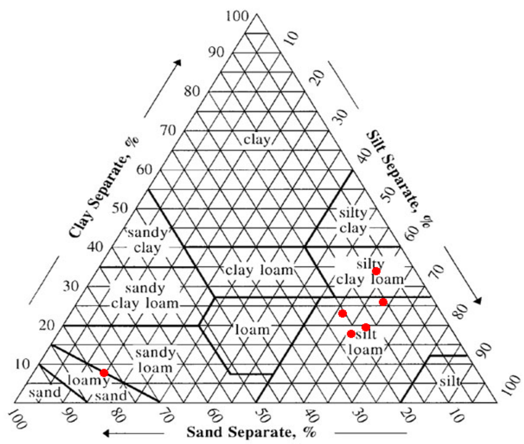
Upper Little Arkansas

Study Bank #2	*% clay*	*% silt*	*% sand*	*Soil Texture*
2.11' V	4.579856	2.794489	92.62565	Sand
6.43' V	12.43266	12.26689	75.30046	Sandy Loam
10.68' V	20.08032	19.35743	60.56225	Sandy Clay Loam
13.42' V	10.20616	8.001633	81.7922	Loamy Sand



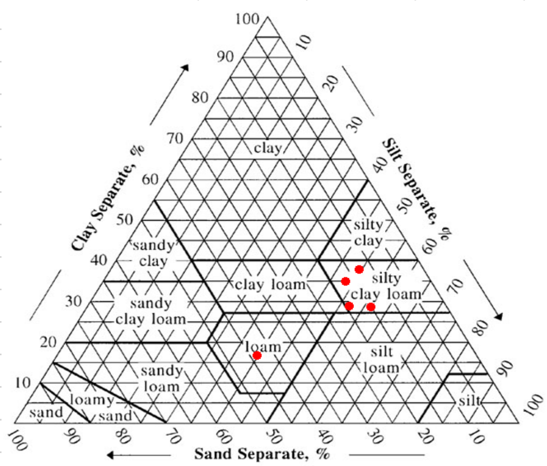
Middle Little Arkansas

Study Bank #1	***% clay***	***% silt***	***% sand***	***Soil Texture***
2.89' V	33.48765	57.48457	9.027778	Silty Clay Loam
3.71' V	25.5302	62.7752	11.69461	Silt Loam
6.54' V	22.43823	55.97408	21.58769	Silt Loam
8.56' V	19.05851	62.51191	18.42958	Silt Loam
10.01' V	7.261121	14.12328	78.6156	Loamy Sand
13.12' V	17.26647	60.29499	22.43854	Silt Loam

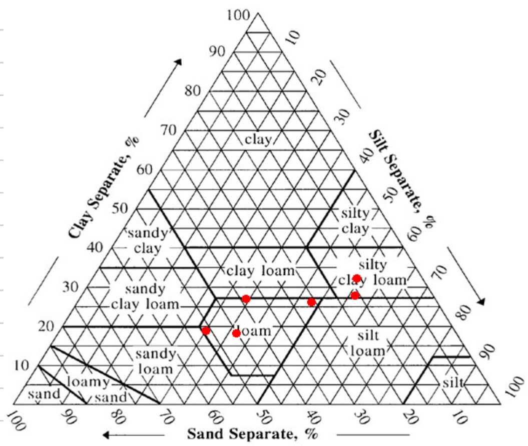


Middle Little Arkansas

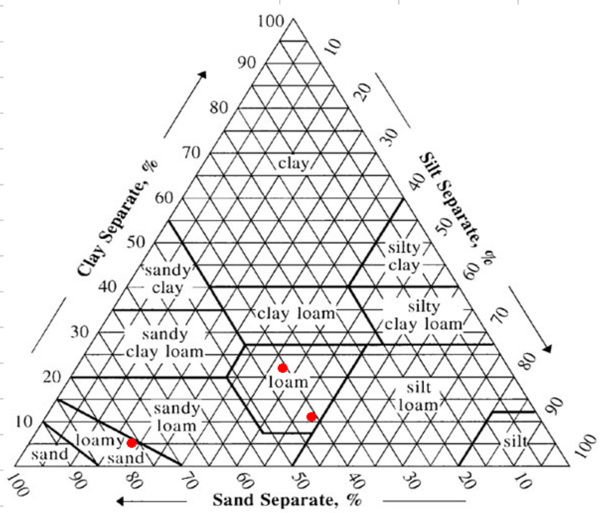
Study Bank #3	***% clay***	***% silt***	***% sand***	***Soil Texture***
2.19' V	16.21726	39.10766	44.67507	Loam
6.66' V	37.50493	48.79589	13.69917	Silty Clay Loam
13.76' V	28.14636	55.72979	16.12384	Silty Clay Loam
15.04' V	34.42854	47.65168	17.91977	Silty Clay Loam
17.58' V	28.32771	51.33902	20.33327	Clay Loam



Lower Little Arkansas				
Study Bank #1	***% clay***	***% silt***	***% sand***	***Soil Texture***
2.04' V	27.42409	55.71009	16.86582	Silty Clay Loam
2.87' V	25.66634	47.54195	26.79171	Loam
4.38' V	31.79524	53.81344	14.39132	Silty Clay Loam
5.27' V	26.48846	33.69785	39.81369	Loam
7.91' V	18.26227	29.44489	52.29284	Sandy Loam
11.10' V	17.63406	36.19201	46.17393	Loam

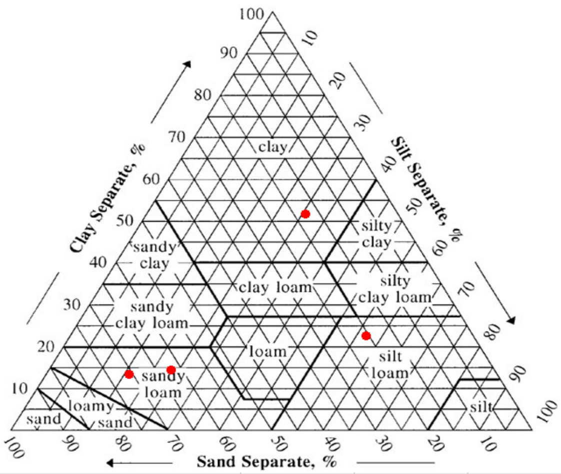


Lower Little Arkansas				
Study Bank #2	***% clay***	***% silt***	***% sand***	***Soil Texture***
1.86' V	21.45923	36.67577	41.865	Loam
6.17' V	10.53472	47.48603	41.97925	Loam
9.36' V	4.612583	17.80295	77.58446	Loamy Sand



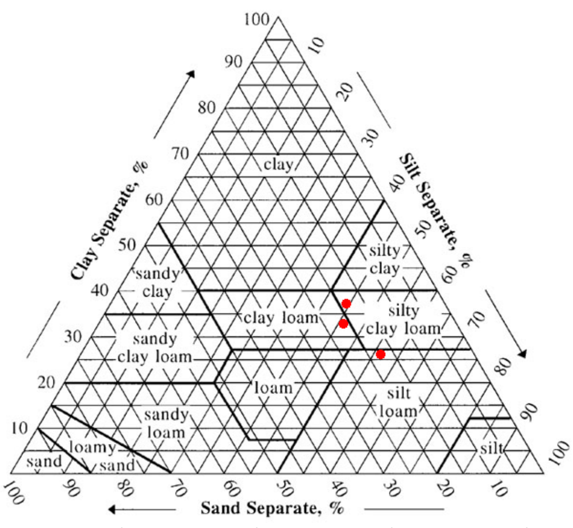
Lower Little Arkansas

Study Bank #3	*% clay*	*% silt*	*% sand*	*Soil Texture*
3.6' V	13.97206	22.83433	63.19361	Sandy Loam
6.35' V	12.96737	15.30149	71.73114	Sandy Loam
10.05' V	51.19803	30.1454	18.65656	Clay
11.71' V	22.08835	56.38554	21.5261	Silt Loam



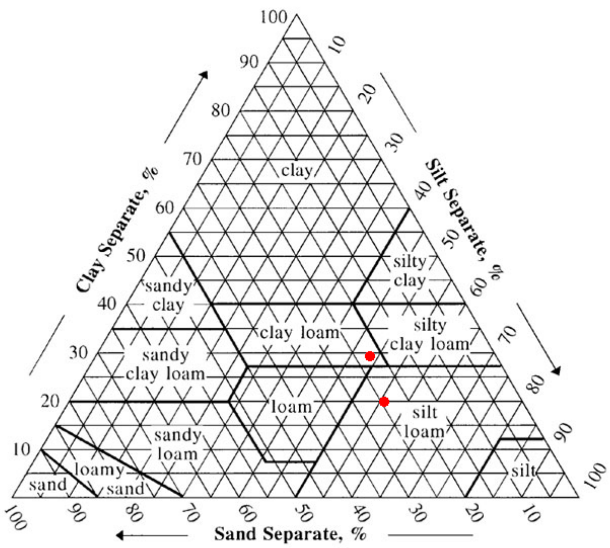
Dry Turkey

Bank Pins	*% clay*	*% silt*	*% sand*	*Soil Texture*
1.5' V	25.75911963	55.75708172	18.48379865	Silt Loam
4' V	36.76367074	43.68199827	19.55433099	Silty Clay Loam
5' V	32.47167704	45.31673847	22.21158449	Clay Loam



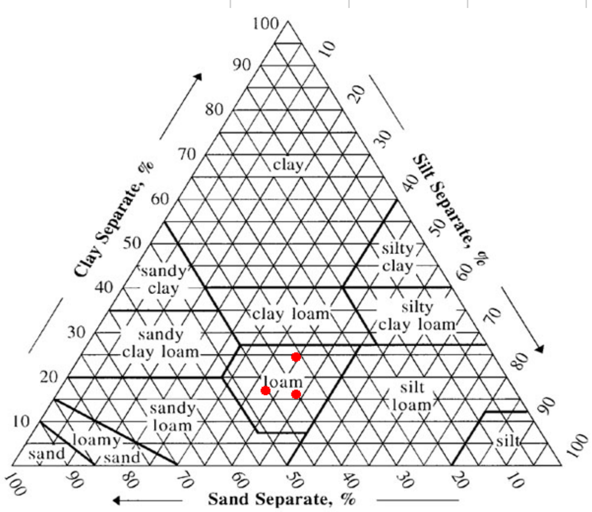
Dry Turkey

Pool Study Bank	% clay	% silt	% sand	Soil Texture
0.1' V	19.4041868	55.07246377	25.52334944	Silt Loam
2.15' V	28.8665629	47.94922072	23.18421638	Clay Loam

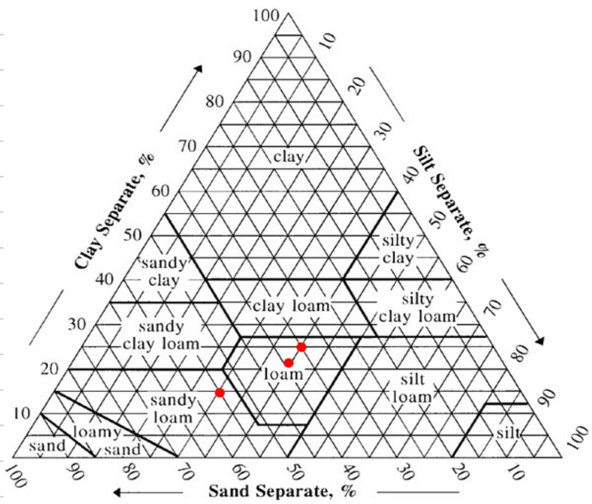


Running Turkey

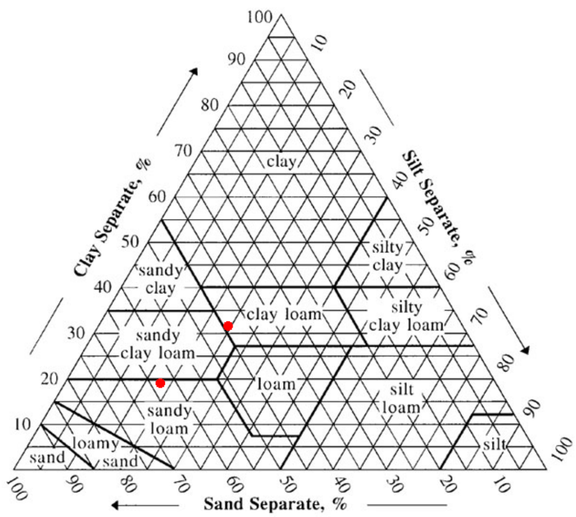
Left Pool Study Bank	% clay	% silt	% sand	Soil Texture
1.88' V	23.9521	38.8024	37.24551	Loam
4.68' V	16.38337	37.19025	46.42638	Loam
7.56'V	15.63331	43.13485	41.23184	Loam



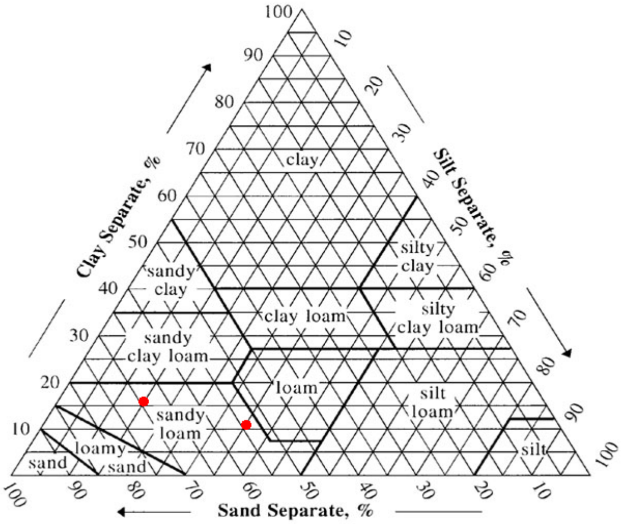
Running Turkey				
Right Pool Study Bank	***% clay***	***% silt***	***% sand***	***Soil Texture***
1.86' V	20.77818	38.98917	40.23265	Loam
4.08' V	24.32541	39.54893	36.12565	Loam
6.70' V	14.16717	29.79154	56.04129	Sandy Loam



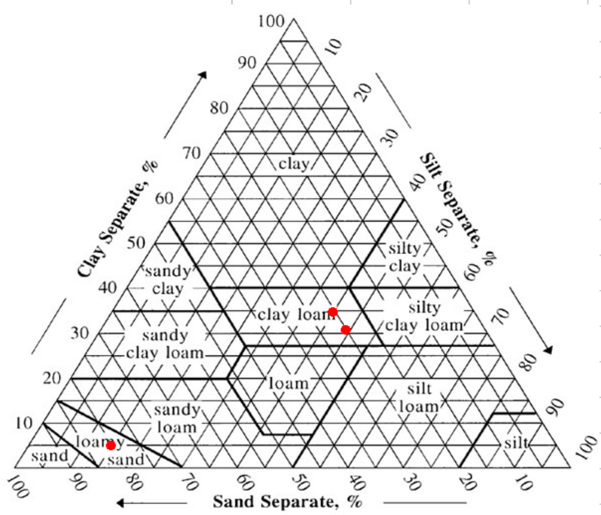
Upper West Emma				
Study Bank	***% clay***	***% silt***	***% sand***	***Soil Texture***
1' V	31.03496	23.8043	45.16074	Sandy Clay Loam
2' V	18.45349	17.33991	64.2066	Sandy Loam



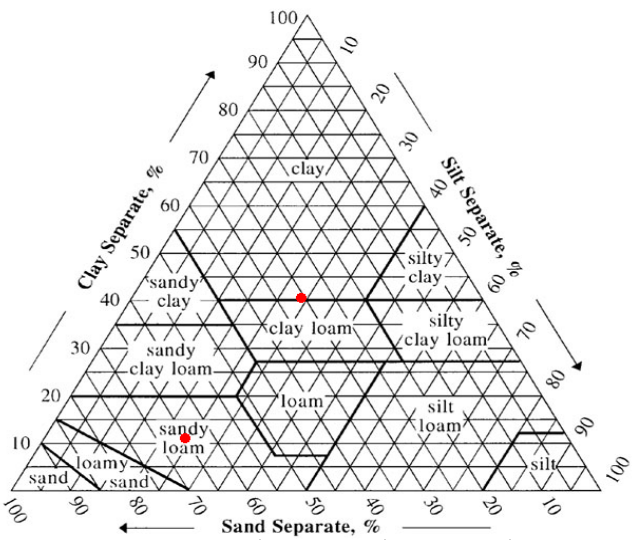
Upper West Emma				
Pool Study Bank	***% clay***	***% silt***	***% sand***	***Soil Texture***
0.92' V	15.37223	14.24547	70.38229	Sandy Loam
2.96' V	10.43685	34.47322	55.08994	Sandy Loam



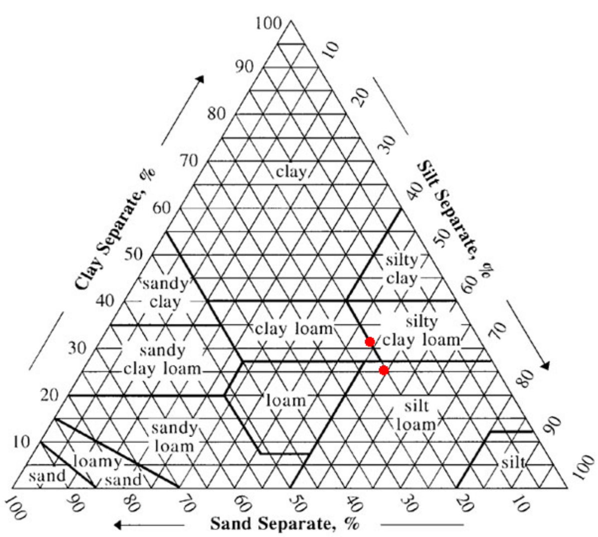
Lower West Emma				
Pool Study Bank	***% clay***	***% silt***	***% sand***	***Soil Texture***
0.94' V	4.530101	14.22611	81.24379	Loamy Sand
2.86' V	30.31156	43.49749	26.19095	Clay Loam
4.50' V	34.17367	39.29572	26.53061	Clay Loam



Lower West Emma				
ISCO Study Bank	***% clay***	***% silt***	***% sand***	***Soil Texture***
2.12' V	10.58034	23.29254	66.12712	Sandy Loam
4.02' V	40.09623	28.22775	31.67602	Clay



Black Kettle				
Pool Study Bank	***% clay***	***% silt***	***% sand***	***Soil Texture***
1.4' V	24.79890131	53.67863449	21.52246419	Silt Loam
2.57' V	30.95623987	48.05510535	20.98865478	Clay Loam



Appendix H – Study Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) Worksheets

Upper Little Arkansas Study Bank #1

Stream: **Upper Little Arkansas River** Location: **2016 SB1**

Station: **3+51** Observers: **KAB**

Date: **04/08/16** Stream Type: **E 5** Valley Type: **U-AL-FD**

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	15 (A)	Bankfull Height (ft) =	11.5 (B)	(A) / (B) =	1.30 (C)	BEHI Score (Fig. 3-7): 4.6

Root Depth / Study Bank Height (E)

Root Depth (ft) =	15 (D)	Study Bank Height (ft) =	15 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	15 (F)	(F) × (E) =	15 (G)	7.9

Bank Angle (H)

Bank Angle as *Degrees* =	85 (H)	6.8

Surface Protection (I)

Surface Protection as % =	30 (I)	5.9

Bank Material Adjustment:

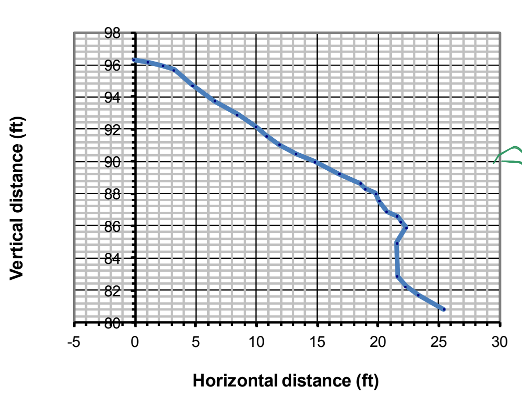
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

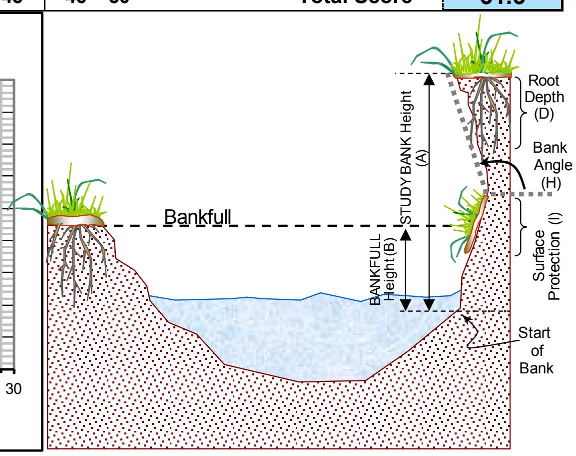
Bank Material Adjustment: 5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** 31.3

Bank Sketch





Estimating Near-Bank Stress (NBS)

Stream: **Upper Little Arkansas River** Location: **2016 SB1**

Station: **3+51** Stream Type: **E 5** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **04/08/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous………… ………………...…NBS = High / Very High
	Extensive deposition (continuous, cross-channel)……………..……………...…………………...NBS = Extreme
	Chute cutoffs, down-valley meander migration, converging flow………………………….……..NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.00016**	**0.00055**	**0.29**	**Low**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.00016**	**0.0011**	**0.15**	**Very Low**

Dominant Near-Bank Stress
Moderate

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**12.27**	**7.81**	**1.57**	**Moderate**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)	**0**	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Moderate**

Upper Little Arkansas Study Bank #2

Stream:	**Upper Little Arkansas River**	Location:	**2015 SB2**
Station:	**11+10.5**	Observers:	**KAB/TK**
Date:	**09/19/15** Stream Type: **E 5**	Valley Type:	**U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	17 (A)	Bankfull Height (ft) =	12 (B)	(A) / (B) =	1.42 (C)	5.4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	14 (D)	Study Bank Height (ft) =	17 (A)	(D) / (A) =	0.82 (E)	2.3

Weighted Root Density (G)

Root Density as % =	20 (F)	(F) × (E) =	16.4706 (G)	7.7

Bank Angle (H)

Bank Angle as *Degrees* =	70 (H)	4.9

Surface Protection (I)

Surface Protection as % =	70 (I)	2.7

Bank Material Adjustment:

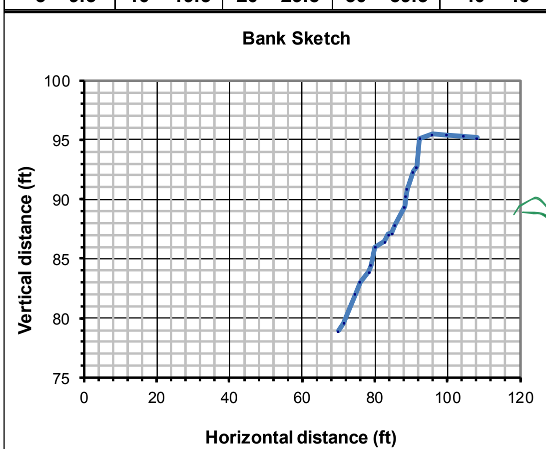
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

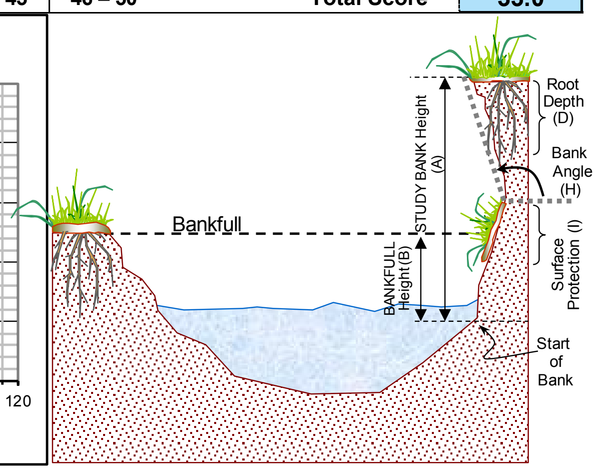
Bank Material Adjustment: 10

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: **High** / **33.0**





Stream:	**Upper Little Arkansas River - Modified**	Location:	**2015 Study Bank #2**
Station:	**11+10.5**	Observers:	**KAB/TK**
Date:	**09/19/15**	Stream Type: **E 5**	Valley Type: **U-AL-FD**

						BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	17 (A)	Bankfull Height (ft) =	12 (B)	(A) / (B) =	1.42 (C)	5.4
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	14 (D)	Study Bank Height (ft) =	17 (A)	(D) / (A) =	0.82 (E)	2.3
Weighted Root Density (G)						
		Root Density as % =	20 (F)	(F) × (E) =	16.4706 (G)	7.7
Bank Angle (H)						
				Bank Angle as *Degrees* =	70 (H)	4.9
Surface Protection (I)						
				Surface Protection as % =	70 (I)	2.7

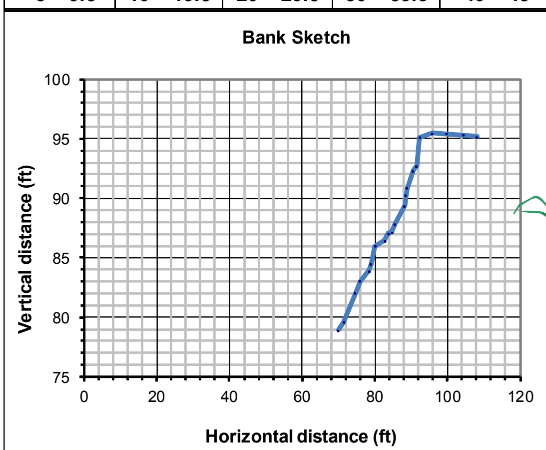
Bank Material Adjustment:

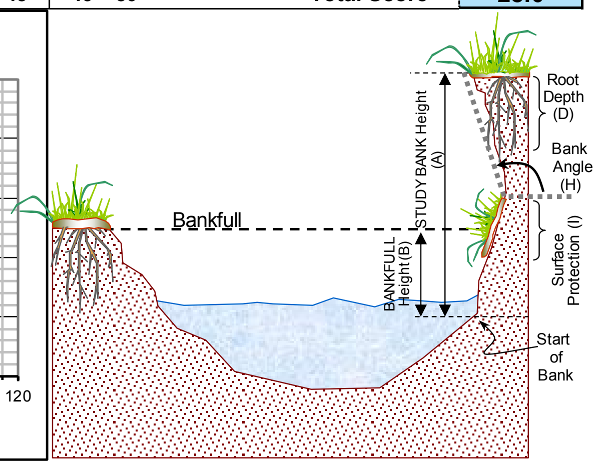
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: 5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Moderate** 28.0





Estimating Near-Bank Stress (NBS)

Stream: **Upper Little Arkansas River** Location: **2015 SB2**

Station: **11+10.5** Stream Type: **E 5** Valley Type: **U-AL-FD**

Observers: **KAB/TK** Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous…………. ………………..….NBS = High / Very High
- Extensive deposition (continuous, cross-channel)……………..……………...…………………...NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow……………………………..….NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
193	**63.25**	**3.05**	**Very Low**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
0.00017	**0.00025**	**0.68**	**High**

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
0.00017	**0.0011**	**0.15**	**Very Low**

Dominant Near-Bank Stress
High

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
11.65	**7.08**	**1.65**	**Moderate**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
11.65	**0.00017**	**0.12**	**7.08**	**0.00025**	**0.11**	**1.12**	**Moderate**

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **High**

Middle Little Arkansas Study Bank #1

Stream:	**Middle Little Arkansas River**	Location:	**2016 SB1**
Station:	**3+93**	Observers:	**KAB**
Date:	**04/08/16**	Stream Type: **E 5**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	26.5 (A)	Bankfull Height (ft) =	17.5 (B)	(A) / (B) =	1.51 (C)	5.6

Root Depth / Study Bank Height (E)

Root Depth (ft) =	4 (D)	Study Bank Height (ft) =	26.5 (A)	(D) / (A) =	0.15 (E)	7.9

Weighted Root Density (G)

Root Density as % =	25 (F)	(F) × (E) =	3.77358 (G)	10.0

Bank Angle (H)

Bank Angle as *Degrees* =	45 (H)	3.2

Surface Protection (I)

Surface Protection as % =	0 (I)	10.0

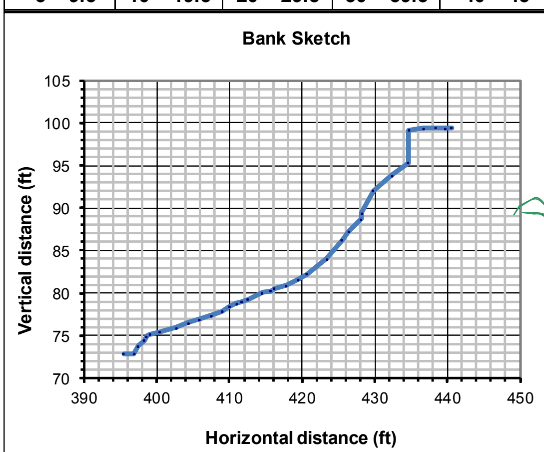
Bank Material Adjustment:

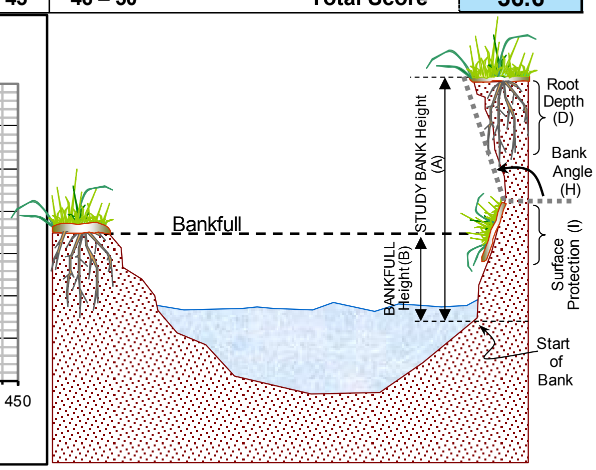
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50		**High** 36.6





Estimating Near-Bank Stress (NBS)

Stream: **Middle Little Arkansas River** Location: **2016 SB1**

Station: **3+93** Stream Type: **E 5** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **04/08/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous………. ………………..….NBS = High / Very High
Extensive deposition (continuous, cross-channel)…………….……………...………………....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow…………………………….….NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
	403.64	**97.1**	**4.16**	**Very Low**

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.00005	**0.00028**	**0.18**	**Very Low**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.00005	**0.00319**	**0.02**	**Very Low**

Dominant Near-Bank Stress
High

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	17.79	**9.61**	**1.85**	**High**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
	17.79	**0.00005**	**0.06**	**9.61**	**0.00028**	**0.17**	**0.33**	**Very Low**

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **High**

Middle Little Arkansas Study Bank #2 – Repeatability Study

Stream:	**Middle Little Arkansas River**	Location:	**2015 SB2 - Repeatability Study**
Station:	**6+51**	Observers:	**All Participants**
Date:	**08/14/15**	Stream Type: **E 5**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	19 (A)	Bankfull Height (ft) =	16 (B)	(A) / (B) =	1.19 (C)	3.9

Root Depth / Study Bank Height (E)

Root Depth (ft) =	19 (D)	Study Bank Height (ft) =	19 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	30 (F)	(F) × (E) =	30 (G)	5.9

Bank Angle (H)

Bank Angle as *Degrees* =	65 (H)	4.4

Surface Protection (I)

Surface Protection as % =	80 (I)	1.9

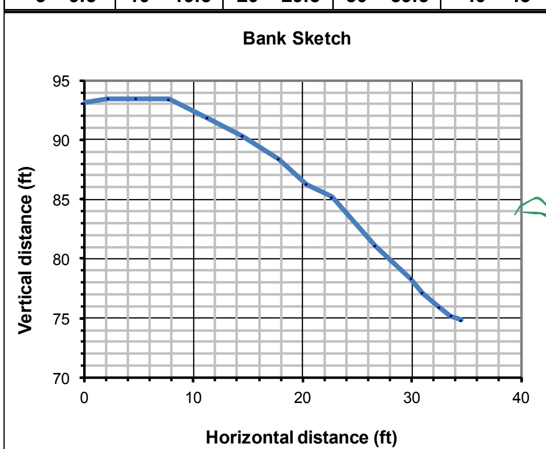
Bank Material Adjustment:

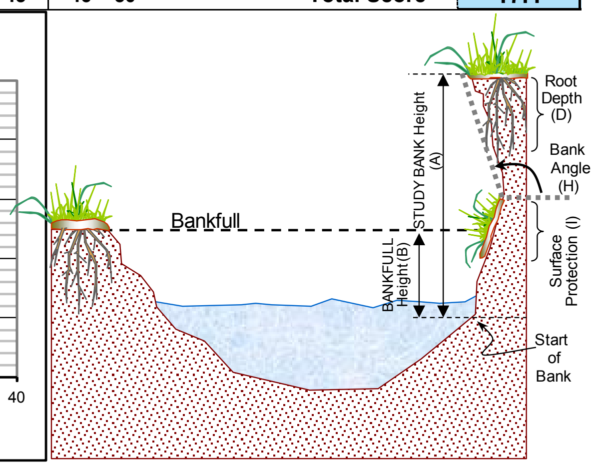
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50		**Low** **17.1**





Estimating Near-Bank Stress (NBS)

Stream: **Middle Little Arkansas River** Location: **2015 SB2 - Repeatability Study**

Station: **6+51** Stream Type: **E 5** Valley Type: **U-AL-FD**

Observers: **All Participants** Date: **08/14/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous……………………………......NBS [illegible] / Very High
Extensive deposition (continuous, cross-channel)………………...………………...…………………....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow……………………………………...NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)	**147.3**	**97.1**	**1.52**	**Very High**

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.00037**	**0.00028**	**1.32**	**Extreme**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.00037**	**0.00048**	**0.77**	**Moderate**

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**16.59**	**10.23**	**1.62**	**Moderate**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)	**16.59**	**0.00037**	**0.38**	**10.23**	**0.00028**	**0.18**	**2.14**	**Extreme**

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)	**0**	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Extreme**

Middle Little Arkansas Study Bank #3

Stream:	**Middle Little Arkansas River**	Location:	**2016 SB3**
Station:	**11+90.5**	Observers:	**KAB**
Date:	**04/08/16**	Stream Type: **E 5**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	**33 (A)**	**Bankfull Height** (ft) =	**17.5 (B)**	(A) / (B) =	**1.89 (C)**	**7.4**

Root Depth / Study Bank Height (E)

Root Depth (ft) =	**3 (D)**	**Study Bank Height** (ft) =	**33 (A)**	(D) / (A) =	**0.09 (E)**	**8.6**

Weighted Root Density (G)

Root Density as **%** =	**40 (F)**	(F) × (E) =	**3.63636 (G)**	**10.0**

Bank Angle (H)

Bank Angle as *Degrees* =	**70 (H)**	**4.9**

Surface Protection (I)

Surface Protection as **%** =	**0 (I)**	**10.0**

Bank Material Adjustment:

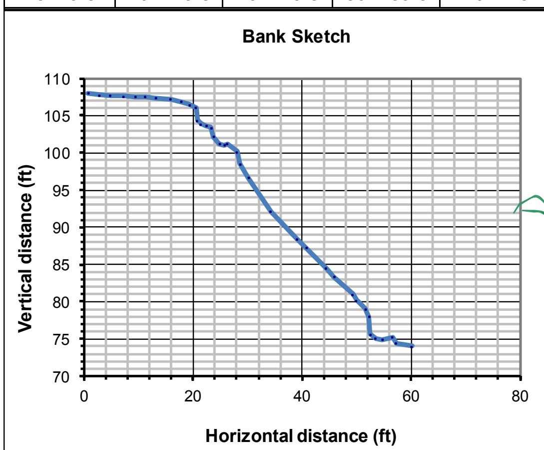
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

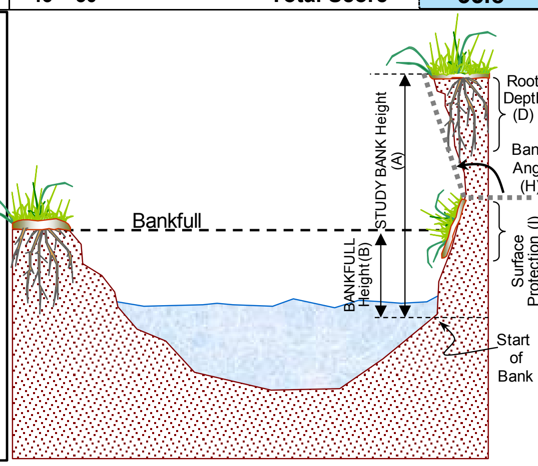
Bank Material Adjustment **-5**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage **0**

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **High** **35.8**





Estimating Near-Bank Stress (NBS)

Stream: **Middle Little Arkansas River** Location: **2016 SB3**

Station: **11+90.5** Stream Type: **E 5** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **04/08/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)

Transverse and/or central bars-short and/or discontinuous………… ………………..….NBS = High / Very High

Extensive deposition (continuous, cross-channel)……………..……………...…………………....NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow…………………………..…..NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
108	**97.1**	**1.11**	**Extreme**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
0.00008	**0.00028**	**0.29**	**Low**

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
0.00008	**0.00048**	**0.17**	**Very Low**

Dominant Near-Bank Stress
Extreme

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
19.56	**12.07**	**1.62**	**Moderate**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
19.56	**0.00008**	**0.1**	**12.07**	**0.00028**	**0.21**	**0.46**	**Very Low**

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Extreme**

Lower Little Arkansas Study Bank #1

Stream:	**Lower Little Arkansas River**	Location:	**2015 SB1**
Station:	**3+79**	Observers:	**KAB/TK**
Date:	**09/19/15**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**

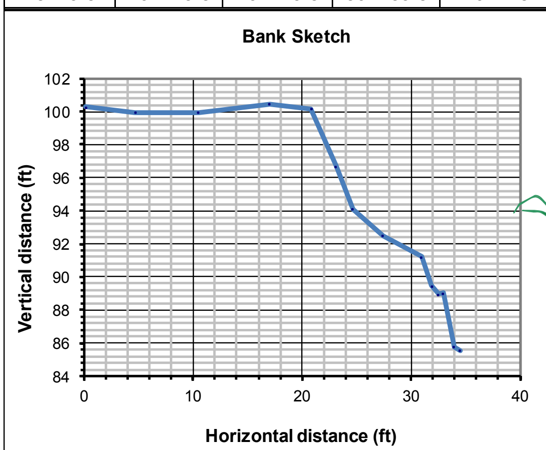
Criterion							BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) =	14.5 (A)	Bankfull Height (ft) =	10.5 (B)	(A) / (B) =	1.38 (C)	5.1
Root Depth / Study Bank Height (E)	Root Depth (ft) =	11 (D)	Study Bank Height (ft) =	14.5 (A)	(D) / (A) =	0.76 (E)	2.6
Weighted Root Density (G)			Root Density as % =	20 (F)	(F) × (E) =	15.1724 (G)	7.9
Bank Angle (H)					Bank Angle as *Degrees* =	80 (H)	5.9
Surface Protection (I)					Surface Protection as % =	0 (I)	10.0

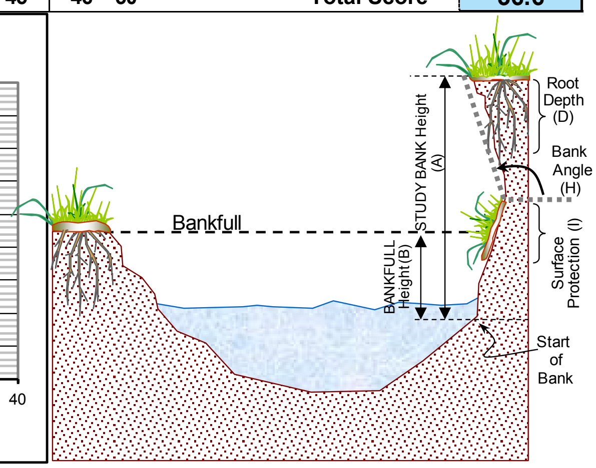
Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment	0
Stratification Adjustment Add 5–10 points, depending on position of unstable layers in relation to bankfull stage	5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Adjective Rating	**High**
						Total Score	**36.6**





Estimating Near-Bank Stress (NBS)

Stream: **Lower Little Arkansas River** Location: **2015 SB1**

Station: **3+79** Stream Type: **C 5c-** Valley Type: **U-AL-FD**

Observers: **KAB/TK** Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous…………. ………………...….NBS = High / Very High
Extensive deposition (continuous, cross-channel)……………..……………...…………………....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow……………………………..….NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
0.00016	**0.00036**	**0.44**	**Moderate**

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
0.00016	**0.00035**	**0.46**	**Low**

Dominant Near-Bank Stress
Moderate

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
10.85	**8.09**	**1.34**	**Low**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
10.85	**0.00016**	**0.11**	**8.09**	**0.00036**	**0.18**	**0.6**	**Very Low**

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Moderate**

Lower Little Arkansas Study Bank #2

Stream:	Lower Little Arkansas River	Location:	2016 SB2
Station:	11+59	Observers:	KAB
Date:	04/09/16	Stream Type: C 5c-	Valley Type: U-AL-FD

Parameter					Result	BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 13 (A)	Bankfull Height (ft) = 11 (B)	(A) / (B) =		1.18 (C)	3.7
Root Depth / Study Bank Height (E)	Root Depth (ft) = 1 (D)	Study Bank Height (ft) = 13 (A)	(D) / (A) =		0.08 (E)	8.7
Weighted Root Density (G)		Root Density as % = 40 (F)	(F) × (E) =		3.07692 (G)	10.0
Bank Angle (H)			Bank Angle as *Degrees* =		45 (H)	3.2
Surface Protection (I)			Surface Protection as % =		50 (I)	4.3

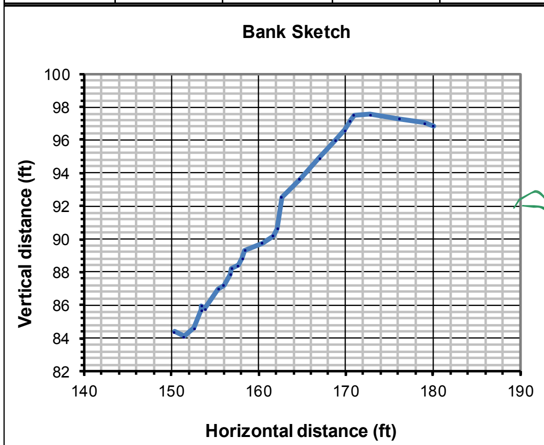
Bank Material Adjustment:

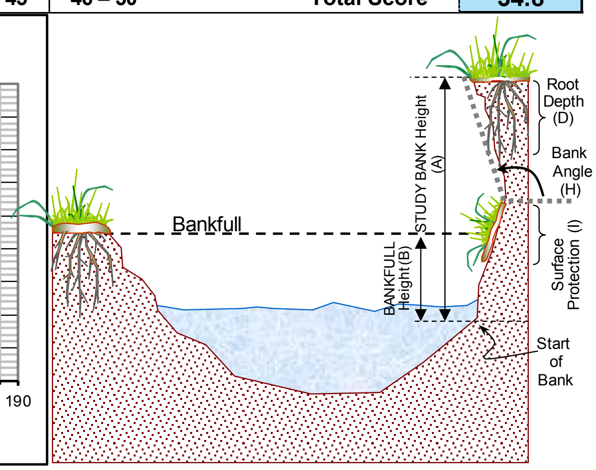
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	High 34.8





Estimating Near-Bank Stress (NBS)

Stream: **Little Arkansas River, Reach - Lower** Location:

Station: **2016 SB2** Stream Type: **C 5c-** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **04/09/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous………….………………..….NBS = High / Very High
- Extensive deposition (continuous, cross-channel)………………..………………...………………....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow…………………………….….NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
638	**160**	**3.99**	**Very Low**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
0.00025	**0.00036**	**0.69**	**High**

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
0.00025	**0.00129**	**0.19**	**Very Low**

Dominant Near-Bank Stress
High

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **High**

Lower Little Arkansas Study Bank #3

Stream:	Lower Little Arkansas River	Location:	2015 SB3
Station:	16+12	Observers:	KAB/TK
Date:	09/19/15	Stream Type: C 5c-	Valley Type: U-AL-FD

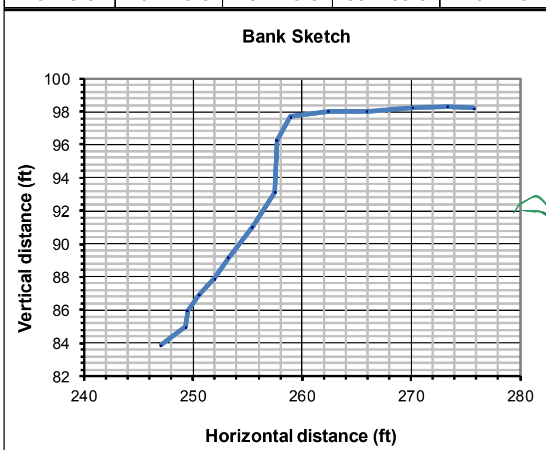
Parameter	Inputs	Result	BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) = 15 (A); Bankfull Height (ft) = 11.5 (B); (A) / (B) =	1.30 (C)	4.6
Root Depth / Study Bank Height (E)	Root Depth (ft) = 13 (D); Study Bank Height (ft) = 15 (A); (D) / (A) =	0.87 (E)	2.1
Weighted Root Density (G)	Root Density as % = 15 (F); (F) × (E) =	13 (G)	8.1
Bank Angle (H)	Bank Angle as *Degrees* =	50 (H)	3.4
Surface Protection (I)	Surface Protection as % =	0 (I)	10.0

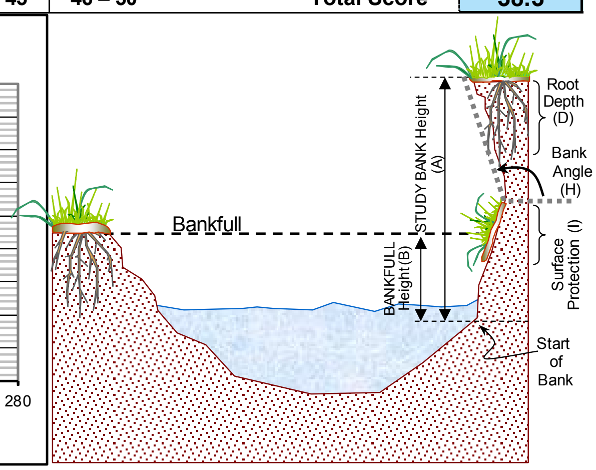
Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment	5
Stratification Adjustment Add 5–10 points, depending on position of unstable layers in relation to bankfull stage	5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Adjective Rating	High
						Total Score	38.3





Estimating Near-Bank Stress (NBS)

Stream: **Lower Little Arkansas River**	Location: **2015 SB3**	
Station: **16+12**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**
Observers: **KAB/TK**		Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)	Transverse and/or central bars-short and/or discontinuous………… ………………..….NBS = High / Very High
	Extensive deposition (continuous, cross-channel)……………..……………...…………………....NBS = Extreme
	Chute cutoffs, down-valley meander migration, converging flow……………………………..….NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)	**653.63**	**159.61**	**4.1**	**Very Low**

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.00025**	**0.00036**	**0.69**	**High**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.00025**	**0.00129**	**0.19**	**Very Low**

Dominant Near-Bank Stress
Very High

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**12.52**	**5.46**	**2.29**	**High**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)	**12.52**	**0.00025**	**0.2**	**5.42**	**0.00036**	**0.12**	**1.6**	**Very High**

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)	**0**	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Very High**

Dry Turkey Bank Pins

Stream: **Dry Turkey Creek** Location: **2015 Bank Pins**

Station: **9+17** Observers: **KAB**

Date: **10/17/15** Stream Type: **C 5c-** Valley Type: **U-AL-FD**

					BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)					
Study Bank Height (ft) =	5.5 (A)	Bankfull Height (ft) =	2.5 (B)	(A) / (B) = 2.20 (C)	8.1
Root Depth / Study Bank Height (E)					
Root Depth (ft) =	5.5 (D)	Study Bank Height (ft) =	5.5 (A)	(D) / (A) = 1.00 (E)	1.0
Weighted Root Density (G)					
		Root Density as % =	20 (F)	(F) × (E) = 20 (G)	7.2
Bank Angle (H)					
				Bank Angle as *Degrees* = 65 (H)	4.4
Surface Protection (I)					
				Surface Protection as % = 5 (I)	10.0

Bank Material Adjustment:

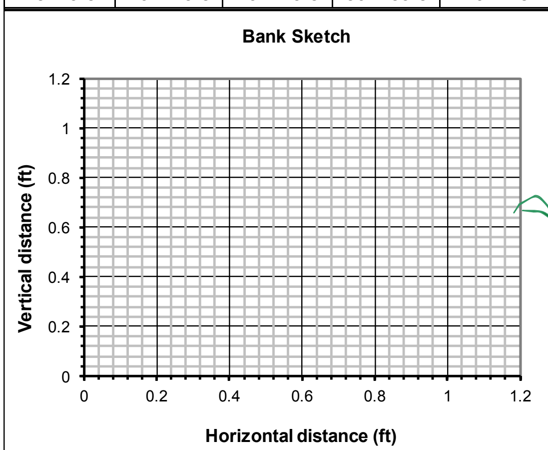
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

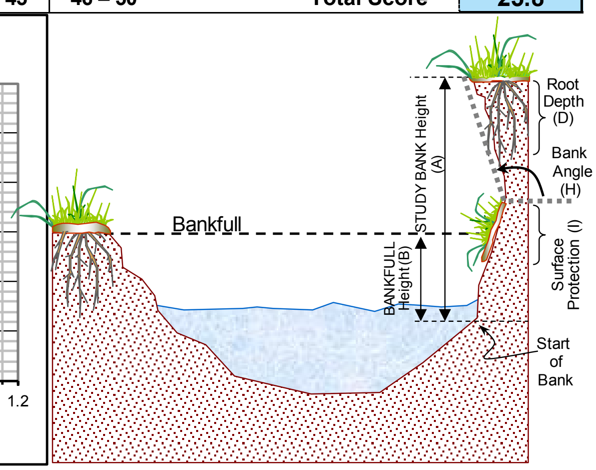
Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and Total Score: **Moderate** 25.8





Estimating Near-Bank Stress (NBS)

Stream: **Dry Turkey Creek** | Location: **2015 Bank Pins**

Station: **9+17** | Stream Type: **C 5c-** | Valley Type: **U-AL-FD**

Observers: **KAB** | Date: **10/17/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous………… ………………..….NBS = High / Very High
- Extensive deposition (continuous, cross-channel)…………….……………...…………………...NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow…………………………….…..NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
	0.00014	**0.00052**	**0.27**	**Low**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
	0.00035	**0.0016**	**0.22**	**Very Low**

Dominant Near-Bank Stress: **Low**

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating: **Low**

Dry Turkey Pool Study Bank

Stream:	**Dry Turkey Creek**	Location:	**2016 Pool XS**
Station:	**10+95**	Observers:	**KAB**
Date:	**04/07/16**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	4 (A)	Bankfull Height (ft) =	3 (B)	(A) / (B) =	1.33 (C)	4.8

Root Depth / Study Bank Height (E)

Root Depth (ft) =	4 (D)	Study Bank Height (ft) =	4 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	20 (F)	(F) × (E) =	20 (G)	7.2

Bank Angle (H)

Bank Angle as *Degrees* =	50 (H)	3.4

Surface Protection (I)

Surface Protection as % =	0 (I)	10.0

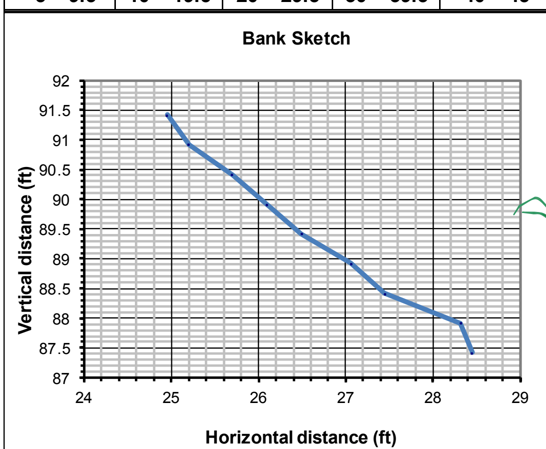
Bank Material Adjustment:

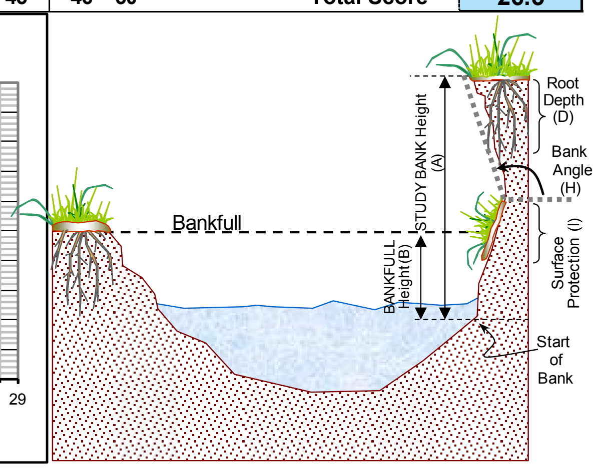
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment	0

Stratification Adjustment Add 5–10 points, depending on position of unstable layers in relation to bankfull stage	0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Moderate** 26.5





Estimating Near-Bank Stress (NBS)

Stream: **Dry Turkey Creek**	Location: **2016 Pool XS**	
Station: **10+95**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**
Observers: **KAB**		Date: **04/07/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous………… ………………..….NBS = High / Very High
- Extensive deposition (continuous, cross-channel)……………..……………...…………………...NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow……………………….……..….NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)				

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.00012**	**0.00052**	**0.23**	**Low**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.00012**	**0.05**	**0**	**Very Low**

Dominant Near-Bank Stress
Low

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)	**4.32**	**3.06**	**1.41**	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)	**4.32**	**0.00012**	**0.03**	**3.06**	**0.00052**	**0.1**	**0.33**	**Very Low**

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)	**0**	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Low**

Running Turkey Pool Study Bank – Left

Stream:	**Running Turkey Creek**	Location:	**2016 Pool XS - Left**
Station:	**7+74**	Observers:	**KAB/TK**
Date:	**09/19/15**	Stream Type: **G5c**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	8 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	2.29 (C)	8.3

Root Depth / Study Bank Height (E)

Root Depth (ft) =	4 (D)	Study Bank Height (ft) =	8 (A)	(D) / (A) =	0.50 (E)	3.9

Weighted Root Density (G)

Root Density as % =	15 (F)	(F) × (E) =	7.5 (G)	8.7

Bank Angle (H)

Bank Angle as *Degrees* =	55 (H)	3.7

Surface Protection (I)

Surface Protection as % =	20 (I)	7.2

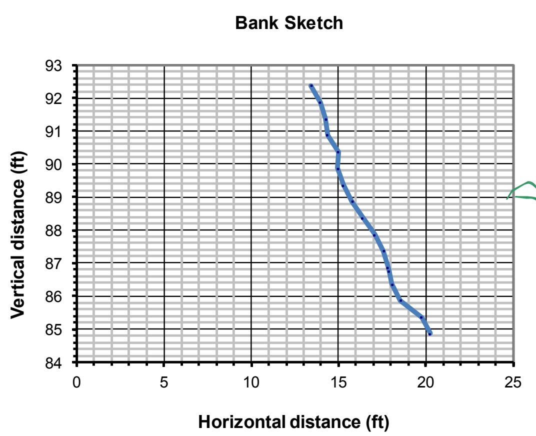
Bank Material Adjustment:

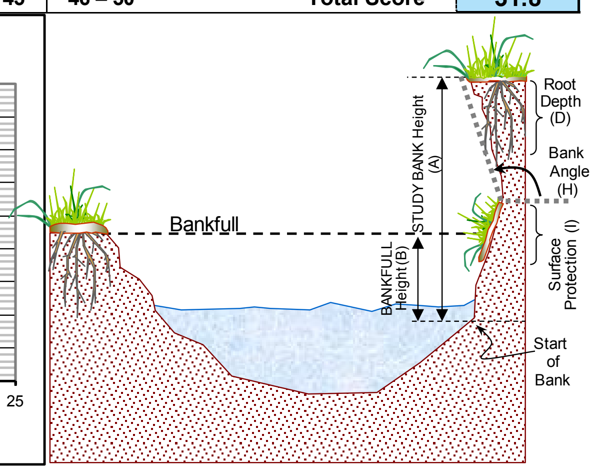
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**High** / **31.8**





Estimating Near-Bank Stress (NBS)

Stream: **Running Turkey Creek** Location: **2015 Pool XS - Left**

Station: **7+74** Stream Type: **G5c** Valley Type: **U-AL-FD**

Observers: **KAB/TK** Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous……………………………...NBS = High / Very High
- Extensive deposition (continuous, cross-channel)……………………………………………....NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow………………………………..NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.00017	**0.00109**	**0.16**	**Very Low**
(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.00017	**0.0032**	**0.05**	**Very Low**

Dominant Near-Bank Stress

Low

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	3.66	**2.92**	**1.25**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Low**

Running Turkey Pool Study Bank – Right

Stream:	**Running Turkey Creek**	Location:	**2016 Pool XS - Right**
Station:	**7+74**	Observers:	**KAB**
Date:	**04/08/16**	Stream Type: **G5c**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	7.5 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	2.14 (C)	8.1

Root Depth / Study Bank Height (E)

Root Depth (ft) =	3 (D)	Study Bank Height (ft) =	7.5 (A)	(D) / (A) =	0.40 (E)	4.9

Weighted Root Density (G)

Root Density as % =	10 (F)	(F) × (E) =	4 (G)	10.0

Bank Angle (H)

Bank Angle as *Degrees* =	65 (H)	4.4

Surface Protection (I)

Surface Protection as % =	5 (I)	10.0

Bank Material Adjustment:

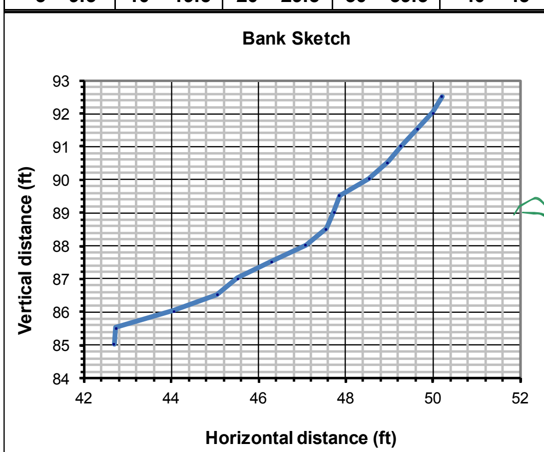
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

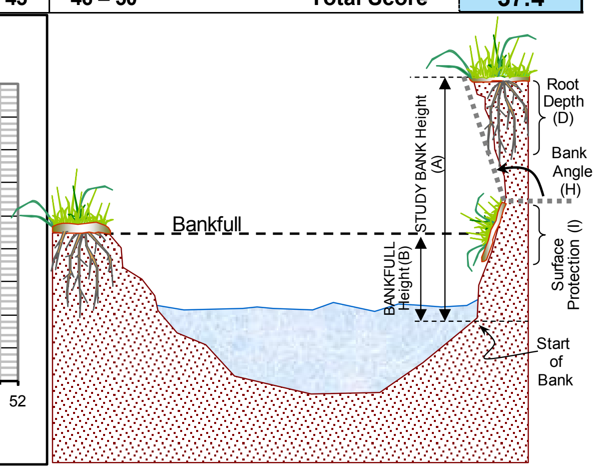
Bank Material Adjustment: 0

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

Adjective Rating and **Total Score**: **High** **37.4**





Estimating Near-Bank Stress (NBS)

Stream: **Running Turkey Creek** Location: **2016 Pool XS - Right**

Station: **7+74** Stream Type: **G5c** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **04/08/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I (1)

Transverse and/or central bars-short and/or discontinuous…………. ………………..….NBS = High / Very High

Extensive deposition (continuous, cross-channel)……………..……………...…………………..NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow……………………………..….NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
0.00017	**0.00109**	**0.16**	**Very Low**

(4)

Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
0.00017	**0.0032**	**0.05**	**Very Low**

Dominant Near-Bank Stress
Low

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
3.66	**2.92**	**1.25**	**Low**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
3.66	**0.00017**	**0.04**	**2.92**	**0.00109**	**0.2**	**0.2**	**Very Low**

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Low**

Upper West Emma Study Bank

Stream:	**Upper West Emma Creek**	Location:	**2015 Study Bank**
Station:	**2+80**	Observers:	**KAB/TK**
Date:	**09/19/15**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	3 (A)	Bankfull Height (ft) =	2.5 (B)	(A) / (B) =	1.20 (C)	4.0

Root Depth / Study Bank Height (E)

Root Depth (ft) =	3 (D)	Study Bank Height (ft) =	3 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	10 (F)	(F) × (E) =	10 (G)	8.4

Bank Angle (H)

Bank Angle as *Degrees* =	50 (H)	3.4

Surface Protection (I)

Surface Protection as % =	5 (I)	10.0

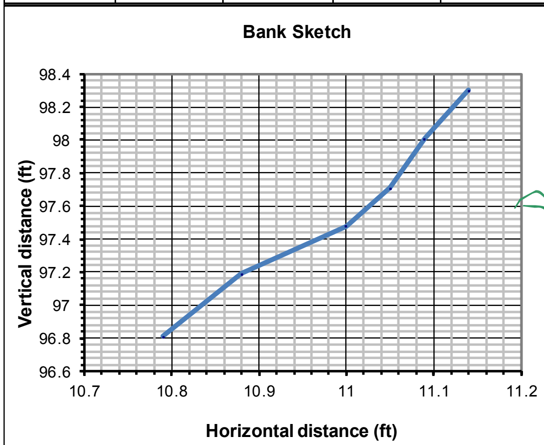
Bank Material Adjustment:

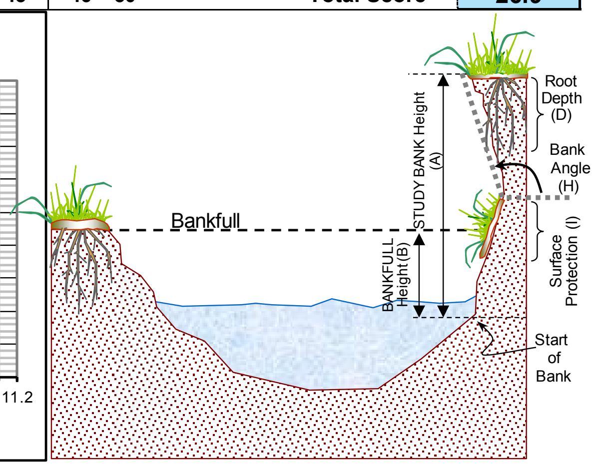
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Moderate** 26.9





Estimating Near-Bank Stress (NBS)

Stream: **Upper West Emma Creek**	Location: **2015 Study Bank**	
Station: **2+80**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**
Observers: **KAB/TK**		Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I — (1)

Transverse and/or central bars-short and/or discontinuous……………………………...….NBS = High / Very High

Extensive deposition (continuous, cross-channel)……………...……………...…………………....NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow…………………………………..NBS = Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
(2)	**80**	**59.02**	**1.36**	**Extreme**

	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
(3)	**0.00063**	**0.00094**	**0.67**	**High**

	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
(4)	**0.00063**	**0.00138**	**0.46**	**Low**

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
(5)				

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
(6)								

Level IV

	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
(7)	**0**	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating: Extreme

Upper West Emma Pool Study Bank

Stream: **Upper West Emma Creek** Location: **2016 Pool XS**

Station: **11+48** Observers: **KAB**

Date: **04/07/16** Stream Type: **C 5c-** Valley Type: **U-AL-FD**

						BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	4.5 (A)	Bankfull Height (ft) =	3.5 (B)	(A) / (B) =	1.29 (C)	4.6
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	4.5 (D)	Study Bank Height (ft) =	4.5 (A)	(D) / (A) =	1.00 (E)	1.0
Weighted Root Density (G)						
		Root Density as % =	25 (F)	(F) × (E) =	25 (G)	6.5
Bank Angle (H)						
				Bank Angle as *Degrees* =	50 (H)	3.4
Surface Protection (I)						
				Surface Protection as % =	5 (I)	10.0

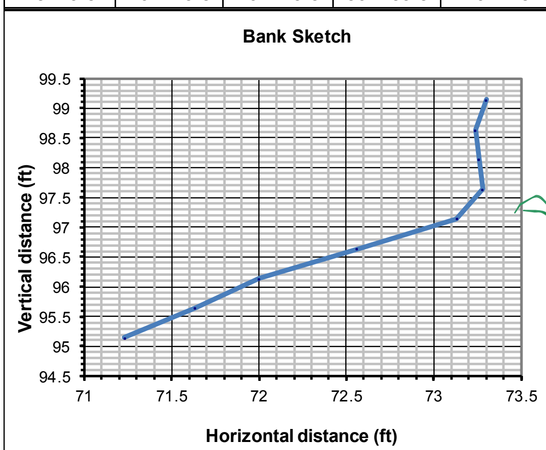
Bank Material Adjustment:

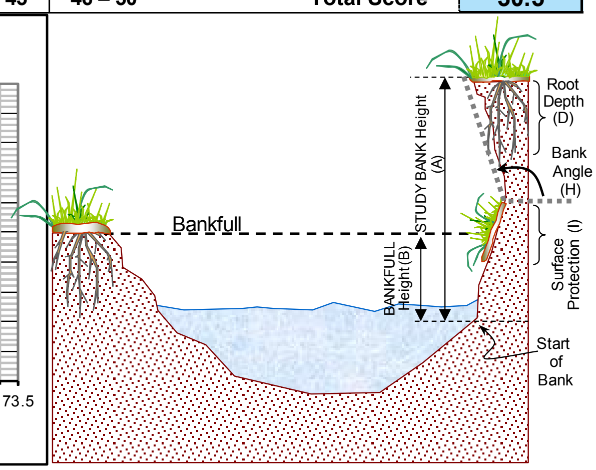
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: 5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score	
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50		**High** / **30.5**





Estimating Near-Bank Stress (NBS)

Stream: **Upper West Emma Creek** Location: **2016 Pool XS**

Station: **11+48** Stream Type: **C 5c-** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **04/07/16**

Methods for Estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous……………………………....NBS = High / Very High
Extensive deposition (continuous, cross-channel)………………………………………....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow…………………………….NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.00014	**0.00094**	**0.15**	**Very Low**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.00014	**0.00138**	**0.1**	**Very Low**

Dominant Near-Bank Stress
Low

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	4.28	**3.58**	**1.2**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Low**

Upper West Emma Bank Pins

Stream: **Upper West Emma Creek**		Location: **2015 Bank Pins**	
Station:		Observers: **KAB/TK**	
Date: **09/19/15**	Stream Type: **C 5c-**	Valley Type: **U-AL-FD**	

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	7 (A)	Bankfull Height (ft) =	5 (B)	(A) / (B) =	1.40 (C)	5.3

Root Depth / Study Bank Height (E)

Root Depth (ft) =	4 (D)	Study Bank Height (ft) =	7 (A)	(D) / (A) =	0.57 (E)	3.6

Weighted Root Density (G)

Root Density as % =	5 (F)	(F) × (E) =	2.85714 (G)	10.0

Bank Angle (H)

Bank Angle as *Degrees* =	90 (H)	7.9

Surface Protection (I)

Surface Protection as % =	5 (I)	10.0

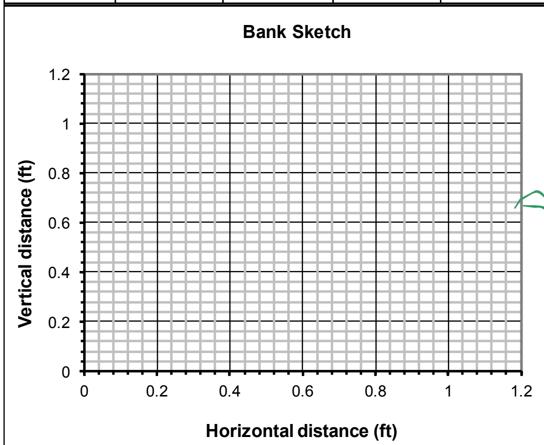
Bank Material Adjustment:

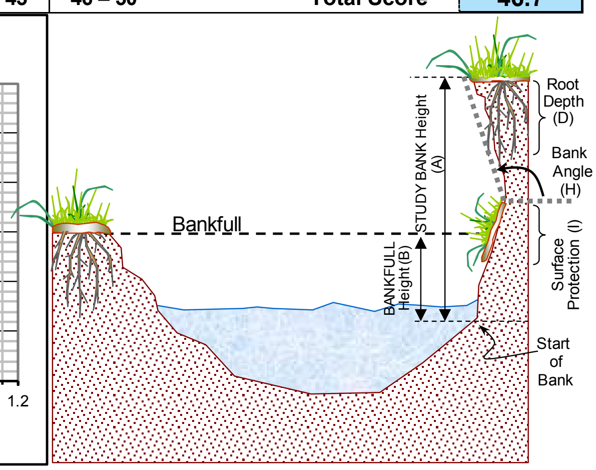
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment — **10**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage — **0**

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Extreme** **46.7**





Estimating Near-Bank Stress (NBS)

Stream: **Upper West Emma Creek** Location: **2015 Bank Pins**

Station: Stream Type: **C 5c-** Valley Type: **U-AL-FD**

Observers: **KAB/TK** Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)

Transverse and/or central bars-short and/or discontinuous…………. ………………...….NBS = High / Very High

Extensive deposition (continuous, cross-channel)……………..……………...…………………...NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow………………………………..….NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
42	**59.02**	**0.71**	**Extreme**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
Extreme

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	**Extreme**

Lower West Emma Pool Study Bank (a.k.a. Study Bank # 1 –Repeatability Study)

Stream:	Lower West Emma Creek	Location:	2016 Pool Study Bank
Station:	6+87	Observers:	KAB
Date:	04/08/16	Stream Type: B 5c	Valley Type: U-AL-FD

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	8.5 (A)	Bankfull Height (ft) =	4.5 (B)	(A) / (B) =	1.89 (C)	7.4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	8.5 (D)	Study Bank Height (ft) =	8.5 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	10 (F)	(F) × (E) =	10 (G)	8.4

Bank Angle (H)

Bank Angle as *Degrees* =	65 (H)	4.4

Surface Protection (I)

Surface Protection as % =	10 (I)	9.0

Bank Material Adjustment:

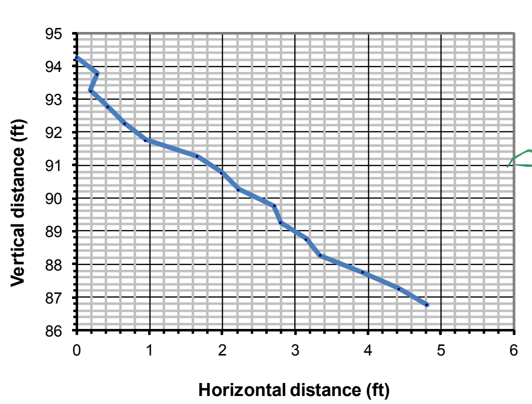
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

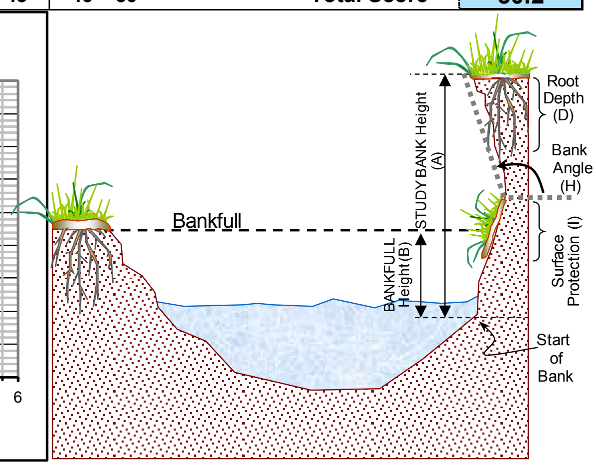
Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	High 30.2

Bank Sketch





Estimating Near-Bank Stress (NBS)

Stream: **Lower West Emma Creek**	Location: **2016 Pool Study Bank**	
Station: **6+87**	Stream Type: **B 5c**	Valley Type: **U-AL-FD**
Observers: **KAB**		Date: **04/08/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I (1)

Transverse and/or central bars-short and/or discontinuous……………………….NBS = High / Very High
Extensive deposition (continuous, cross-channel)…………………………………….NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow………………………….NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
	69	**64.4**	**1.07**	**Extreme**

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.00017	**0.00018**	**0.94**	**Very High**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.00017	**0.0006**	**0.28**	**Very Low**

Dominant Near-Bank Stress
Extreme

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	6.56	**4.76**	**1.38**	**Low**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Extreme**

Lower West Emma ISCO Study Bank (a.k.a. Study Bank # 2 – Repeatability Study)

Stream: **Lower West Emma Creek**		Location: **2016 ISCO Study Bank**	
Station: **17+69**		Observers: **KAB**	
Date: **04/08/16**	Stream Type: **B 5c**	Valley Type: **U-AL-FD**	

						BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	7.5 (A)	**Bankfull Height** (ft) =	5.5 (B)	(A) / (B) =	1.36 (C)	5.0
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	2 (D)	**Study Bank Height** (ft) =	7.5 (A)	(D) / (A) =	0.27 (E)	6.3
Weighted Root Density (G)						
		Root Density as % =	10 (F)	(F) × (E) =	2.66667 (G)	10.0
Bank Angle (H)						
				Bank Angle as *Degrees* =	70 (H)	4.9
Surface Protection (I)						
				Surface Protection as % =	0 (I)	10.0

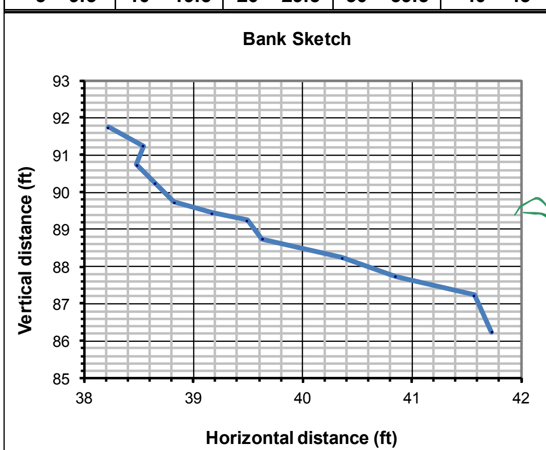
Bank Material Adjustment:

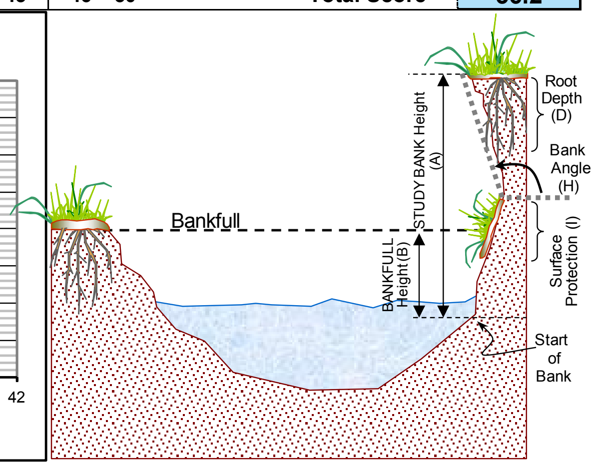
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	High 36.2





Estimating Near-Bank Stress (NBS)

Stream: **Lower West Emma** Location: **2016 ISCO Study Bank**

Station: **17+69** Stream Type: **B5C** Valley Type: **U-AL-FD**

Observers: **KAB** Date: **4/08/16**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I (1)

Transverse and/or central bars-short and/or discontinuous……….… ………………..….NBS = High / Very High

Extensive deposition (continuous, cross-channel)……………..……………...………………....NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow……………………………..….NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
	152	**64.4**	**2.36**	**Low**

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.000001	**0.00018**	**0.01**	**Very Low**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.000001	**0.00018**	**0.01**	**Very Low**

Dominant Near-Bank Stress
High

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	5.4	**2.2**	**2.45**	**High**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
	5.4	**0.000001**	**0**	**2.2**	**0.00018**	**0.02**	**0.01**	**Very Low**

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating	High

Lower West Emma Study Bank # 3 – Repeatability Study

Stream: **Lower West Emma Creek** Location: **2015 SB3 - Repeatability Study**

Station: **14+92** Observers: **KAB**

Date: **10/17/15** Stream Type: **B 5c** Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	6 (A)	Bankfull Height (ft) =	3.75 (B)	(A) / (B) =	1.60 (C)	6.0

Root Depth / Study Bank Height (E)

Root Depth (ft) =	6 (D)	Study Bank Height (ft) =	6 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	15 (F)	(F) × (E) =	15 (G)	7.9

Bank Angle (H)

Bank Angle as *Degrees* =	60 (H)	3.9

Surface Protection (I)

Surface Protection as % =	5 (I)	10.0

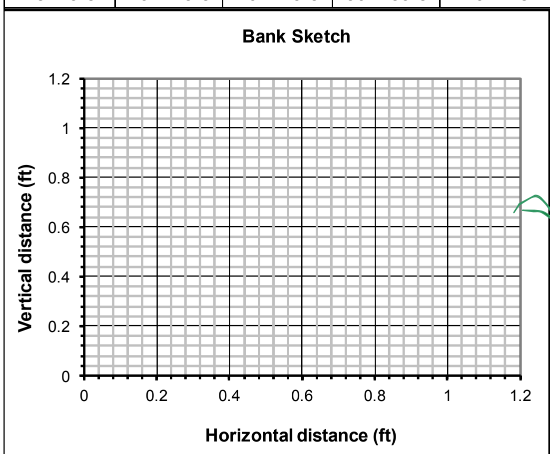
Bank Material Adjustment:

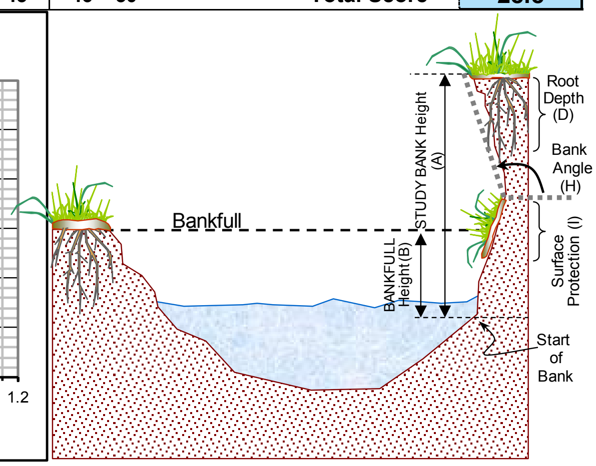
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	**Moderate** 28.8





Estimating Near-Bank Stress (NBS)

Stream: **BANCS Repeatability Assessment**	Location: **LWE #3**	
Station:	Stream Type: **B5C**	Valley Type: **U-AL-FD**
Observers: **All Participants**		Date: **08/14/15**

Methods for Estimating Near-Bank Stress (NBS)

	Method	Level	Use
(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous……………………………NBS = High / Very High
- Extensive deposition (continuous, cross-channel)………………………………………NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow………………………NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
	346	**64.4**	**5.37**	**Very Low**

(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.0004	**0.00018**	**2.22**	**Extreme**

(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.0004	**0.00198**	**0.2**	**Very Low**

Dominant Near-Bank Stress
Extreme

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
	5.17	**3.15**	**1.64**	**Moderate**

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
	5.17	**0.0004**	**0.13**	**3.15**	**0.00018**	**0.04**	**3.65**	**Extreme**

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Extreme**

Black Kettle Pool Study Bank

Stream:	**Black Kettle Creek**	Location:	**2015 Pool XS**
Station:	**5+20**	Observers:	**KAB/TK**
Date:	**09/19/15**	Stream Type: **C 6c-**	Valley Type: **U-AL-FD**

Measure	Input 1	Value	Input 2	Value	Calculation	Result	BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)	Study Bank Height (ft) =	3 (A)	Bankfull Height (ft) =	3 (B)	(A) / (B) =	1.00 (C)	1.0
Root Depth / Study Bank Height (E)	Root Depth (ft) =	3 (D)	Study Bank Height (ft) =	3 (A)	(D) / (A) =	1.00 (E)	1.0
Weighted Root Density (G)			Root Density as % =	15 (F)	(F) × (E) =	15 (G)	7.9
Bank Angle (H)					Bank Angle as *Degrees* =	30 (H)	2.4
Surface Protection (I)					Surface Protection as % =	25 (I)	6.5

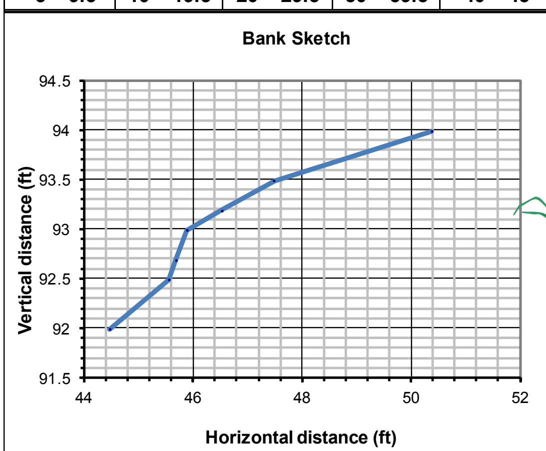
Bank Material Adjustment:

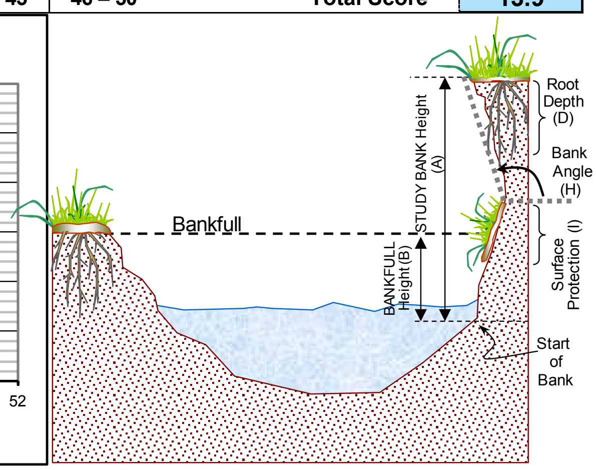
- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform medium to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Low 13.9





Estimating Near-Bank Stress (NBS)

Stream: **Black Kettle Creek** Location: **2015 Pool XS**

Station: **5+20** Stream Type: **C 6c-** Valley Type: **U-AL-FD**

Observers: **KAB/TK** Date: **09/19/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)
- Transverse and/or central bars-short and/or discontinuous………… ………………..….NBS = High / Very High
- Extensive deposition (continuous, cross-channel)……………..……………...…………………...NBS = Extreme
- Chute cutoffs, down-valley meander migration, converging flow……………………………….…NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	Ratio S_p / S	Near-Bank Stress (NBS)
0.00005	**0.00007**	**0.71**	**High**

Dominant Near-Bank Stress

High

(4)

Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p / S_{rif}	Near-Bank Stress (NBS)
0.00005	**0.00023**	**0.22**	**Very Low**

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **High**

Black Kettle Bank Pins

Stream: **Black Kettle Creek** Location: **2015 Bank Pins**

Station: **8+91** Observers: **KAB**

Date: **10/02/15** Stream Type: **C 6c-** Valley Type: **U-AL-FD**

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	3.5 (A)	Bankfull Height (ft) =	3 (B)	(A) / (B) =	1.17 (C)	3.4

Root Depth / Study Bank Height (E)

Root Depth (ft) =	3.5 (D)	Study Bank Height (ft) =	3.5 (A)	(D) / (A) =	1.00 (E)	1.0

Weighted Root Density (G)

Root Density as % =	15 (F)	(F) × (E) =	15 (G)	7.9

Bank Angle (H)

Bank Angle as *Degrees* =	30 (H)	2.4

Surface Protection (I)

Surface Protection as % =	40 (I)	5.1

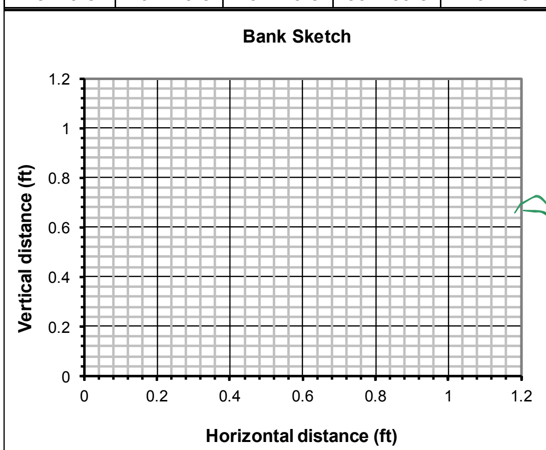
Bank Material Adjustment:

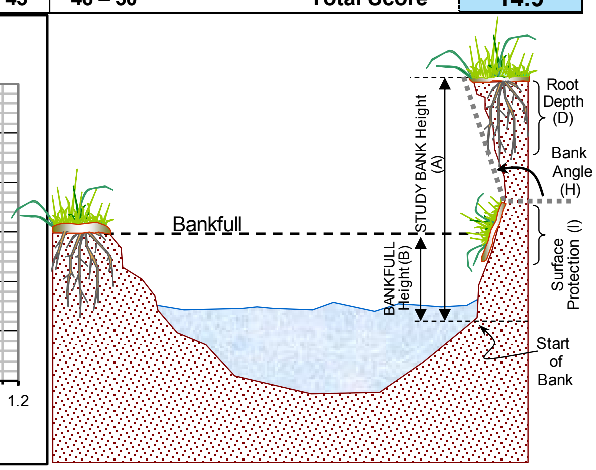
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment unless primarily clay, then subtract 20 points)

Bank Material Adjustment: -5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 0

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Low 14.9





Estimating Near-Bank Stress (NBS)

Stream: **Black Kettle Creek**	Location: **2015 Bank Pins**	
Station: **8+91**	Stream Type: **C 6c-**	Valley Type: **U-AL-FD**
Observers: **KAB/TK**		Date: **10/02/15**

Methods for Estimating Near-Bank Stress (NBS)

(1)	Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2)	Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3)	Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4)	Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5)	Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6)	Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7)	Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I (1)

Transverse and/or central bars-short and/or discontinuous…………………………....NBS = High / Very High
Extensive deposition (continuous, cross-channel)…………………………………………....NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow………………………………NBS = Extreme

Level II

(2)	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
	98	**38.5**	**2.55**	**Low**
(3)	Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)
	0.00018	**0.00007**	**2.57**	**Extreme**
(4)	Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)
	0.00018	**0.00035**	**0.51**	**Low**

Dominant Near-Bank Stress
Extreme

Level III

(5)	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)	Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
	0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating | **Extreme**

Appendix I – Bank Pin Measurements

Black Kettle

Bank Pins 1 - No Bank Profile Survey (Sta. 8+91)					**Total Days**	1157	**Years**	3.169863							
												All Available Data			
3/23/2006	Book 1 pg. 97			**7/7/2006**	Book 1 pg. 97			**Days**	107		**Total Lateral Erosion**			**0.108**	ft
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**		**Annual Lateral Erosion Rate**			**0.034071**	ft/yr
0	93.88	Lower		0.07	93.88	Reset		93.88	0.07						
0	94.72	Middle		0.05	94.72	Reset		94.72	0.05						
0	95.72	Upper		0.04	95.72	Reset		95.72	0.04						
								Average	0.053333	ft					
								Cut							
7/7/2006	Book 1 pg. 97			**11/3/2006**	Book 1 pg. 97			**Days**	120						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	93.88			0	93.88			93.88	0						
0	94.72			-0.03	94.72			94.72	-0.03						
0	95.72			0.06	95.72	Reset		95.72	0.06						
								Average	0.01	ft					
								Cut							
11/3/2006	Book 1 pg. 97			**10/28/2007**	Book 1 pg. 97			**Days**	360						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	93.88			N/A	93.88	Not found		93.88	N/A						
-0.03	94.72			0.003	94.72	Reset		94.72	0.033						
0	95.72			0.003	95.72	Reset		95.72	0.003						
								Average	0.018	ft					
								Cut							
10/28/2007	Book 1 pg. 97			**5/19/2009**	Book 4 pg. 104			**Days**	570						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	93.88			-0.08	93.88	Reset?		93.88	-0.08						
0	94.72			-0.08	94.72	Reset?		94.72	-0.08						
0	95.72			0.24	95.72	Reset?		95.72	0.24						
								Average	0.026667	ft					
								Cut							

Pool XS (Sta. 5+21) -- Problems with Cattle **Total Days** 1155 **Years** 3.1643836

3/24/2006	Black Kettle File (pg. 8)		**7/7/2006**	Book 1 pg. 109		**Days**	106	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.1	Assumption	0	-0.1	Assumption			
0.47	0	TOP OF TOE PIN		0				
1.56	0.5			0.5				
1.69	0.7	bank pin	1.69	0.7	0' exposed	0.7	0	
1.89	1			1				
2.53	1.2	bank pin	2.83	1.2	0.3' exposed, reset	1.2	0.3	
3.49	1.5			1.5				
6.38	2		6.38	2	Assumption			
						Average	**0.15**	ft
						Cut		
						From RM	**0.14**	ft
						Cut		
7/7/2006	Book 1 pg. 109		**11/3/2006**	Book 1 pg. 109		**Days**	120	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.1	Assumption	0	-0.1	Assumption			
	0			0				
	0.5			0.5				
1.69	0.7		1.69	0.7	No exposure	0.7	0	
	1			1				
2.83	1.2		2.83	1.2	No exposure	1.2	0	
	1.5			1.5				
6.38	2	Assumption	6.38	2	Assumption			
						Average	**0**	ft
						Cut		
11/3/2006	Book 1 pg. 109		**10/28/2007**	Book 1 pg. 109		**Days**	360	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.1	Assumption	0	-0.1	Assumption			
	0			0				
	0.5			0.5				
1.69	0.7		1.96	0.7	0.27 exposed, reset	0.7	0.27	
	1			1				
2.83	1.2		2.92	1.2	0.09 exposed, reset	1.2	0.09	
	1.5			1.5				
6.38	2	Assumption	6.38	2	Assumption			
						Average	0.18	ft
						Cut		
						From RM	**0.115**	ft
						Cut		

(shaded)	interpolated	
All Available Data		
Average		
Total Lateral Erosion	**0.42**	ft
Annual Lateral Erosion Rate	**0.132727**	ft/yr
River Morph		
Total Lateral Erosion	**0.315**	ft
Annual Lateral Erosion Rate	**0.099545**	ft/yr

10/28/2007	Book 1 pg. 109			**5/18/2009**	Book 4, pg. 100,116			**Days**	569	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	-0.1	Assumption		0	-0.1	Assumption				
	0				0					
	0.5				0.5					
1.96	0.7			2.09	0.7	0.13 exposed, not reset		0.7	0.13	
	1				1					
2.92	1.2			2.97	1.2	0.05 exposed, not reset		1.2	0.05	
	1.5				1.5					
6.38	2	Assumption		6.38	2	Assumption				
								Average	0.09	ft
								Cut		
								From RM	**0.06**	ft
								Cut		

Dry Turkey

Bank Pins - No Bank Profile Survey (Sta. 9+17)						**Total Days**	3701	**Years**	10.13973						
2/4/2006	Book 2 pg. 10			**7/7/2006**	Book 2 pg. 10			**Days**	154		**All Available Data**				
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**		**Total Lateral Erosion**			**0.665**	ft
0	1.5	Lower		0	1.5			1.5	0		**Annual Lateral Erosion Rate**			**0.065583626**	ft/yr
0	2.5	Middle		0	2.5	Left		2.5	0						
								Average	0	ft					
7/7/2006	Book 2 pg. 10			**11/2/2006**	Book 2, pg. 10			**Days**	119						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	1.5	Lower		0	1.5			1.5	0						
0	2.5	Middle		0	2.5			2.5	0						
								Average	0	ft					
11/2/2006	Book 2, pg. 10			**10/6/2007**	Book 5, pg. 14			**Days**	339						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	1.5			0.15	1.5	not reset?		1.5	0.15						
0	2.5			0.18	2.5	not reset?		2.5	0.18						
								Average	**0.165**	ft					
								Cut							
10/6/2007	Book 5, pg. 14			**2/28/2008**	Book 5, pg. 14			**Days**	146						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0.15	1.5			0.19	1.5	not reset		1.5	0.04						
0.18	2.5			0.19	2.5	reset		2.5	0.01						
								Average	0.025	ft					
								Cut							
2/28/2008	Book 5, pg. 14			**5/19/2009**	Book 2, pg. 103			**Days**	447						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0.19	1.5			0.38	1.5	not reset		1.5	0.19						
0	2.5			0.17	2.5	not reset		2.5	0.17						
								Average	0.18	ft					
								Cut							

5/19/2009	Book 2, pg. 103			**3/18/2016**	Book 7, pg. 15			**Days**	2496	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0.38	1.5	not reset		0.86	1.5	not reset		1.5	0.48	
0.17	2.5	not reset		0.28	2.5	not reset		2.5	0.11	
								Average	0.295	ft
								Cut		

Upper West Emma

Bank Pins (Horseshoe Meander - No Bank Profile Survey)							Total Days	1178	Years	3.227397			
3/10/2006	Book 1, pg. 77		**7/7/2006**	Book 1, pg. 77			**Days**	120					
Horiz.	**Vert.**		**Horiz.**	**Vert.**			**Vert.**	**Horz.**		**All Available Data**			
0	2	lower	N/A	2	not found		2			**Average**			
0	3	middle	0.27	3	reset		3	0.27		**Total Lateral Erosion**		**0.296667**	ft
0	4	upper	0.18	4	reset		4	0.18		**Annual Lateral Erosion Rate**		**0.091921**	ft/yr
							Average	0.225	ft				
							Cut						
7/7/2006	Book 1, pg. 77		**11/3/2006**	Book 1, pg. 76			**Days**	120					
Horiz.	**Vert.**		**Horiz.**	**Vert.**			**Vert.**	**Horz.**					
0	2		0	2			2	0					
0	3		0.05	3	reset		3	0.05					
0	4		0.04	4	reset		4	0.04					
							Average	0.03	ft				
							Cut						
11/3/2006	Book 1, pg. 76		**10/7/2007**	Book 1, pg. 76			**Days**	339					
Horiz.	**Vert.**		**Horiz.**	**Vert.**			**Vert.**	**Horz.**					
0	2		0	2	not found		2	0					
0	3		0	3	not found		3	0					
0	4		0	4	not found		4	0					
							Average	0	ft				
10/7/2007	Book 1, pg. 76		**2/28/2008**	Book 1, pg. 81			**Days**	145					
Horiz.	**Vert.**		**Horiz.**	**Vert.**			**Vert.**	**Horz.**					
0	2		N/A	2			2						
0	3		-0.3	3	reset		3	-0.3					
0	4		0.17	4	reset		4	0.17					
							Average	-0.065	ft				
							Deposition						

2/28/2008	Book 1, pg. 81			**5/26/2009**	Book 5, pg. 78			**Days**	454	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	2			-0.3	2			2	-0.3	
0	3			0.24	3			3	0.24	
0	4			0.38	4			4	0.38	
								Average	0.106667	ft
								Cut		

Appendix J – Low Bank Repeated Cross Profiling Technique Measurements

Dry Turkey

Pool XS (Sta. 10+95 to 11+48)				**Total Days**	3698	**Years**	10.13150685								
2/3/2006	Dry Turkey File pg .2			**10/6/2007**	Dry Turkey File pg .5			**Days**	611		**All Available Data**				
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**		**Average**				
0	-0.1			0	-0.1						**Total Lateral Erosion**			**0.633333333**	ft
0.56	0	Toe Pin		1.03	0	Toe Pin		0	0.47		**Annual Lateral Erosion Rate**			**0.062511267**	ft/yr
1.55	0.5			1.84	0.5			0.5	0.29						
2.37	1			2.89	1			1	0.52						
3.43	1.5			3.24	1.5			1.5	-0.19		**River Morph**				
4.02	2	Lower Pin		3.88	2	Reset?		2	-0.14		**Total Lateral Erosion**			**0.925**	ft
4.44	2.5			4.35	2.5			2.5	-0.09		**Annual Lateral Erosion Rate**			**0.091299351**	ft/yr
4.89	3	Upper Pin		4.82	3	Reset?		3	-0.07						
5.51	3.5			5.35	3.5			3.5	-0.16		**Surveyed Data Only**				
6.82	4	Top of Bank		6.04	4			4	-0.78		**Average**				
								Average	**-0.01667**	ft	**Total Lateral Erosion**			**0.633333333**	ft
								Deposition			**Annual Lateral Erosion Rate**			**0.062511267**	ft/yr
								From RM	0.005	ft					
											River Morph				
10/6/2007	Dry Turkey File pg .5			**3/18/2016**	Book 7, pg. 14			**Days**	3087		**Total Lateral Erosion**			**0.925**	ft
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**		**Annual Lateral Erosion Rate**			**0.091299351**	ft/yr
0	-0.1			1.7	-0.55										
1.03	0	Toe Pin		2.55	0			0	1.52						
1.84	0.5			2.68	0.5			0.5	0.84						
2.89	1			3.55	1			1	0.66						
3.24	1.5			3.94	1.5			1.5	0.7						
3.88	2			4.51	2	lower bnkpn		2	0.63						
4.35	2.5			4.91	2.5			2.5	0.56						
4.82	3			5.3	3	upper bnkpn		3	0.48						
5.35	3.5			5.8	3.5			3.5	0.45						
6.04	4	Top of Bank		6.05	4			4	0.01						
								Average	**0.65**						
								Erosion							
								From RM	0.92						

Running Turkey

Lower Pool Left Study Bank (Sta. 7+74)				**Total Days**		3351	**Years**	9.180822					
1/16/2006	RT Folder, pg. 6			**10/7/2007**	RT Folder, pg. 6			**Days**	630			Interpolated	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**				
0	-0.1			0	-0.1						**All Available Data**		
1.53	0.5			1.82	0.5			0.5	0.29		**Average**		
1.8	1			2.39	1			1	0.59		**Total Lateral Erosion**	**1.462429**	ft
2.19	1.5			2.9	1.5			1.5	0.71		**Annual Lateral Erosion Rate**	**0.159292**	ft/yr
2.61	2	Lower		3.35	2	Lower		2	0.74				
2.97	2.5			3.5	2.5			2.5	0.53				
3.29	3			3.85	3			3	0.56		**River Morph**		
3.67	3.5			4.02	3.5			3.5	0.35		**Total Lateral Erosion**	**1.9643**	ft
3.91	4	Middle		4.24	4	Middle		4	0.33		**Annual Lateral Erosion Rate**	**0.213957**	ft/yr
4.28	4.5			4.66	4.5			4.5	0.38				
4.62	5			5.11	5			5	0.49		**Surveyed Data Only**		
5.17	5.5			5.58	5.5			5.5	0.41		**Average**		
5.56	6	Upper		5.96	6	Upper		6	0.4		**Total Lateral Erosion**	**1.462429**	ft
5.82	6.5			6.08	6.5			6.5	0.26		**Annual Lateral Erosion Rate**	**0.159292**	ft/yr
6.58	7			6.37	7			7	-0.21				
								Average	0.416429	ft			
								Cut			**River Morph**		
								From RM	**0.4257**	ft	**Total Lateral Erosion**	**1.9643**	ft
								Cut			**Annual Lateral Erosion Rate**	**0.213957**	ft/yr

10/7/2007	RT Folder, pg. 6			**3/19/2015**	Book 6, pg. 58			**Days**	2721	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	-0.1			0	-0.4	Streambed				
1.82	0.5			1.45	0					
2.39	1			1.95	0.5			0.5	0.13	
2.9	1.5			3.14	1			1	0.75	
3.24	1.88			3.65	1.5			1.5	0.75	
3.35	2	Lower		3.79	1.88	Next to Lower Pin		1.88	0.55	
3.5	2.5			3.86	2			2	0.51	
3.85	3			4.11	2.5			2.5	0.61	
4.02	3.5			4.64	3			3	0.79	
4.24	4	Middle		5.32	3.5			3.5	1.3	
4.66	4.5			5.92	4	Next to Middle Pin		4	1.68	
5.11	5			6.42	4.5			4.5	1.76	
5.58	5.5			6.74	5			5	1.63	
5.96	6	Upper		6.72	5.5			5.5	1.14	
6.08	6.5			7.34	6			6	1.38	
6.37	7			7.42	6.5			6.5	1.34	
				7.74	7			7	1.37	
				8.28	7.5			7.5		
								Average	**1.046**	ft
								Cut		
								From RM	**1.5386**	ft
								Cut		

Lower Pool Right Study Bank (Sta. 7+74)					**Total Days**	3718	**Years**	10.1863							
1/16/2006	RT Folder, pg. 6			**10/7/2007**	RT Folder, pg. 6			**Days**	630			Interpolated			
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	-0.1			0	-0.1							**All Available Data**			
1.37	0.5			2.08	0.5			0.5	0.71		**Average**				
1.89	1			2.34	1			1	0.45		**Total Lateral Erosion**			**4.247595**	ft
2.24	1.5			2.72	1.5			1.5	0.48		**Annual Lateral Erosion Rate**			**0.416991**	ft/yr
2.5	2	Lower		3.05	2	(Lower @ 2.91)		2	0.55						
2.27	2.5			3.15	2.5			2.5	0.88						
2.43	3			3.72	3			3	1.29		**River Morph**				
2.45	3.5			3.83	3.5			3.5	1.38		**Total Lateral Erosion**			**4.3731**	ft
2.49	4	Middle		3.71	4	(Middle @ 3.45)		4	1.22		**Annual Lateral Erosion Rate**			**0.429312**	ft/yr
2.2	4.5			3.61	4.5			4.5	1.41						
2.31	5			3.65	5			5	1.34			**Surveyed Data Only**			
2.41	5.5			3.32	5.5			5.5	0.91		**Average**				
2.61	5.75			3.15	5.75	(Upper @ 2.98)		5.75	0.54		**Total Lateral Erosion**			**4.247595**	ft
2.81	6	Upper		2.98	6			6	0.17		**Annual Lateral Erosion Rate**			**0.416991**	ft/yr
3	6.5			3.22	6.5			6.5	0.22						
3.82	7			3.85	7			7	0.03	ft					
								Average	**0.772**		**River Morph**				
								Cut			**Total Lateral Erosion**			**4.3731**	ft
								From RM	**0.7929**	ft	**Annual Lateral Erosion Rate**			**0.429312**	ft/yr
								Cut							

10/7/2007	RT Folder, pg. 6			**5/20/2009**	Book 2, pg. 113			**Days**	592	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	-0.1			0	-0.1					
2.08	0.5			1.54	0	Top of Toe Pin		0.5	-0.71	
2.34	1			1.37	0.5			1	0.71	
2.72	1.5			3.05	1			1.5	0.58	
2.89	1.75			3.3	1.5			1.75	0.91	
3.05	2	(Lower @ 2.91)		3.8	1.75	Lower		2	0.84	
3.15	2.5			3.89	2			2.5	1.13	
3.72	3			4.28	2.5			3	0.76	
3.83	3.5			4.48	3			3.5	0.76	
3.75	3.85			4.59	3.5			3.85	0.92	
3.71	4	(Middle @ 3.45)		4.67	3.85	Middle		4	0.9	
3.62	4.45			4.61	4			4.45	0.8	
3.61	4.5			4.42	4.45			4.5	0.8	
3.65	5			4.41	4.5			5	0.62	
3.58	5.1			4.27	5			5.1	0.67	
3.32	5.5			4.25	5.1			5.5	0.79	
3.15	5.75	(Upper @ 2.98)		4.11	5.5			5.75	0.88	
3.13	5.78			4.03	5.75			5.78	0.89	
2.98	6			4.02	5.78			6	0.82	
3.22	6.5			3.8	6			6.5	0.59	
3.85	7			3.81	6.5			7	0.36	
				4.21	7			**Average**	**0.701**	ft
								Cut		
								From RM	**0.69**	ft
								Cut		

5/20/2009	Book 2, pg. 113			**3/19/2015**	Book 6, pg. 60			**Days**	2130	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	-0.1			0	-0.07					
1.54	0	Top of Toe Pin		2.15	0			0	0.61	
1.37	0.5			2.75	0.5			0.5	1.38	
3.05	1			4.24	1			1	1.19	
3.3	1.5			4.79	1.5			1.5	1.49	
3.8	1.75	Lower		5.19	1.75			1.75	1.39	
3.89	2			5.58	2			2	1.69	
4.28	2.5			6.12	2.5			2.5	1.84	
4.48	3			6.32	3			3	1.84	
4.59	3.5			6.22	3.5			3.5	1.63	
4.67	3.85	Middle		6.57	3.85			3.85	1.9	
4.61	4			6.7	4			4	2.09	
4.42	4.45			7.11	4.45			4.45	2.69	
4.41	4.5			7.16	4.5			4.5	2.75	
4.27	5			7.72	5			5	3.45	
4.25	5.1			7.95	5.1			5.1	3.7	
4.11	5.5			8.86	5.5			5.5	4.75	
4.02	5.78			8.64	5.78			5.78	4.62	
3.8	6			8.46	6			6	4.66	
3.81	6.5			8	6.5			6.5	4.19	
4.21	7			7.88	7			7	3.67	
				8.7	7.5			7.5		
								Average	**2.5765**	ft
								Cut		
								From RM	**2.4929**	ft
								Cut		

3/19/2015	Book 6, pg. 60			3/18/2016	Book 7, pg. 12			Days	366	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	-0.07			1.58	-0.82					
2.15	0			2.18	0			0	0.03	
2.75	0.5			2.23	0.5			0.5	-0.52	
4.24	1			3.55	1			1	-0.69	
4.79	1.5			4.55	1.5			1.5	-0.24	
5.19	1.75			4.79	1.75			1.75	-0.4	
5.58	2			5.02	2			2	-0.56	
6.12	2.5			5.81	2.5			2.5	-0.31	
6.32	3			6.59	3			3	0.27	
6.22	3.5			7.06	3.5			3.5	0.84	
6.57	3.85			7.18	3.85			3.85	0.61	
6.7	4			7.23	4			4	0.53	
7.11	4.45			7.35	4.45			4.45	0.24	
7.16	4.5			7.36	4.5			4.5	0.2	
7.72	5			8.04	5			5	0.32	
7.95	5.1			8.12	5.1			5.1	0.17	
8.86	5.5			8.46	5.5			5.5	-0.4	
8.64	5.78			8.63	5.78			5.78	-0.01	
8.46	6			8.77	6			6	0.31	
8	6.5			9.14	6.5			6.5	1.14	
7.88	7			9.5	7			7	1.62	
8.7	7.5			9.71	7.5			7.5	1.01	
								Average	**0.198095**	ft
								Cut		
								From RM	**0.3973**	ft
								Cut		

Lower West Emma

Pool Study Bank (Sta. 6+87)				**Total Days**	3636	**Years**	9.961643836								
4/8/2006	LWE Folder, pg. 4			**10/27/2007**	LWE Folder, pg. 4			**Days**	568			interpolated			
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**		**All Available Data**				
0	-0.1			0	-0.1						**Average**				
1.73	0	toe pin		2.27	0	toe pin		0	0.54		**Total Lateral Erosion**			**3.441333**	ft
2.08	0.5			2.83	0.5			0.5	0.75		**Annual Lateral Erosion Rate**			**0.345458**	ft/yr
2.57	1			3.59	1			1	1.02						
3.17	1.5	Lower Pin		3.94	1.5	reset		1.5	0.77						
3.12	2			4.08	2			2	0.96		**River Morph**				
3.53	2.5			4.64	2.5			2.5	1.11		**Total Lateral Erosion**			**4.209**	ft
4.45	3	Middle Pin		5.53	3	reset		3	1.08		**Annual Lateral Erosion Rate**			**0.422521**	ft/yr
5.16	3.5			5.55	3.5			3.5	0.39						
5.28	4			5.77	4			4	0.49		**Surveyed Data Only**				
5.45	4.5	Upper Pin		5.99	4.5	reset		4.5	0.54		**Average**				
5.57	5			6.01	5			5	0.44		**Total Lateral Erosion**			**3.441333**	ft
5.68	5.5			6.07	5.5			5.5	0.39		**Annual Lateral Erosion Rate**			**0.345458**	ft/yr
5.57	6			6.04	6			6	0.47						
5.68	6.5			6.09	6.5			6.5	0.41						
5.92	7	TB		6.51	7			7	0.59		**River Morph**				
								Average	0.663333	ft	**Total Lateral Erosion**			**4.209**	ft
								Cut			**Annual Lateral Erosion Rate**			**0.422521**	ft/yr
								From RM	0.6743	ft					
								Cut							

10/27/2007	LWE Folder, pg. 4		**5/27/2009**	Book 5, pg. 101		**Days**	579	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		Vert.	Horz.	
0	-0.1		0	-0.1				
2.27	0	toe pin	2.12	0	Top of toe pin	0	-0.15	
2.83	0.5		3.13	0.5		0.5	0.3	
3.59	1		3.92	1		1	0.33	
3.94	1.5	lower: (2.97 face of p	4.63	1.5	Lower Bank Pin (@ face 3.82)	1.5	0.69	
4.08	2		5.37	2		2	1.29	
4.64	2.5		5.75	2.5		2.5	1.11	
5.53	3	middle: (4.44 face of	5.73	3	Middle Bank Pin (@ face 5.57)	3	0.2	
5.55	3.5		6.2	3.5		3.5	0.65	
5.77	4		6.63	4		4	0.86	
5.99	4.5	upper: (5.48 face of p	7.05	4.35	Top Bank Pin (@ face 6.49)	4.35	1.06	
6.01	5		7.52	5		5	1.51	
6.07	5.5		7.62	5.5		5.5	1.55	
6.04	6		7.62	6		6	1.58	
6.09	6.5		7.62	6.5		6.5	1.53	
6.51	7		7.62	7		7	1.11	
						Average	0.908	ft
						Cut		
						From RM	0.9471	ft
						Cut		

5/27/2009	Book 5, pg. 101		**3/18/2015**	Book 6, pg. 54			**Days**	2122	
Horiz.	**Vert.**		**Horiz.**	**Vert.**			Vert.	Horz.	
0	-0.1		0	-1.44	Streambed				
2.12	0	Top of toe pin	4.4	0			0	2.28	
3.13	0.5		4.8	0.5			0.5	1.67	
3.92	1		5.5	1	Lower Pin		1	1.58	
4.63	1.5	Lower Bank Pin (@ fa	5.86	1.5			1.5	1.23	
5.37	2		6.16	2			2	0.79	
5.75	2.5		6.7	2.5	Middle Pin		2.5	0.95	
5.75	2.62		6.78	2.62			2.62	1.03	
5.73	3	Middle Bank Pin (@ fa	6.72	3			3	0.99	
6.2	3.5		6.96	3.5			3.5	0.76	
6.63	4		7.34	4	Upper Pin		4	0.71	
7.05	4.35	Top Bank Pin (@ face	8.22	4.5			4.5	1.17	
7.52	5		8.8	5			5	1.28	
7.62	5.5		9	5.5			5.5	1.38	
7.62	6	Assumption	9.16	6			6	1.54	
7.62	6.5	Assumption	9.38	6.5			6.5	1.76	
7.62	7	Assumption	9.6	7			7	1.98	
7.62	7.5	Assumption	9.76	7.5			7.5	2.14	
							Average	1.367059	ft
							Cut		
							From RM	1.7129	ft
							Cut		

3/18/2015	Book 6, pg. 54			**3/18/2016**	Book 7, pg. 18			**Days**	367	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			Vert.	Horz.	
0	-1.44	Streambed		3.74	-1.33					
4.4	0			5.19	0			0	0.79	
4.8	0.5			5.58	0.5			0.5	0.78	
5.5	1	Lower Pin		6.08	1	lower pin		1	0.58	
5.86	1.5			6.66	1.5			1.5	0.8	
6.16	2			6.85	2			2	0.69	
6.7	2.5	Middle Pin		7.2	2.5	middle pin		2.5	0.5	
6.78	2.62			7.2	2.62			2.62	0.42	
6.72	3			7.29	3			3	0.57	
6.96	3.5			7.78	3.5			3.5	0.82	
7.34	4	Upper Pin		8.01	4	upper pin		4	0.67	
8.22	4.5			8.34	4.5			4.5	0.12	
8.8	5			9.06	5			5	0.26	
9	5.5			9.35	5.5			5.5	0.35	
9.16	6			9.57	6			6	0.41	
9.38	6.5			9.81	6.5			6.5	0.43	
9.6	7			9.72	7			7	0.12	
9.76	7.5			10	7.5			7.5	0.24	
								Average	0.502941	ft
								Cut		
								From RM	0.8747	ft
								Cut		

ISCO Study Bank (Sta. 17+69) | **Total Days** 3635 | **Years** 9.95890411

4/8/2006	LWE Folder, pg. 7		**10/27/2007**	LWE Folder, pg. 7		**Days**	568	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.1		0	-0.1				
0.31	0	toe pin	1.2	0	toe pin	0	0.89	
0.89	0.7		2.92	0.7		0.7	2.03	
1.52	1		3.44	1		1	1.92	
2.03	1.5	lower pin	3.82	1.5	reset	1.5	1.79	
2.77	2		4.89	2		2	2.12	
3.4	2.5		5.43	2.5		2.5	2.03	
3.96	3	middle pin	6.11	3	reset	3	2.15	
4.06	3.5		6.55	3.5		3.5	2.49	
4.25	4		6.54	4		4	2.29	
4.42	4.3	top pin	6.54	4.3	reset	4.3	2.12	
4.61	4.5		6.68	4.5		4.5	2.07	
4.63	5		6.71	5		5	2.08	
4.69	5.7	top of bank	7.02	5.7	top of bank	5.7	2.33	
						Average	1.998333	
						Cut		
						From RM	2.0456	ft
						Cut		

	interpolated	
All Available Data		
Average		
Total Lateral Erosion	**7.279872**	ft
Annual Lateral Erosion Rate	**0.730991**	ft/yr
River Morph		
Total Lateral Erosion	**7.6526**	ft
Annual Lateral Erosion Rate	**0.768418**	ft/yr
Surveyed Data Only		
Average		
Total Lateral Erosion	**7.279872**	ft
Annual Lateral Erosion Rate	**0.730991**	ft/yr
River Morph		
Total Lateral Erosion	**7.6526**	ft
Annual Lateral Erosion Rate	**0.768418**	ft/yr

10/27/2007	LWE Folder, pg. 7		**3/18/2015**	Book 6, pg. 52		**Days**	2700	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.1		0	-1.8	Top of Pin to Streambed			
1.2	0	toe pin	6.56	0		0	5.36	
2.92	0.7		6.66	0.5		0.5	3.74	
3.44	1		7.16	1		1	3.72	
3.82	1.5	lower	7.74	1.5		1.5	3.92	
4.89	2		8.28	2		2	3.39	
5.43	2.5		8.8	2.5		2.5	3.37	
6.11	3	middle	9.4	3	reset	3	3.29	
6.55	3.5		10	3.5		3.5	3.45	
6.54	4		10.76	4		4	4.22	
6.54	4.3	upper	10.96	4.3		4.3	4.56	
6.68	4.5		11.1	4.5		4.5	4.22	
6.71	5		10.9	5		5	4.49	
7.02	5.7	top of bank	11.2	5.7		5.7	4.18	
						Average	3.993077	ft
						Cut		
						From RM	4.8877	ft
						Cut		

3/18/2015	Book 6, pg. 52			**3/18/2016**	Book 7, pg. 20			**Days**	367	
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**	
0	-1.8	Top of Pin to Streamb		7.04	-0.79					
6.56	0			8.27	0			0	1.71	
6.66	0.5			8.43	1			1	1.77	
7.16	1			9.15	1.5			1.5	1.99	
7.74	1.5			9.64	2			2	1.9	
8.28	2			10.37	2.5			2.5	2.09	
8.8	2.5			10.51	3			3	1.71	
9.4	3	reset		10.83	3.2			3.2	1.43	
10	3.5			11.18	3.5			3.5	1.18	
10.76	4			11.35	4			4	0.59	
10.96	4.3			11.45	4.3			4.3	0.56	
11.1	4.5			11.52	4.5			4.5	0.36	
10.9	5			11.46	5			5	0.88	
11.2	5.7			11.78	5.5			5.5	0.58	
								Average	1.288462	ft
								Cut		
								From RM	0.7193	ft
								Cut		

Upper West Emma

Study Bank (Sta. 2+77 to 2+80)				**Total Days**	1174	**Years**	3.2164384								
3/11/2006	UWE Folder, pg. 3			**2/28/2008**	UWE Folder, pg. 3			**Days**	720			Interpolated			
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	-0.01			0	-0.1						**All Available Data**				
0.79	0	toe pin		1.66	0	toe pin		0	0.87		**Average**				
0.88	0.38	lower bank pin		1.44	0.33	not reset		0.33	0.56		**Total Lateral Erosion**			**1.018667**	ft
1	0.67			1.43	0.67			0.67	0.43		**Annual Lateral Erosion Rate**			**0.316706**	ft/yr
1.05	0.9	upper bank pin		1.4	0.9	reset		0.9	0.35						
1.09	1.2			1.5	1.2			1.2	0.41						
1.14	1.49	top of bank		1.71	1.49	top of bank		1.49	0.57		**River Morph**				
				2.48	2						**Total Lateral Erosion**			**1.0188**	ft
								Average	0.531667	ft	**Annual Lateral Erosion Rate**			**0.316748**	ft/yr
								Cut							
								From RM	0.5638	ft	**Surveyed Data Only**				
								Cut			**Average**				
											Total Lateral Erosion			**1.018667**	ft
2/28/2008	UWE Folder, pg. 3			**5/26/2009**	Book 5, pg. 68			**Days**	454		**Annual Lateral Erosion Rate**			**0.316706**	ft/yr
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	-0.1			0	-0.1										
1.66	0	toe pin		2.35	0	toe Pin		0	0.69		**River Morph**				
1.49	0.25			2.68	0.25	left exposed		0.25	1.19		**Total Lateral Erosion**			**1.0188**	ft
1.44	0.33	base of lower (face @		2.38	0.33			0.33	0.94		**Annual Lateral Erosion Rate**			**0.316748**	ft/yr
1.44	0.5			1.73	0.5			0.5	0.29						
1.43	0.67			1.74	0.68	left exposed		0.67	0.31						
1.4	0.9	base of upper (face @		1.6	0.9			0.9	0.2						
1.43	1			1.55	1			1	0.12						
1.5	1.2			1.72	1.2			1.2	0.22						
1.71	1.49	top of bank		1.98	1.5			1.49	0.27						
2.48	2			3.12	2			2	0.64						
				4.04	2.5										
								Average	0.487	ft					
								Cut							
								From RM	0.455	ft					
								Cut							

Pool XS (Sta. 11+48 to 11+88)				**Total Days**	3665	**Years**	10.041096								
3/10/2006	UWE Folder, pg. 6			**10/7/2007**	UWE Folder, pg. 7			**Days**	577			Interpolated			
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	-0.1			0	-0.1						**All Available Data**				
1.22	0	toe pin		1.19	0	toe pin		0	-0.03		**Average**				
1.07	0.5			1.44	0.5			0.5	0.37		**Total Lateral Erosion**			**0.996806**	ft
1.35	1	lower pin		1.43	1	lower (face of pin @ 1.		1	0.08		**Annual Lateral Erosion Rate**			**0.099273**	ft/yr
1.87	1.5			1.81	1.5			1.5	-0.06						
1.94	2	upper pin		1.99	2	upper (face of pn @ 1.		2	0.05						
1.59	2.5			1.8	2.5			2.5	0.21		**River Morph**				
1.61	3			1.86	3			3	0.25		**Total Lateral Erosion**			**1.14**	ft
1.94	3.5	top of bank		2.2	3.5			3.5	0.26		**Annual Lateral Erosion Rate**			**0.113533**	ft/yr
								Average	**0.14125**	ft					
								Cut			**Surveyed Data Only**				
								From RM	**0.1429**	ft	**Average**				
								Cut			**Total Lateral Erosion**			**0.996806**	ft
											Annual Lateral Erosion Rate			**0.099273**	ft/yr
10/7/2007	UWE Folder, pg. 7			**5/27/2009**	Book 5, pg. 85			**Days**	599						
Horiz.	**Vert.**			**Horiz.**	**Vert.**			**Vert.**	**Horz.**						
0	-0.1			0	-0.1						**River Morph**				
1.19	0	toe pin		1.61	0			0	0.42		**Total Lateral Erosion**			**1.14**	ft
1.44	0.5			1.51	0.5			0.5	0.07		**Annual Lateral Erosion Rate**			**0.113533**	ft/yr
1.43	1	lower (face of pin @ 1		1.68	0.97	Left exposed		1	0.25						
1.81	1.5			1.87	1.5			1.5	0.06						
1.99	2	upper (face of pn @ 1		2.24	2	Left exposed		2	0.25						
1.8	2.5			2.28	2.5			2.5	0.48						
1.86	3			2.18	3			3	0.32						
2.2	3.5			2.03	3.5			3.5	-0.17						
				2.4	3.84										
								Average	0.21	ft					
								Cut							
								From RM	**0.2314**	ft					
								Cut							

5/27/2009	Book 5, pg. 85		**3/19/2015**	Book 6, pg. 56		**Days**	2123	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.1		0	-0.58	Streambed			
1.61	0		1.21	0		0	-0.4	
1.51	0.5		1.6	0.5		0.5	0.09	
1.68	0.97		1.9	1	Bank Pin	0.97	0.22	
1.87	1.5		2.39	1.5		1.5	0.52	
2.24	2		2.88	2	Bank Pin	2	0.64	
2.28	2.5		3.05	2.5		2.5	0.77	
2.18	3		3.04	3		3	0.86	
2.03	3.5		3.01	3.5		3.5	0.98	
2.4	3.84		3.01	3.84		3.84	0.61	
			3.01	4	Top of Bank			
						Average	0.476667	ft
						Cut		
						From RM	**0.5807**	ft
						Cut		

3/19/2015	Book 6, pg. 56		**3/18/2016**	Book 7, pg. 16		**Days**	366	
Horiz.	**Vert.**		**Horiz.**	**Vert.**		**Vert.**	**Horz.**	
0	-0.58	Streambed	0.74	-0.4				
1.21	0		1.23	0		0	0.02	
1.6	0.5		1.63	0.5		0.5	0.03	
1.9	1	Bank Pin	2	1		1	0.1	
2.39	1.5		2.56	1.5		1.5	0.17	
2.88	2	Bank Pin	3.13	2		2	0.25	
3.05	2.5		3.28	2.5		2.5	0.23	
3.04	3		3.26	3		3	0.22	
3.01	3.5		3.24	3.5		3.5	0.23	
3.01	3.84		3.28	3.84		3.84	0.27	
3.01	4	Top of Bank	3.3	4				
						Average	0.168889	ft
						Cut		
						From RM	**0.185**	ft
						Cut		

Appendix K – Tall Bank Repeated Cross Profiling Technique Survey Shots

Lower Little Arkansas Study Bank 1

2015

Point,Northing,Easting,Elevation,Note[26]

1,0.00000,0.00000,99.54350,ts

3,41.91000,142.10000,85.50000,toptoe

10,41.86080,142.13120,85.47470,toptoe

11,41.97420,142.12470,85.04000,nexttoe

12,41.70270,143.60880,85.56570,sb

13,41.48760,144.17470,85.78850,lew

14,41.59140,145.59480,88.94640,lb

15,41.62810,146.20630,89.47700,lb

16,41.38680,147.14190,91.21940,lb-bkf

17,41.48380,150.71990,92.48740,lb

18,41.12510,153.50130,94.10770,lb

19,41.53630,155.03030,96.69130,bp2

20,41.49060,157.26350,100.16730,lb

21,41.65580,161.10600,100.44190,lb

22,40.39560,167.68270,99.93920,lb

23,39.86960,173.49160,99.94440,lb

24,38.68120,177.97940,100.28560,nexttop

25,39.33670,178.01180,100.82510,toptop

26,41.55580,145.19020,89.02380,bp1

27,42.46270,140.11020,84.62360,sb

---

[26] ts: total station; bm#: benchmark; toptoe: top of toe pin; nexttoe: next to toe pin; nexttop: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bp#: bankpin

28,42.72730,134.11530,84.62020,sb

29,43.50880,130.38440,84.66130,sb

30,43.80890,126.81660,84.84250,sb

31,44.04960,124.00580,85.17370,sb

32,44.23570,119.66480,85.41570,sb

33,44.12760,114.68670,85.54040,sb

34,43.65510,103.65850,85.77200,rew

35,44.01130,99.53330,86.10750,rb

36,43.71240,96.89470,86.31320,rb

37,43.85260,94.65120,86.79030,rb

38,43.36040,86.25100,87.14370,rb

39,42.31620,77.25730,87.10750,rb

40,41.83190,70.65870,87.50650,rb

41,38.87930,62.03090,87.86130,rb

42,37.58850,52.55950,88.20470,rb

43,38.62780,47.62800,88.55460,rb

44,38.35590,38.00090,88.83500,rb

45,37.61860,28.23770,88.62360,rb

46,36.96770,22.48280,92.31120,rb

47,36.30470,15.30500,96.13310,rb

48,35.34240,11.43740,97.90390,rb

49,35.44000,5.97830,98.40060,rb

50,-122.01290,-5.22280,100.02370,bm1

2016

Point,Northing,Easting,Elevation,Note[27]

1,0.0000,0.0000,99.5435,ts

2,-122.0129,-5.2228,100.0237,bm1

[27] ts: total station; bm#: benchmark; toetop: top of toe pin; toenxt: next to toe pin; topnxt: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bnkpn: bankpin; ltb: left top of bank; rtb: right top of bank

3,40.3963,100.8072,86.1763,rew

4,40.7475,93.0940,86.3060,rb

5,39.7689,83.3061,86.6431,rb

6,39.5858,73.5257,86.9532,rb

7,39.6049,71.5714,87.0570,rb

8,39.6426,70.2950,86.8974,rb

9,41.0229,103.5232,85.6560,sb

10,40.9461,109.8064,85.5986,sb

11,41.0683,116.9064,85.2856,sb

12,41.3376,123.9717,85.1248,sb

13,41.1715,130.1807,84.5920,sb

14,41.5882,135.6199,84.5517,sb

15,41.6537,139.7929,84.4241,sb

16,41.7084,142.2546,84.9480,toenxt

17,41.6620,142.0656,85.4420,toetop

18,41.5836,143.1525,85.1179,sb

19,41.5545,143.5835,85.3569,sb

20,41.5836,144.4245,86.0788,lew

21,41.4749,144.6809,86.0737,lb

22,41.3624,146.0223,86.8360,lb

23,41.5170,146.6266,87.2934,lb

24,41.4667,147.0528,88.3958,bnkpn

25,41.7147,148.9414,89.8972,lb

26,41.7249,149.5857,92.2385,lb

27,41.7626,150.9029,92.7098,lb

28,41.6337,152.0506,93.0693,lb

29,41.6809,153.3844,93.6798,lb

30,41.6969,154.3793,94.3946,lb

31,41.4189,155.3124,96.0487,bnkpn

32,41.6895,156.9745,97.0890,lb

33,41.6306,158.0080,99.0333,lb

34,41.7175,158.8981,100.0576,lb

35,41.4630,159.8628,100.4427,ltb

36,41.1180,163.3975,100.2841,lb

37,40.7194,167.8092,100.1411,lb

38,39.9978,172.3113,100.0352,lb

39,-121.9436,-5.2476,99.9287,bm1

Lower Little Arkansas Study Bank #2 and #3

2015

Point,Northing,Easting,Elevation,Note[28]

1,0.00000,0.00000,97.44860,ts

3,49.11000,84.80000,102.39000,bm5

10,49.10540,84.79300,102.37520,bm5

11,94.48420,-233.05500,84.95820,toptoe

12,94.55300,-233.14360,84.49670,nexttoe

13,94.40350,-235.49480,85.28810,rew

14,93.83200,-237.08210,86.45790,rb

15,93.24380,-237.84770,87.04210,bp1

16,93.15920,-238.80660,87.46150,rb

17,92.81370,-241.43690,89.02890,rb

18,93.02510,-242.75970,89.57820,rb

19,92.50670,-245.40440,91.14720,rb-bkf

20,91.91000,-248.34180,92.65370,rb

21,92.07150,-251.10930,94.33130,rb

22,91.61200,-254.52680,97.05200,rb

23,91.31500,-256.48040,97.39970,rb

24,90.85050,-258.67900,97.21770,rb

[28] ts: total station; bm#: benchmark; toptoe: top of toe pin; nexttoe: next to toe pin; nexttop: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bp#: bankpin; rd: root depth

25,90.45580,-261.79810,96.95020,rb
26,90.08520,-264.39550,96.71100,nexttop
27,89.98370,-264.36200,96.99000,toptop
28,94.63420,-231.14000,84.58410,sb
29,96.25780,-225.99420,84.79410,sb
30,98.05620,-221.67290,84.57280,sb
31,99.86030,-215.60030,84.30820,sb
32,99.82060,-212.74160,84.33050,sb
33,99.94870,-209.17800,84.54580,sb
34,100.86810,-205.90430,84.53510,sb
35,101.51000,-198.32460,84.75240,sb
36,103.00750,-191.46070,85.31330,lew
37,103.55980,-188.53400,85.53020,lb
38,104.27390,-185.19630,86.08310,lb
39,107.80170,-176.03460,86.68900,lb
40,109.03400,-167.52170,87.33370,lb
41,111.12140,-158.89390,87.74670,lb
42,113.77060,-151.30460,88.39870,lb
43,115.03120,-144.97100,89.12950,lb
44,120.75290,-132.81010,89.78290,lb
45,123.37020,-128.87500,89.92010,lb
46,128.06560,-122.58990,90.48940,lb
47,132.92900,-113.81960,94.61460,lb
48,134.73850,-106.03480,97.34370,lb
49,136.14630,-95.69870,98.62190,lb
50,136.63260,-89.13260,98.97780,lb
100,-274.74480,-3.72360,83.80790,toptoe
101,-274.70030,-3.93880,83.43740,nexttoe
102,-277.09950,-5.08040,83.87240,sb
103,-279.06750,-6.16820,84.97840,rew
104,-279.21050,-6.33250,85.97560,rb

105,-280.08400,-6.84960,86.91760,bp1
106,-281.40620,-7.51540,87.90340,rb
107,-282.49710,-8.09550,89.17730,bp2
108,-284.59380,-8.86680,91.05800,rb
109,-286.36960,-9.95200,93.11660,rb-rd-bkf
110,-286.57230,-9.86310,96.28130,rb
111,-287.58240,-10.71030,97.69950,rb
112,-290.61200,-12.44180,98.04420,rb
113,-293.80760,-14.02740,98.03600,rb
114,-297.18270,-16.39730,98.25590,rb
115,-299.89720,-18.11090,98.31370,rb
116,-301.77430,-19.73420,98.20400,nexttop
117,-301.82270,-19.68450,98.50040,toptop
200,-273.49680,-3.37910,83.21830,sb
201,-270.23470,-1.75990,83.25920,sb
202,-264.08550,0.71790,84.40480,sb
203,-257.00630,2.77330,84.08230,sb
204,-251.63140,4.99350,84.13840,sb
205,-239.03690,9.58300,85.01790,lew
206,-232.49540,12.32890,85.34210,lb
207,-225.92580,15.24770,87.18620,lb
208,-215.36030,21.89000,87.93150,lb
209,-197.05290,34.42440,90.48250,lb
210,-187.86270,39.98070,91.33420,lb
211,-180.36400,45.26780,92.02460,lb
212,-177.19480,48.18680,92.34110,lb
213,-154.87990,64.94630,93.44030,lb
214,-136.19920,81.09950,93.91050,lb
215,-117.92850,91.22290,94.76240,lb
216,-97.04610,104.20850,95.74100,lb
217,-91.19080,107.82030,96.14140,lb

218,-84.29790,113.27150,96.44210,lb

219,-80.99280,115.49410,96.16670,lb

220,-77.22610,117.47440,96.20070,lb

221,-72.48050,120.02430,98.17870,lb

222,-66.29910,123.81980,97.01590,lb

2016

Point,Northing,Easting,Elevation,Note[29]

1,0.0000,0.0000,97.4486,ts

2,49.1054,84.7930,102.3752,bm5

3,102.8964,-180.4249,85.7501,lew

4,104.5871,-175.6533,86.3740,lb

5,105.7771,-172.9338,86.8291,lb

6,105.8132,-166.2692,86.7755,lb

7,106.6258,-159.9802,87.5008,lb

8,108.0544,-153.3318,87.9107,lb

9,108.5730,-151.3141,87.8706,lb

10,109.9597,-145.7563,88.9895,lb

11,110.9540,-141.0760,89.0459,lb

12,111.8329,-132.0971,90.0054,lb

13,114.0989,-126.3633,90.0796,lb

14,114.1659,-122.4052,89.5810,lb

15,113.9447,-117.5379,90.1203,lb

16,101.8028,-184.5193,85.1163,sb

17,101.1217,-189.9566,85.0838,sb

18,99.7749,-197.4689,85.1412,sb

19,98.4917,-204.9372,84.8023,sb

20,97.1233,-212.2377,84.7208,sb

---

[29] ts: total station; bm#: benchmark; toetop: top of toe pin; toenxt: next to toe pin; topnxt: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bnkpn: bankpin; ltb: left top of bank; rtb: right top of bank

21,96.2541,-218.8229,84.6022,sb

22,95.7124,-225.5133,84.4827,sb

23,94.9284,-230.2622,84.6761,sb

24,94.3580,-233.2025,84.6948,toenxt

25,94.3992,-233.0619,84.9875,toetop

26,94.0823,-234.8111,84.4187,sb

27,94.0830,-235.8915,84.1286,sb

28,93.7026,-237.0157,84.6346,sb

29,93.4695,-237.8528,85.7508,rew

30,93.0365,-237.8027,86.0048,bnkpn

31,93.6180,-238.2794,85.8127,rb

32,93.4128,-239.8271,87.0301,rb

33,93.3425,-240.4351,87.2273,rb

34,93.2272,-241.1497,87.9025,rb

35,93.1828,-241.3085,88.2767,rb

36,93.0038,-242.0445,88.4479,rb

37,93.0315,-242.5449,88.8633,rb

38,92.9640,-242.8331,89.3671,rb

39,92.6443,-244.7944,89.7829,rb

40,92.5351,-246.0396,90.2279,rb

41,92.3685,-246.5209,90.6592,rb

42,92.2552,-246.9967,92.5791,rb

43,91.9818,-249.0456,93.6740,rb

44,91.6997,-251.2772,94.9385,rb

45,91.2695,-253.0268,96.0179,rb

46,91.0167,-254.1320,96.6185,rb

47,90.9405,-254.7400,97.2020,rb

48,90.8526,-255.1450,97.5326,rtb

49,90.7752,-257.0248,97.5742,rb

50,90.3478,-260.3070,97.3063,rb

51,89.9149,-263.2098,97.0781,rb

52,89.9013,-264.3639,96.8757,topnxt

53,89.9098,-264.2700,97.0210,toptop

54,-74.9178,102.8558,97.1535,lb

55,-77.9034,101.1813,95.8120,lb

56,-88.2510,95.5662,95.5575,lb

57,-101.4619,88.5080,95.2239,lb

58,-115.2720,81.6775,95.0947,lb

59,-129.2726,74.2412,95.0260,lb

60,-141.7225,67.6334,94.1924,lb

61,-156.7214,60.1813,93.4497,lb

62,-169.9750,53.2621,92.4713,lb

63,-183.0700,46.4179,91.7337,lb

64,-196.2287,39.7805,90.7677,lb

65,-207.3903,34.2755,89.9697,lb

66,-213.4290,30.7777,89.5334,lb

67,-218.5548,28.4931,88.3754,lb

68,-223.6739,25.9221,87.4877,lb

69,-229.0443,23.0978,87.3121,lb

70,-231.8891,21.5070,86.7453,lb

71,-235.8927,19.3321,86.1720,lb

72,-240.6205,16.5057,85.5992,lew

73,-244.5813,14.2248,84.7849,sb

74,-248.2188,11.7920,84.3950,sb

75,-251.5638,10.0067,84.0373,sb

76,-255.5759,7.9052,83.6466,sb

77,-257.6413,6.7008,83.7240,sb

78,-259.6049,5.2253,83.9723,sb

79,-261.6660,4.1882,83.8850,sb

80,-264.7026,2.3597,84.0577,sb

81,-267.3951,0.8677,84.0410,sb

82,-270.6234,-1.1569,83.7928,sb

83,-273.3286,-2.7431,83.4702,sb
84,-274.8230,-3.6709,83.4764,toenxt
85,-274.6166,-3.6508,83.8656,toetop
86,-276.2708,-4.6551,83.7724,sb
87,-278.2206,-5.8704,84.1339,sb
88,-279.3368,-6.6266,84.4786,sb
89,-280.3240,-7.1739,85.6330,rew
90,-281.2497,-7.6258,85.8966,rb
91,-282.1896,-8.0659,86.6448,rb
92,-282.6623,-8.2470,87.2986,bnkpn
93,-283.3646,-8.6170,87.4524,rb
94,-284.5671,-8.9988,88.9859,bnkpn
95,-285.6799,-9.8702,91.0131,rb
96,-286.7807,-10.6383,93.9596,rb
97,-288.8558,-11.7818,96.4605,rb
98,-289.1885,-11.9167,97.0381,rb
99,-289.3440,-12.0216,98.0179,rtb
100,-290.4858,-12.7199,98.3376,rb
101,-291.8134,-13.4540,98.2655,rb
102,-292.6517,-13.8819,98.1650,rb
103,-295.3426,-15.3550,98.8679,rb
104,-298.5094,-17.4291,98.8072,rb
105,-301.1220,-19.0876,98.7246,rb
106,-301.9112,-19.5874,98.3515,topnxt excavated
107,-301.7957,-19.5336,98.5397,toptop
108,49.1253,84.7788,102.3803,bm5

Middle Little Arkansas Study Bank #1

2015

Point,Northing,Easting,Elevation,Note[30]

1,0.00000,0.00000,92.16280,ts

2,54.50000,-17.92000,93.45000,bm5

10,54.47650,-17.95620,93.45800,bm5

11,-73.12740,48.70870,73.28990,toptoe

12,-73.06500,48.80180,72.94510,nexttoe

13,-73.74450,49.25770,73.45270,sb

14,-75.79890,51.21770,74.32580,sb

15,-76.76560,51.96900,75.04870,rew

16,-79.76570,54.27230,76.03040,rb

17,-81.22170,55.98610,76.70130,rb

18,-82.54630,57.48960,77.48760,rb

19,-84.49900,59.61150,79.05230,bp1

20,-87.16900,61.90040,80.66040,rb

21,-89.31520,64.38680,80.81740,rb

22,-91.19220,66.63030,81.63570,rb

23,-92.56410,67.64370,82.53650,rb

24,-94.11030,68.75680,83.59020,rb

25,-97.21940,71.32370,86.68770,rb

26,-97.73440,72.57180,90.04220,bp2

27,-97.83240,73.40090,92.32720,rb

28,-100.61360,74.60690,93.73840,rb

29,-98.92820,73.46800,98.71150,lb

30,-99.91720,74.41460,99.39440,lb

[30] ts: total station; bm#: benchmark; toptoe: top of toe pin; nexttoe: next to toe pin; nexttop: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bp#: bankpin

31,-102.38390,76.57320,99.52440,rb

32,-104.43540,78.62270,99.55060,rb

33,-107.55620,81.62190,99.37300,nexttop

34,-107.41370,81.79310,99.76480,toptop

50,-72.62790,48.60250,72.87980,sb

51,-69.10940,45.16100,73.50900,sb

52,-65.53820,43.66930,74.00440,sb

53,-63.77320,42.49190,74.28460,sb

54,-60.37900,39.39830,74.88150,lew

55,-58.09250,38.56310,75.33730,lb

56,-52.29360,31.75140,79.46610,lb

57,-49.60710,28.47110,80.24730,lb

58,-46.50170,26.64360,81.87340,lb

59,-43.46970,24.80990,82.21590,lb

60,-38.73660,21.52520,82.70930,lb

61,-35.62170,18.75440,82.43710,lb

62,-33.23060,16.38400,83.39900,lb

63,-31.06420,13.41900,84.43930,lb

64,-27.26980,8.91790,84.97840,lb

65,-23.59870,6.18250,86.25970,lb

66,-20.60980,3.44370,86.77700,lb

67,-18.11130,1.36190,87.79490,lb

68,-15.68790,-2.43090,90.23380,lb

69,-12.48430,-5.20570,91.32890,lb

70,-87.17380,61.88220,80.63590,bkf

2016

Point,Northing,Easting,Elevation,Note[31]

1,0.0000,0.0000,92.1628,ts

2,54.4765,-17.9562,93.4580,bm5

3,-16.4779,-10.9199,91.2109,lb

4,-18.8699,-8.5747,90.6434,lb

5,-21.1762,-6.2353,89.8623,lb

6,-24.1760,-3.2723,87.8470,lb

7,-27.0201,-0.1900,86.8521,lb

8,-30.1437,2.9370,85.4692,lb

9,-30.6729,4.6082,85.6164,lb

10,-33.4484,6.7792,86.0021,lb

11,-35.4924,9.2342,85.3218,lb

12,-37.0170,12.2637,85.1395,lb

13,-40.1445,15.0843,84.7019,lb

14,-42.3853,17.0723,84.2109,lb

15,-44.4530,19.1012,83.7726,lb

16,-46.2321,20.9257,83.1833,lb

17,-47.5004,22.1421,82.8530,lb

18,-49.8056,24.4413,81.4452,lb

19,-52.2700,27.0437,80.1616,lb

20,-55.0091,29.7444,79.4673,lb

21,-58.0449,32.4137,78.0423,lb

22,-60.7444,35.4678,76.4249,lb

23,-62.3085,37.2109,75.7054,lb

24,-64.4249,39.6420,75.2027,lew

[31] ts: total station; bm#: benchmark; toetop: top of toe pin; toenxt: next to toe pin; topnxt: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bnkpn: bankpin; ltb: left top of bank; rtb: right top of bank; toe?: toe pin not found but Northing, Easting staked; tree: tree on bank

25,-67.3705,42.1554,74.2275,sb

26,-69.3839,44.4065,73.5875,sb

27,-71.5815,46.6431,73.4334,sb

28,-73.3751,48.5373,73.2546,toe?

29,-75.1086,50.2255,72.9074,sb

30,-76.0668,51.2399,72.8468,sb

31,-76.5546,51.5982,73.7885,sb

32,-77.1749,52.1430,74.4098,sb

33,-77.4163,52.3667,74.9533,sb

34,-77.5850,52.7437,75.1797,rew

35,-78.5777,53.6695,75.4393,rb

36,-80.1706,55.3520,75.9078,rb

37,-81.3407,56.5987,76.5220,rb

38,-82.5173,57.6519,76.9410,rb

39,-83.4791,58.8133,77.3898,rb

40,-84.5853,59.8369,77.8646,rb

41,-85.3044,60.5919,78.4542,rb

42,-85.8431,61.3605,78.8055,bnkpn

43,-86.2990,61.8707,78.9887,rb

44,-87.0850,62.4077,79.2656,rb tree

45,-88.5025,63.8413,80.0191,rb tree

46,-89.2742,64.6930,80.2720,rb tree

47,-89.5679,65.0451,80.5229,rb tree

48,-90.8326,66.2062,80.9302,rb tree

49,-92.1304,67.1826,81.6269,rb tree

50,-92.9537,68.0370,82.2733,rb tree

51,-94.4311,70.4653,84.0453,rb tree

52,-96.2438,71.5244,86.2091,rb

53,-97.0091,72.1113,87.2022,rb

54,-98.5620,73.0010,88.7508,rb

55,-98.6520,73.0411,89.4421,bnkpn

56,-99.2265,74.6236,92.0282,rb

57,-101.0542,76.4811,93.8332,rb

58,-102.7729,77.9148,95.3233,rb

59,-102.8561,77.9931,99.1849,rtb

60,-104.3964,79.2629,99.3887,rb

61,-105.7077,80.3194,99.4404,rb

62,-106.7160,81.2510,99.4105,rb

63,-107.4326,81.9088,99.4374,topnxt

64,-107.3151,81.8912,99.8149,toptop

65,54.4203,-17.9311,93.4760,bm5

Middle Little Arkansas Study Bank #3

2015

Point,Northing,Easting,Elevation,Note[32]

1,0.00000,0.00000,93.41270,ts

2,-24.95000,-10.71000,93.94000,bm7

10,-24.94920,-10.70970,93.93960,bm7

11,-7.13410,4.60550,92.67950,rb

12,-6.11700,5.94750,92.53620,rb

13,0.56980,25.95150,80.67820,rb

14,8.82830,34.18550,78.02800,rb

15,13.98450,46.59120,76.47250,rb

16,17.92290,51.26460,75.01440,rew

17,21.54260,56.99790,73.09510,sb

18,24.22570,63.61170,70.95500,sb

19,27.54340,67.75450,71.04070,sb

20,30.27540,72.97790,73.63230,toptoe

[32] ts: total station; bm#: benchmark; toptoe: top of toe pin; nexttoe: next to toe pin; nexttop: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bp#: bankpin; rd: root depth

21,30.22700,73.09930,73.20290,nexttoe

22,33.62400,78.06330,74.56500,lb

23,34.13600,79.54050,75.11370,lew

24,34.97430,81.33700,79.45330,bp1

25,36.01470,83.26670,81.20600,lb

26,39.58370,89.95560,86.63770,lb

27,39.67950,90.37660,88.37630,lb

28,40.95350,92.14610,89.40850,lb-bkf

29,43.63030,96.25140,91.77290,lb

30,47.35450,104.05920,100.50410,lb

31,47.57710,104.92870,101.19910,lb-rd

32,47.78820,105.40770,103.08980,lb

33,48.85200,107.52810,104.35110,lb

34,49.28380,108.35030,105.94100,lb

35,51.83340,114.27290,107.20460,lb

36,54.84180,121.15980,107.52760,lb

37,57.82120,128.67750,107.83120,nexttop

38,57.59090,128.75220,108.30690,toptop

2016

Point,Northing,Easting,Elevation,Note[33]

1,0.0000,0.0000,93.4127,ts

2,-24.9492,-10.7097,93.9396,bm7

3,-8.7380,-10.8065,92.3954,rb

4,-5.8819,-5.3236,93.1844,rb

5,-4.6036,-2.3962,92.9141,rb

6,-3.8803,0.0022,92.8196,rb

7,-2.6157,2.9078,92.6703,rb

---

[33] ts: total station; bm#: benchmark; toetop: top of toe pin; toenxt: next to toe pin; topnxt: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bnkpn: bankpin; ltb: left top of bank; rtb: right top of bank; rootball: rootball on bank

8,-0.3609,5.1897,91.1386,rb

9,0.8288,6.9957,90.4998,rb

10,2.6086,11.4446,88.1364,rb

11,4.6075,16.6897,84.9470,rb

12,5.1586,19.7719,82.9485,rb

13,7.9938,23.9094,80.3217,rb

14,9.9716,28.8641,78.1957,rb

15,10.8900,31.1840,77.5873,rb

16,13.0252,36.1255,76.5491,rb

17,14.7654,39.6231,75.8840,rb

18,16.1516,42.7633,75.5685,rb

19,18.4279,48.0504,75.3381,rb

20,19.7123,50.8662,75.1102,rb

21,19.9711,51.2574,75.1822,rew

22,21.1148,53.9723,74.1127,sb

23,22.5133,57.2228,73.0385,sb

24,24.0058,60.5654,72.1674,sb

25,25.3069,63.4003,71.1463,sb

26,26.4473,65.5451,70.9373,sb

27,27.8185,68.2211,71.7825,sb

28,29.5867,71.5386,72.6561,sb

29,30.2834,72.4360,73.3788,toenxt

30,30.2526,72.3683,73.5813,toetop

31,31.0194,74.2324,74.0048,sb

32,32.1307,76.8156,74.3881,sb

33,32.9526,77.2182,75.1608,lew

34,33.1500,79.1545,74.8268,lb

35,33.5581,80.3518,75.0112,lb

36,34.2309,81.0653,75.5868,lb

37,34.3344,81.3242,77.9320,lb

38,35.3078,81.5810,78.9916,bnkpn

39,35.4127,83.3011,80.1625,lb

40,35.7133,83.9074,80.9538,lb

41,37.3776,86.9647,83.3392,lb

42,37.7071,88.3642,84.4399,lb rootball

43,39.5802,91.4942,87.2041,lb rootball

44,40.2009,93.1969,88.3933,lb

45,42.5723,97.3333,92.0990,lb

46,44.5027,100.9401,96.5984,lb

47,45.1789,102.3488,98.4602,lb

48,45.2956,102.8580,100.1102,lb

49,46.0719,104.4689,101.1398,lb

50,46.4046,104.9875,101.0233,lb

51,46.7521,105.7411,101.1673,lb

52,47.2892,106.7206,102.1157,lb

53,47.4813,107.1685,103.3809,lb

54,47.9525,107.9448,103.6101,lb

55,48.3965,108.7823,103.8434,lb

56,48.7330,109.3421,104.3469,lb

57,48.8440,109.5461,106.0163,ltb

58,49.2181,110.6759,106.4848,lb

59,49.9595,112.1257,106.8645,lb

60,50.6729,113.8511,107.1597,lb

61,51.9678,116.2696,107.3273,lb

62,52.7343,118.0176,107.4718,lb

63,53.3806,119.7321,107.5164,lb

64,54.3401,121.6876,107.5827,lb

65,55.4647,123.7603,107.6973,lb

66,56.4169,125.6946,107.7706,lb

67,57.2728,127.4285,107.9484,lb

68,57.8566,128.6805,107.8980,topnxt

69,57.8317,128.5769,108.3176,toptop

70,-24.8920,-10.6761,93.9265,bm7

Upper Little Arkansas Study Bank #1

2015

Point,Northing,Easting,Elevation,Note[34]

1,0.00000,0.00000,92.36370,ts

2,53.86390,-1.83860,81.52310,toptoe

3,27.91000,-102.70000,88.27000,bm2

4,53.75640,-1.80410,80.87130,nexttoe

5,55.41530,-1.80410,81.10670,sb

6,57.45340,-1.43610,82.21960,sb

7,58.28580,-1.26190,85.06150,bp1

8,58.88180,-1.16970,87.55680,lb

9,59.97920,-0.97510,87.97470,lb

10,60.96930,-0.58850,88.32250,lb

11,61.93230,-0.22820,88.81960,lb

12,64.92410,0.61890,89.93960,lb

13,67.69460,1.51520,90.87570,lb

14,70.18590,2.08450,92.41870,lb

15,73.09360,3.03940,93.81390,lb

16,75.33450,3.69990,95.14710,lb

17,77.26780,4.19830,96.03240,lb

18,79.41030,4.78900,96.27170,nexttop

19,79.41420,4.71540,96.60700,toptop

20,52.98650,-2.11730,80.88000,sb

21,39.53720,-5.31540,80.92410,sb

22,33.40190,-7.40820,80.80070,sb

---

[34] ts: total station; bm#: benchmark; toptoe: top of toe pin; nexttoe: next to toe pin; nexttop: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bp#: bankpin; rd: root depth

23,28.89520,-9.07430,80.95920,sb

24,25.69780,-10.31860,81.46980,sb

25,20.41220,-10.92240,82.69280,rew

26,18.84560,-11.61720,82.92890,rb

27,17.67700,-12.34910,83.28190,rb

28,10.61310,-13.47510,91.22050,rb

29,8.78150,-13.68090,92.18490,rb

30,5.07570,-15.76910,93.07060,rb

31,1.34190,-16.67110,93.02650,rb

32,-0.94250,-15.76420,92.87970,rb

33,27.89620,-102.74980,88.23220,bm2

2016

Point,Northing,Easting,Elevation,Note[35]

1,0.0000,0.0000,92.3637,ts

2,27.8962,-102.7498,88.2322,bm2

3,-1.5867,-17.4490,92.7738,rb

4,1.4170,-15.7259,92.9405,rb

5,3.2480,-15.7483,92.9693,rb

6,6.4233,-14.8075,92.6074,rb

7,9.5993,-14.0579,92.1446,rtb

8,10.6165,-13.7148,91.2876,rb

9,15.3680,-12.7111,84.7745,rb

10,18.0574,-11.2541,83.1597,rb

11,19.2588,-10.9035,82.8965,rb

12,22.2052,-9.9155,82.7909,rb

13,22.5961,-9.9763,82.8545,rew

14,24.2853,-9.0753,81.9515,sb

[35] ts: total station; bm#: benchmark; toetop: top of toe pin; toenxt: next to toe pin; topnxt: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bnkpn: bankpin; ltb: left top of bank; rtb: right top of bank; os #in: offset number of inches (undercut)

15,28.2660,-8.0929,81.2015,sb

16,31.9334,-7.5975,81.0269,sb

17,36.1602,-6.6426,80.9371,sb

18,40.4419,-5.4958,80.8550,sb

19,45.5182,-4.1133,80.6572,sb

20,50.0210,-2.9004,80.5523,sb

21,53.0998,-1.9623,80.4981,sb

22,53.8154,-1.8128,80.7218,nxttoe

23,53.8639,-1.8187,81.5244,toptoe

24,54.7679,-1.5169,80.8193,sb

25,56.8730,-1.3369,81.7060,sb

26,57.9406,-1.2492,82.2659,sb

27,57.8982,-1.2818,82.8595,lew os 9in

28,57.9643,-1.3751,84.9630,bnkpn os 9in

29,57.7830,-0.8332,85.9049,lb grass fallen

30,58.2304,-0.7856,86.2684,lb grass fallen

31,58.4988,-0.6739,86.6121,lb grass fallen

32,59.3467,-0.5608,86.9066,lb grass fallen

33,60.0203,-0.5387,87.5394,lb grass fallen

34,60.2997,-0.4010,88.0363,lb

35,61.1114,-0.2136,88.3281,lb

36,61.5005,-0.1244,88.6254,lb

37,63.2016,0.2759,89.2124,lb

38,65.1647,0.7761,89.9879,lb

39,66.6335,1.1361,90.4749,lb

40,67.9920,1.5380,91.0681,lb

41,69.0241,1.8073,91.5882,lb

42,69.7836,2.0626,92.1503,lb

43,71.2729,2.4613,92.9068,lb

44,73.1291,2.9060,93.7652,lb

45,74.9104,3.4281,94.7458,lb

46,76.3582,3.7948,95.6791,ltb

47,77.2287,4.0142,95.9347,lb

48,78.3942,4.3828,96.1738,lb

49,79.5536,4.7456,96.3059,nxttop

50,79.4978,4.7438,96.5866,toptop chewed

51,27.9074,-102.7122,88.1814,bm2

Upper Little Arkansas Study Bank #2

2015

Point,Northing,Easting,Elevation,Note[36]

1,0.00000,0.00000,90.36730,ts

2,-3.45000,-15.50000,90.66000,bm3

10,-3.45250,-15.51490,90.64110,bm3

11,-56.92620,25.53130,78.75850,toptoe

12,-57.04910,25.58710,78.10820,nexttoe

13,-58.14110,27.05480,78.93710,sb

14,-59.34710,28.05540,79.61470,sb

15,-60.79860,29.48580,80.52290,rew

16,-60.96670,30.81700,82.04390,rb

17,-62.04430,31.75880,83.04040,rb

18,-63.66780,33.52140,83.91080,rb

19,-64.10480,33.91080,84.47450,bp1

20,-64.77860,34.87530,86.00000,rb-bkf

21,-66.50700,36.90390,86.42800,rb

22,-67.15470,37.62900,87.05360,rb

23,-67.82680,38.33170,87.15380,rb

24,-68.40260,38.95210,87.86890,rb

---

[36] ts: total station; bm#: benchmark; toptoe: top of toe pin; nexttoe: next to toe pin; nexttop: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bp#: bankpin; rd: root depth

25,-70.12330,41.01100,89.39380,rb

26,-70.69480,41.48940,90.85740,rb

27,-71.76920,42.62480,92.34930,rb

28,-72.33830,43.38900,92.75790,rb

29,-72.88540,44.20150,95.14080,rb

30,-75.02260,46.95930,95.49740,rb

31,-77.37050,49.87160,95.42140,rb

32,-80.44690,53.48880,95.32130,rb

33,-82.88310,56.48850,95.17650,rb

34,-82.90690,56.48060,95.15230,nexttop

35,-82.79100,56.62810,95.51640,toptop

36,-70.14060,41.37880,90.22380,bp2

50,-56.70460,25.14680,78.04450,sb

51,-53.81590,21.13120,78.55700,sb

52,-49.21860,15.36950,79.70450,sb

53,-46.74790,14.14520,79.54620,sb

54,-43.30260,12.00550,79.89570,sb

55,-40.77610,9.89450,80.44100,lew

56,-37.57160,7.98440,81.14120,lb

57,-36.15030,6.82820,81.29250,lb

58,-32.77480,4.10990,82.28690,lb

59,-25.97900,-0.61540,84.59210,lb

60,-16.39090,-8.27640,89.69310,lb

61,-12.62120,-11.92600,90.73490,lb

62,-10.21350,-13.98360,90.90680,lb

63,-3.76460,-18.63440,90.44050,lb

2016

Point,Northing,Easting,Elevation,Note[37]

1,0.0000,0.0000,90.3673,ts

2,-3.4525,-15.5149,90.6411,bm3

3,-17.3501,-20.6769,90.8924,lb

4,-20.0655,-18.0312,90.4277,lb

5,-22.1734,-15.7716,89.3187,lb

6,-24.7848,-13.6042,88.0563,lb

7,-25.7512,-12.8613,87.6807,lb

8,-28.6548,-9.5528,85.7556,lb

9,-30.5217,-7.3275,84.8470,lb

10,-31.4152,-6.8930,83.3633,lb

11,-32.7417,-5.9937,82.6552,lb

12,-34.1049,-2.5222,81.3061,lb

13,-38.6890,3.8316,81.0786,lb

14,-39.8717,5.5348,80.4243,lb

15,-40.5046,6.1978,80.3878,lew

16,-41.9893,7.6703,79.9663,sb

17,-44.4912,10.6356,79.7279,sb

18,-46.8060,13.4241,79.4072,sb

19,-49.0646,16.2949,78.6072,sb

20,-51.6002,19.1696,77.8995,sb

21,-53.1387,21.4055,77.5163,sb

22,-54.6671,23.1151,77.6589,sb

23,-56.0367,24.5324,77.7046,sb

24,-56.8896,25.7092,77.7444,toenxt

25,-56.8762,25.6335,78.7539,toetop

---

[37] ts: total station; bm#: benchmark; toetop: top of toe pin; toenxt: next to toe pin; topnxt: next to top pin; toptop: top of top pin sb: streambed; lew: left edge of water; rew: right edge of water; lb: left bank; rb: right bank; bkf: bankfull; bnkpn: bankpin; ltb: left top of bank; rtb: right top of bank; os #in: offset number of inches (undercut)

26,-57.6635,26.7915,78.2860,sb

27,-58.8127,28.1983,78.9073,sb

28,-59.2579,29.1337,79.3482,sb

29,-59.5906,29.3766,79.9479,sb

30,-60.1488,29.6971,80.4159,rew

31,-60.6470,30.1821,80.6116,rb

32,-60.8367,30.3486,80.8944,rb

33,-60.9828,30.7947,82.0075,rb

34,-61.7468,31.6227,82.9974,rb

35,-62.1018,32.0555,83.2658,rb

36,-62.7811,32.7525,83.6529,rb

37,-63.4912,33.6550,83.9293,rb

38,-63.7112,33.8816,84.1419,rb

39,-63.9704,33.7619,84.4457,bnkpn

40,-64.0500,34.3546,85.2948,rb

41,-64.2606,34.7220,85.8398,rb

42,-64.8039,35.3811,86.0905,rb

43,-65.5897,36.2339,86.2300,rb

44,-66.2224,36.9482,86.4003,rb

45,-66.6731,37.3588,86.6360,rb

46,-67.1158,37.8240,87.0323,rb

47,-67.7553,38.6064,87.1920,rb

48,-67.9155,38.9815,87.5713,rb

49,-68.1887,39.4833,88.0141,rb

50,-68.8263,40.2591,88.4639,rb

51,-69.5911,41.1132,89.1985,rb

52,-70.0018,41.7341,89.5291,rb

53,-70.2935,41.8314,90.2793,bnkpn

54,-70.3805,42.0584,90.8346,rb

55,-71.0156,42.8961,91.7026,rb

56,-71.8221,43.8491,92.6425,rb

57,-72.1667,44.1746,93.1100,rb

58,-72.4067,44.5391,93.5146,rb

59,-72.5160,44.6681,95.1688,rtb

60,-73.5070,45.7539,95.3762,rb

61,-74.9872,47.4776,95.4167,rb

62,-76.8789,49.7078,95.3683,rb

63,-78.2913,51.5099,95.3813,rb

64,-79.6489,52.9845,95.2843,rb

65,-81.4295,55.0866,95.1628,rb

66,-82.5959,56.6866,95.1092,topnxt

67,-82.7034,56.8139,95.5049,toptop

68,-3.4299,-15.4857,90.6221,bm3