PRIORITIZING STREAM RESTORATION: A DECISION SUPPORT TOOL FOR USE IN RESTORING WATERS IMPAIRED BY EXCESS SEDIMENT IN THE BLUE EARTH RIVER BASIN OF MINNESOTA

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF MINNESOTA

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Abstract

The hydrology of the Blue Earth River Basin has been dramatically altered following European settlement in the mid-to-late 1800's. Land use change has resulted in hydrologic instability leading to streambank and bluff erosion and increased sediment transport (Magner et al., 2003). Hydrologic change has led to an increase in turbidity, or cloudiness of the river commonly measured as total suspended sediment (TSS). Excessive turbidity in water can be harmful to both humans (if used for drinking water) and aquatic life. In the Greater Blue Earth River Basin, there are 39 stream/river reaches that fail to meet the state's water quality standards for turbidity, which is 90 parts per million TSS (MPCA, 2005). The purpose of this study is to create a tool that researchers can use to prioritize stream restoration in the Blue Earth River Basin in a relatively quick, productive and cost-effective way. The tool created will help prioritize stream sites for restoration based on a set of decision support metrics. A field test of the tool was conducted on two tributaries to the Blue Earth; Elm and Center Creek. The tool was tested on a total of 30 sites from these two tributaries. The future goal for this tool is for it to be used to help local officials prioritize restoration on unstable areas throughout the Blue Earth River Basin that are actively eroding and contributing sediment to the Blue Earth River.

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1. Introduction

1.1 Problem Statement

"Sediment is the second leading cause of impairment of monitored rivers and streams in the United States according to the U.S. Environmental Protection Agency (Van Eps et al., 2004; U.S. EPA, 2000)." The Blue Earth River Basin (BERB), was selected for this study because it contributes the highest amount of flow to the Minnesota River (46%) as well as the highest amount of Total Suspended Solids (TSS) (55%) (MPCA, 2005). The Blue Earth River is impaired for turbidity, exceeding the Minnesota numerical standard of 25 NTU (Lenhart, 2008). Two tributaries to the BERB, Elm Creek and Center Creek, which are focused on in the case study, are also impaired for turbidity (Lenhart, 2008). Excessive turbidity in water can be harmful to both humans and aquatic life. Because the Blue Earth River (BER) is such a high contributor of flow and TSS to the Minnesota River, it should be given a high priority for restoration due to the importance of Lake Pepin and the issues with hypoxia in the Gulf of Mexico.

The hydrology of the BERB has been dramatically altered following European settlement of the area in the mid-to-late 1800's and has resulted in hydrologic instability, streambank erosion and impaired water quality (Magner et al., 2003). Sekely et al (2002) found that 31-44% of the total suspended sediment load for the Blue Earth River (BER) comes from streambank erosion. This increase in sediment loading has led to an increase in turbidity, or cloudiness of the river.

"The Federal Clean Water Act (CWA) requires states to adopt water-quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A waterbody is considered "impaired" if it fails to meet one or more water quality standards (MPCA, 2012)." Once a waterbody is listed, a Total Maximum Daily Load (TMDL) must be done to determine how much of a pollutant that waterbody can receive while still meeting its designated uses (MPCA, 2012).

In the Greater Blue Earth River Basin, there are 39 stream/river reaches that fail to meet the state's water quality standards for turbidity, which is 90 parts per million (MPCA, 2005). Therefore, in order to meet the goals of the TMDL and reduce turbidity, a tool is needed that would prioritize unstable areas that are actively eroding and contributing sediment to the Blue Earth River, while taking into account other important metrics, such as cost and site conditions. It is important to make the distinction that restoration in this context does not refer to restoring the site to its pre-disturbance conditions, but rather restoring it to a more stable state.

1.2 Research Objectives

The purpose of this study is to create a tool that researchers can use to prioritize stream restoration in the Blue Earth River Basin in a relatively quick, productive and cost-effective way. It is important when beginning a restoration planning process to determine how restoration actions should be carried out. Beechie et al (2008) found that, "The restoration planning process should have four distinct steps: (1) Identify the restoration goal, (2) Select a project prioritization approach that is consistent with the goal, (3) Use watershed assessments to identify restoration actions, and (4) Prioritize the list of actions."

With this in mind, the restoration goal for this project is to reduce sediment loading to the Blue Earth River Basin by reducing streambank and bluff erosion. To achieve this goal, a decision support tool will be created to prioritize the eroding sites. The tool will be field tested on two tributaries to the Blue Earth; Elm and Center Creek. The prioritization method that will be used is a Decision Support System approach, which is used to assemble and weigh information considered important in determining prioritizes (Beechie et al., 2008). Watershed assessment tools that will be used to determine priorities include: the Bank Erosion Hazard Index, Modified Pfankuch Assessment for Low to Mid-Gradient Streams, Near-Bank Sheer Stress Assessment, and the Channel Evolution Model. The field test of the tool will help choose potential restoration locations based on different ranked metrics. The locations with the highest scores will be recommended for restoration. Once sites are prioritized, the information can be given to local officials to determine the appropriate restoration actions for each site. The field tool can then be used throughout the BERB to help prioritize restoration throughout.

1.3 Research Questions

A Stream Restoration Prioritization Score Sheet (SRPSS) was created as a part of a decision support tool and field tested on 2 tributaries of the Blue Earth River; Elm and Center Creeks. Since the goal of the project is to reduce sediment loading to the Blue Earth River in a productive, cost effective way, it is important to include metrics in the score sheet that assess cost, erosion amounts, and site conditions. However, because the main goal of this project is to reduce sediment loading, the other metrics in the SRPSS should not overshadow the amount of erosion at a site. With that in mind, it is important to compare the amount of erosion for sites ranked as having a high priority based on the SRPSS to those that are prioritized based on the amount of erosion alone. It is also essential that the SRPSS used in the decision support tool be repeatable by different researchers. Therefore, the main research questions of this project are:

1. Will sites ranked as having high priority for restoration in the Stream Restoration Prioritization Score Sheet have similar erosion amounts as those prioritized based on erosion alone?

2. Will the Stream Restoration Prioritization Score Sheet be repeatable by different researchers?

1.4 Research Hypotheses

The following research hypotheses were formulated in response to the research questions stated in section 1.3:

<u>Research Hypothesis:</u>

1. H_o: The sites with the highest SRPSS scores will have similar erosion rates as the highest sites prioritized by erosion alone.

   $H_{a:}$ The sites with the highest SRPSS scores will not have similar erosion rates as the highest sites prioritized by erosion alone.

2. H_o: The SRPSS will be repeatable by different users.

   $H_{a:}$ The SRPSS will not be repeatable by different users.

2. Literature Review

2.1 Background on the Blue Earth River Basin

The BERB was selected for this study because it contributes the highest amount of flow to the Minnesota River (46%) as well as the highest amount of Total Suspended Solids (55%) (MPCA, 2005). “The Blue Earth River Watershed is located in the south central Minnesota Counties of Blue Earth, Brown, Cottonwood, Faribault, Freeborn, Jackson, Le Sueur, Martin, Steele, Waseca, and Watonwan and in the North Central Iowa counties of Emmet, Kossuth, and Winnebago (MPCA, 2005).” The BERB has an area of 992,034 acres, with major tributaries being the Watonwan River flowing from the southwest, the Le Sueur River flowing from the southeast, and the Blue Earth River flowing from the south, and also drains thirty one smaller tributaries (MPCA, 2005). The Blue Earth River contains a dam built in 1910 for hydroelectric power generation (MPCA, 2005) The Rapidan Dam impounds the river 12 miles upstream from its mouth (MPCA, 2005). Above the dam, the Blue Earth River flows through farmland and bluffs and below the dam, the river runs through a gorge, which features canyons, waterfalls and cliffs (MPCA, 2005).

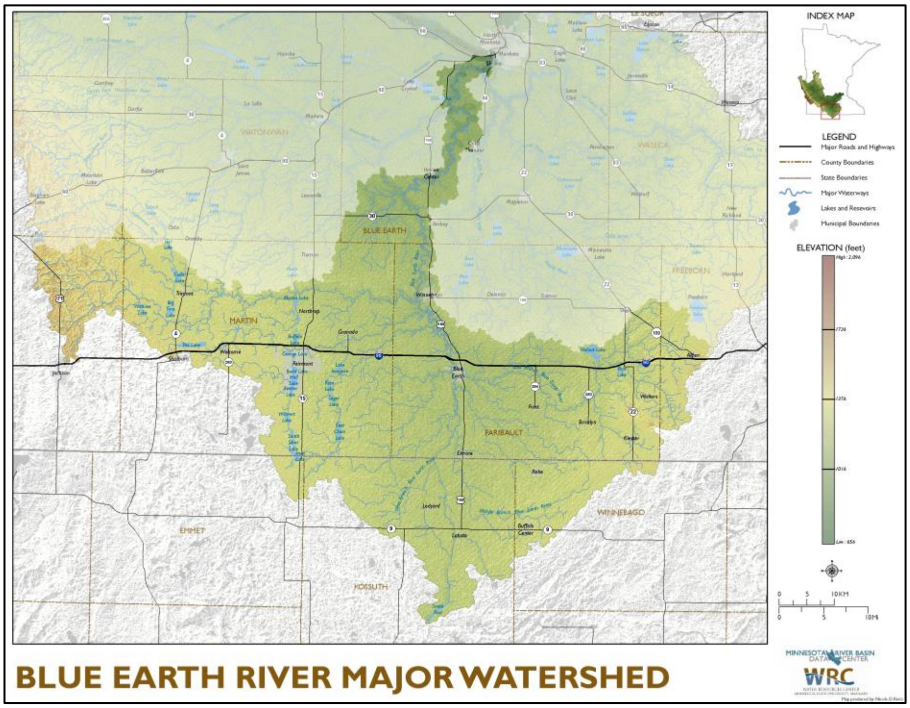


Figure 2.1: The Blue Earth River Basin (BERB) located in South-Central Minnesota. Map courtesy of MRB Data Center.

The landscape in the BERB ranges from rolling, hilly morainal belts in the south and east to flat lake plains in the north (Magner et al., 1993). Pre-settlement vegetation in the BERB was made up of deciduous hardwoods in the north, with flat plains and tall grass prairies in the south (MPCA, 2005). After settlement of the area in the l800's, land-use was converted mainly to agriculture, accounting for approximately 84% of the available acres. Currently, two-year corn/soybean rotations make up roughly 92% of cropped lands, with the balance being comprised of small grains, hay, and grasslands enrolled in the Conservation Reserve Program (MPCA, 2005). The BERB has roughly 2,300 feedlot facilities, with an estimated 2.2 million swine raised in the basin. Soils in the area include mostly poorly-drained clay and silt/clay (MPCA, 2005). The climate varies from extreme cold in winter to extreme heat in the summer. Precipitation rates average 30 inches per year (MPCA, 2005).

2.2 Land-Use Changes and Channel Instability in the BERB

The hydrology of the BERB has been dramatically altered following European settlement of the area in the mid-to-late 1800's and has resulted in hydrologic instability, streambank erosion and impaired water quality (Magner et al., 2003). Historically, the basin was driven by slow groundwater movement through silty-clay loam and silt-loam soils (Magner et al., 1993). This allowed isolated wetland basins to form, in the "pothole" depressions that resulted from the last glacial advance (Suppes, 2009; Miller, 1999). With the development of the land for agricultural use, vegetation was transformed from deciduous trees and perennial grasses to annual row crops. In order to cultivate the land for crops, over 90% of the wetlands were tile drained to decrease soil moisture conditions (Lenhart, 2008). This decrease in storage has led to an increase in water and sediment yields to rivers and streams, as well as higher runoff peaks (Lenhart, 2007; Miller, 1999). Tile drains and ditches also alter the pathways of flow, by redirecting water from depressional storage, evaporation and transpiration to channel flow (Brooks and Magner, 2005). The introduction of subsurface tile-drains and ditches increased contributing drainage areas, which resulted in larger amounts of water delivered to rivers (Lenhart, 2007; Kuehner, 2005; Leach and Magner, 1992).

The conversion of perennial grasses and trees has also altered the hydrology of the basin by reducing the amount of evapotranspiration (ET) that occurs during the spring, which leads to an increase in runoff events and peak-flows (Lenhart, 2007; Brooks et al., 2006). This increase in peak-flow alters the fluvial dynamic equilibrium of the system and forces stream channels to adjust to accommodate added inputs of water (Suppes, 2009). Therefore, many stream channels in the BERB have become entrenched and disconnected from their floodplain (Suppes, 2009). Because stream channels are unable to handle the energy associated with increased flows, many erode and entrain sediment that is transported downstream (Suppes, 2009; Rosgen 1994).

Rural and urban areas each make-up about 1% of land use in the Blue Earth River Basin, which also contribute to changing hydrology. Impervious surfaces associated with urban development produce increases in peak stormflows, which leads to erosion of streambanks (Brooks and Magner, 2005).

Although channels naturally migrate laterally over time, changes in land-use and climate that increase run-off can increase streamflow, which accelerates the rate of bank erosion (Lenhart et al., 2012). Land-use modifications, resulting in changes in evapotranspiration (ET), groundwater recharge and interception, all have effects on streamflow (Lenhart, et al., 2012). An increase in the amount and/or intensity of precipitation, can also affect streamflow. Streamflow in southern Minnesota has increased significantly in recent decades in southern Minnesota, with low to moderately high flows having the greatest percentage increases (Figure 2) (Lenhart et al., 2012). Large floods, with more than a 50-year recurrence interval, were not found to increase significantly in the past 30 years (Lenhart et al., 2012; Nieber et al., 2010). This research suggests that the increase in streamflow is mostly due to land-use changes rather than precipitation increases (Lenhart et. al, 2011).

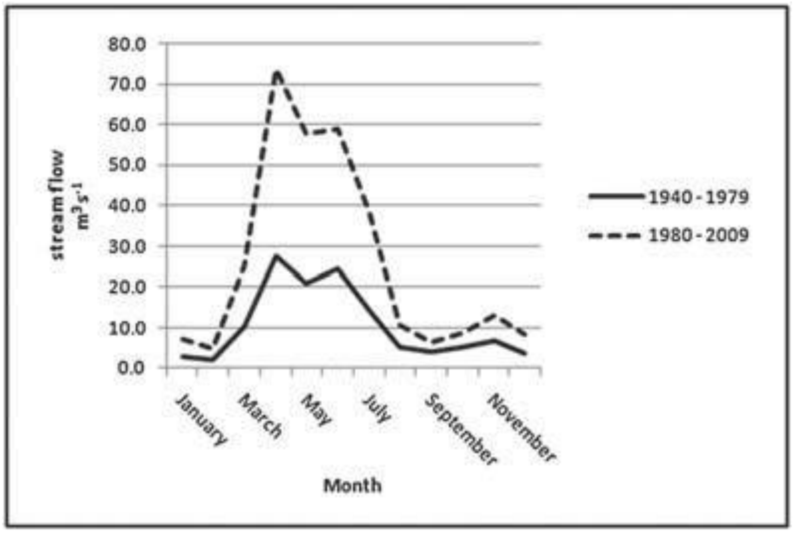


Figure 2.2: Median monthly streamflow by water year for the Blue Earth River comparing 1980-2009 to the 1940–1979 time period. (Lenhart et al., 2011).

Riparian community disturbances in the Blue Earth River Basin are frequent and include: agricultural conversion, channelization, grazing, road development and loss of floodplain community due to altered hydrology and the introduction of invasive species. Forested riparian areas perform very important ecosystem functions and services. For example, forested riparian areas improve streambank health due to deep rooted vegetation, shade and litter, which lead to improved bank stability, water quality and stream temperature (USDA, 2000). Forested riparian areas also provide habitat for aquatic and terrestrial wildlife, which is important for ecological and recreational values (USDA, 2000). Contributions of coarse woody debris from forested riparian areas help to create and maintain pools, which are important for aquatic life (USDA, 2000). Riparian vegetation also plays an important role in trapping suspended material and slowing the velocity of flow, which allows the sediment to drop out, reducing the amount of nutrients, sediment and flow in the stream (USDA, 2000). The loss of forested riparian areas in the BERB has resulted in a loss of ecological functions causing an overall decrease in stream and riparian health. This loss has resulted in an increase in nutrient and sediment contributions, a loss of wildlife habitat and streambank instability.

Figure 2.2a: Loss of Forested Riparian Habitat in the BERB. Grazing has also accelerated the amount of erosion. Photo: Center Creek: 2011 by Presnail.

Direct stream disturbances, such as road construction, culvert installation, ditching, tilling, dewatering and dredging can affect multiple processes leading to stream channel instability and thus, changes to sediment supply and transport (Rosgen, 2008). Channel straightening due to road development, natural cut-offs and ditching have shortened Elm Creek (a major tributary to the BER) by 15% between 1938 and 2003 (Lenhart et al., 2012). Stream channel modification, such as straightening results in a loss of stream sinuosity, which causes an increase in unit stream power. This increase in stream power increases instability, leading to erosion and sediment transport (Suppes, 2009; Lenhart, 2007) Stream channels in disequilibrium often result in streambank erosion and accelerated sediment yields as they attempt to reach a new equillibrium (Rosgen, 2008).

2.3 Streambank Erosion in the Blue Earth River Basin

For most of the 20th century, the main source of sediment loading in the BERB was from agricultural field erosion carried by runoff (UMN, 2010). However, after the formation of the Soil Conservation Service in the 1930's focus was paid on reducing field erosion and with agricultural practice improvements, field erosion contributions decreased on a per unit basis (UMN, 2010; Trimble, 1981). Channel erosion is now thought to be responsible for an ever increasing percentage of sediment loads (UMN, 2010; Thoma et al., 2005).

Figure 2.3 Actively eroding streambank on Elm Creek, a tributary to the BER. Photo by Presnail, taken fall, 2011.

In a study conducted in 2012 by Lenhart et al, 30 stream channel surveys were conducted on Elm and Center Creeks, two tributaries to the BER. This was done to assess the stability of the channels and potential contributions of channel erosion to turbidity (Lenhart et al., 2012). It was found that the lower reaches were highly entrenched, leading to increased sediment delivery to the downstream Blue Earth and Minnesota rivers (Lenhart et al., 2012).

In the Greater Blue Earth River basin, 39 sections of streams and rivers fail to meet the state water quality standard for turbidity (MPCA, 2005) This means that the water is too cloudy, which has harmful effects on aquatic life such as fish. Under current state standards, the level of total suspended solids (TSS) for rivers in the BERB should be 90 parts per million (ppm) (MPCA, 2005). However, levels in the BERB average from 175-675 ppm according to water monitoring from 2000-2008 (MPCA, 2005).

2.4 Detrimental Effects of Stream Instability and Excess Sediment

Excessive turbidity in water can be harmful to both humans and aquatic life. Harmful pathogens use turbidity particles for food and shelter and can be a threat to human health if a turbid waterbody is used for drinking water (EPA, 1999). An increase in sediment also brings with it an increase in phosphorus which is attached to the sediment and results in eutrophication of the river (Sekely et al., 2002). In addition, a study by Henely et al. (2000) found that an increase in turbidity can lead to a decline in local fish populations, Periphyton quality, Phytoplankton production and Macroinvertebrate diversity and density.

2.5 Current Tools for Stream Restoration

Before doing restoration planning it is important to know and understand where a channel currently is in the stream channel evolution scenario. In addition, it is also important to understand where the channel is evolving in the future because different restoration techniques only work well on certain stream types. To develop an effective decision support tool we need this understanding as part of the process. Understanding that stream classification can and will change throughout a watershed is important so we don't try to package things as a one size fits all scenario. With this in mind, a study by Lenhart et al., 2012, which surveyed 30 stream sites on Elm and Center Creek, found that most sites were moderately entrenched. It was also found that, "Headwater streams and tributary gullies are actively down cutting and/or widening (CEM stages III-IV), while the far downstream end of Elm & Center Creeks went through the channel enlargement and are now stabilizing (stage V) (Lenhart et al., 2012)." Therefore, it is important to focus on areas that are actively evolving and contributing sediment to the BER.

It is also essential to know what your project's goal is and what restoration techniques will be best suited to meet the objectives. The goal of this project is to reduce sediment loading to the Blue Earth River Basin by reducing streambank and bluff erosion. Therefore, both riparian and in-stream restoration techniques can be utilized to meet this goal. Some techniques that are available are: increasing storage, riparian buffers, limiting grazing, removing log jams, flow diversion, streambank armoring and tile removal.

3. Stream Restoration Prioritization (SRP) Decision Support Tool for the Blue Earth River Basin

The Stream Restoration Decision Support Tool was created to prioritize restoration in the Blue Earth River Basin. This tool is a 2-step process involving a preliminary screening to locate sites of interest, followed by an on-site in-depth analysis and prioritization. The tool was important to create because of the increasing number of eroding sites and the cost associated with restoration projects.

Step 1: Preliminary Screening:

The preliminary screening is the first step in the Decision Support Tool. This is to find sites that are contributing large amounts of sediment due to bank or bluff erosion and are threatening damage to infrastructure or loss of land. This step is also to determine the attitude of the landowner to evaluate whether a potential restoration project could take place on their property. Once the subsequent tasks of Step 1 are carried out, proceed to Step 2: On-site in-depth analysis and prioritization.

Step 1a.) Locate Highly Erodible Stream Sites:

- **a.)** Locate aerial imagery of the stream of interest.
- **b.)** Find stream sites with high radii of curvature*, or ones with non-vegetated banks, or large bluffs.
- **c.)** Communicate with the local SWCD to determine if they already information on highly erodible stream sites that you can add to your list.
- **d.)** Make a spreadsheet with the information for each site, including site ID, stream name, and coordinates.

Image 3.1: Image from Google Earth ™ showing an example of a site with a high radius of curvature

Step 1b.) Erosion Calculation Instructions:

Once a list is compiled of potential eroding sites, the next step is to get an estimate of the amount of erosion occurring at each site. Using LiDAR, that is available for the Blue Earth River Basin, use GIS to determine estimates of erosion for each selected site. To do this, use multiple years of aerial imagery (GIS or Google Earth) to calculate the amount that the bank is retreating over time. Then use the 3D line measuring tool in ArcMap to get an estimate of the bank height. Then calculate the length of the eroding bank. Using the bank height, length and distance of bank retreat, you can get an estimate of the amount of erosion in cubic feet/year. To date, there is not a lot of research on how accurate this method is, so this should only be used as a preliminary estimation of erosion amounts for now.

Step 1c.) Infrastructure or Loss of Land Assessment

When assessing this metric, look at the adjacent land use to determine what is near the eroding portion of the stream. It is important to compare the rate of erosion, with aerial imagery to determine how far the bank is retreating each year.

Low Priority: Stream is stable and not actively eroding. Stream could be eroding, but is not near any infrastructure, farm fields, or other property that would result in a loss of property value or structures.

Moderate Priority: Stream is eroding at a rate that is not going to cause damage to any property or infrastructure in the near future. Not going to cause any adverse effect to managed land.

High Priority: Stream is actively eroding and will likely result in a high loss of managed land, infrastructure, or structure within the next year.

Very High Priority: Damage due to erosion is imminent or already occurring. Especially important if infrastructure, such as a road, bridge or home is threatened.

Step 1d.) Preliminary Screening Score Sheet:

Once the estimates of erosion and threat to infrastructure/land are determined, use the following score sheet for each site to determine the sites with the highest priority (Note: for ones with highest priority, these scores will be transferred to the Stream Restoration Prioritization Score Sheet in Step 2. Do not transfer the erosion score if the LiDAR method was used until research has been done to test the how accurate it is. Transfer the erosion amount that is calculated using the BANCs method in Step 2).

Ranking:	Low Priority (0 - 0)	Moderate Priority (0 - 8)	High Priority (9 - 16)	Very High Priority (17 - 24)
A. Estimated amount of Erosion (see guidance manual)	Less than 100 cubic ft/yr/site 0	100-500 cubic ft/yr/site 4	500-1000 cubic ft/yr/site 8	More than 1000 cubic ft/yr/site 12
I. Instability Threatening Infrastructure or Loss of Land to Landowners	None present or Unlikely 0	Potentially; in a 5 or more years 4	Likely; in 1 year or less 8	Imminent; Already occurring or will occur within a year 12

Step 1e.) Contact Landowners to Gauge Interest/Attitude:

For this step, determine who the landowners are for each of the properties. Then contact them and if they would be interested in a potential restoration project obtain approval for an on-site field assessment. Do not include those stream sites where the landowner is opposed.

Once the sites are ranked for erosion and threat to infrastructure and the landowner has been contacted, the next step is to do an on-site in-depth analysis. Select the sites with the top rankings and landowner interest to move on to Step 2.

Step 2: On-site in-depth analysis and prioritization:

This step involves doing an on-site in-depth analysis using certain watershed assessment tools for sites prioritized in Step 1. For this project, one of the field watershed assessments used is the BANCS erosion estimation method, because there has not been a lot of research on the LiDAR method for determining erosion rates. This includes the Bank Erosion Hazard Index (BEHI) and the Near Bank Stress (NBS) assessment. The Modified Pfankuch (MPf) for Low to Mid-Gradient Streams assessment was also used. The purpose of these assessments is to evaluate the stability of the streambanks and better estimate the amount of erosion occurring. The amount of erosion and the Modified Pfankuch scores will also be used as metrics in the Stream Restoration Prioritization Score Sheet (SRPSS). See section 3.3: Field Procedures for detailed information on these assessment tools.

Once the watershed assessments are complete, the next step is to fill out the "Stream Restoration Prioritization Score Sheet." This score sheet uses 13 metrics that will help to prioritize the need, ease and cost for restoration. Follow the step by step guide in the "Guidance Manual for the Stream Restoration Prioritization Score Sheet" to determine score sheet rankings.

3.1 Stream Restoration Prioritization Score Sheet (SRPSS):

A decision support tool score sheet by Beechie et al (2008) and the Modified Pfankuch Assessment (Asmus and Magner, 2008) were used as a guide to create the Stream Restoration Prioritization Score Sheet (SRPSS). The SRPSS was created to help prioritize restoration based on a set of 13 metrics. The metrics were chosen and assigned weights by 4 researchers (Dr. Ken Brooks, Dr. Chris Lenhart, Dr. Joe Magner, and Mary Presnail) at the University of Minnesota. The SRPSS was broken into two categories. The first category is an “Inventory of Site Conditions”. It is imperative to determine the site conditions prior to assessing the need for restoration. The second and final category in the SRPSS is “Variables Affecting Cost to Restore”. Stream restoration projects can be extremely expensive and funding is often limited, therefore the metrics chosen for these categories were very important to include.

The following table is the final version of the Stream Restoration Prioritization Score Sheet:

Stream Restoration Prioritization Score Sheet (SRPSS)

Stream Name:______________ Site ID:_________________ Date: ___________

Assessors____Total Score: [ ]

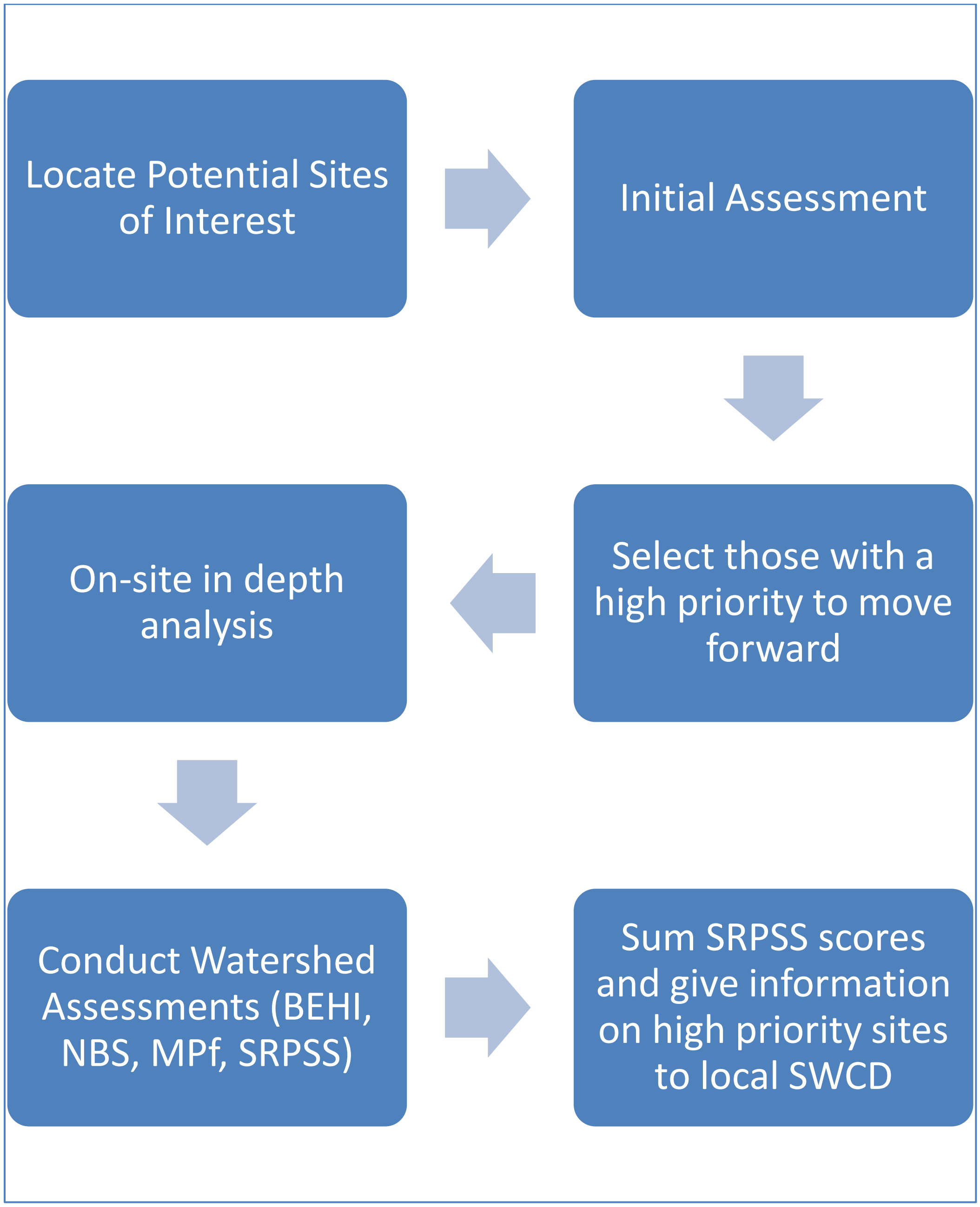
Ranking:		**Low Priority (0 - 14)**		**Moderate Priority (15 - 50)**		**High Priority (51 - 85)**		**Very High Priority (86 - 120)**	
2.) Inventory of Site Conditions	A. Estimated amount of Erosion (see guidance manual)	Less than 100 cubic ft/yr/site	0	100-500 cubic ft/yr/site	4	500-1000 cubic ft/yr/site	8	More than cubic ft/yr	12
	B. Modified Pfankuch for Low-Gradient Streams Score (MPCA)	Excellent	2	Good	4	Fair	6	Poor	8
	C. Site's Potential for Water Storage during small flood events (1.5 year recurrence interval) (i.e. Potential for oxbow /floodplain reconnection, interceptor wetland.,etc)	Low; No potential for water storage (Land is too flat; no oxbow presence., channel is too entrenched, so water won't be able to get over the bank, etc)	2	Moderate; 1 storage features present with slight entrenchment. Water can reach storage feature during low flooding event.	4	High; 1-2 storage features present with little to no channel entrenchment. Water can reach storage feature during low flooding event.	6	Very High; More than 2 storage features ; little to no channel entrenchment; Water can reach storage feature during low flooding event.	8

D. Adjacent Riparian Buffer Width	Riparian Buffer Area immediately adjacent to streambank is at 95 feet wide	2	Riparian Buffer Area immediately adjacent to streambank is 50-95 feet wide	4	Riparian Buffer Area immediately adjacent to streambank is 25-50 feet	6	Riparian Buffer Area immediately adjacent to streambank is 0-25 feet wide	8
E. Adjacent Riparian Buffer Vegetation	Quality mix of forbs/grasses/trees	2	Some mix, but poor quality: mostly trees with few forbs and grasses	4	Poor mix of vegetation; mainly trees or grasses.	6	Poor vegetative mix: row crops or grazed grasses	8
F. Adjacent Land Management	Forest or prairie with evidence of partial management	0	Non-managed Forest/Prairie	4	Conventional grazing with the potential for rotational grazing	6	Intensively managed (row cropping)	8
G. Stage of Channel Evolution Model (MPCA: guidance manual)	Type I: Pre-adjustment or Type 5: New Dynamic Equillibrium	2	Type II (Incising and/ or bank failure)	4	Type III (Incising and/ or bank failure)	6	Type IV: Re-stabilizing	8
H. Dominant Streambank Material (That if eroded would contribute to turbidity and phosphorus in stream)	Loamy Sand	2	Cohesive Soil Mix	4	Silts	6	Silty Clay/Clay	8
I. Instability Threatening Infrastructure or Loss of Land to Landowners	None present or Unlikely	0	Potentially; in a 5 or more years	4	Likely; in 1 year or less	8	Already occur-ing or within a year	12

3.) Variables affecting Cost to Restore	J. Length of Eroding Streambank	More than 1000 Ft 0	500-1000Ft 4	100-500 Ft 8	Less than 100 feet 12
	K. Amount of Wood, Woody Debris or Large Rock Available for Restoration (See SRPSS Guidance Manual)	None Present 2	Few (1-3) Large Trees/ Woody debris or Rock present in-stream or in Riparian area. 4	Several (3-5) Trees/ Woody debris or Rock present instream or in Riparian area 6	Many (>5) Trees/Woody debris or Rock present in-stream or in Riparian area 8
	L. Site Accessibility (Distance and Terrain)	None; no access by vehicle. Dense woods and/or difficult terrain 0	Somewhat; more than .5 mile to access and/or somewhat difficult terrain, while still being accessible 4	Mostly; less than .5 mile to access, easy terrain 8	Very, adjacent to road or field that can be easily accessed by a vehicle 12
	M. Sod/Willow Mat Availability	None present on landowner's property or available but poor quality because of grazing or >1mile away or not easily accessible. (or if readily available would cause significant disturbance if harvested) 0	On site and good quality: between 2000-5000 feet away and accessible by vehicle (Won't cause significant disturbance if harvested) 2	On-site and good quality: between 1000-2000 feet away and accessible by vehicle (Won't cause significant disturbance if harvested) 6	On-site and good quality: <1000 feet away and easily accessible by vehicle (Won't cause significant disturbance if harvested) 8

Column totals:

Figure 3.1: Flowchart Depicting Overall Decision Support Tool Process:



3.2.1 Guidance Manual for the Stream Restoration Prioritization Score Sheet

This guidance manual was created to be used in conjunction with the Stream Restoration Prioritization Score Sheet (SSRPSS) to provide background information and instructional assistance for each of the metrics. The score sheet is broken into the two sections of the score sheet: "Inventory of Site Conditions," and "Variables Affective Cost to Restore." These sections each have metrics associated with them that will be described in greater detail below.

Section One: Inventory of Site Conditions:

This section is extremely important when determining whether or not a site will have a high priority for restoration. Because the SRPSS was created with the goal of reducing sediment loading into the Blue Earth River, it is essential to assess the following metrics:

A.) Estimated Amount of Erosion:

	Low Priority		**Moderate Priority**		**High Priority**		**Very High Priority**	
a. Estimated Amount of Erosion	Less than 100ft^3/ yr/site	0	100 - 500 ft^3/yr/site	4	500- 1000 ft^3/yr/site	8	More than 1000 ft^3/yr/site	12

In order to determine the estimated amount of erosion, researchers have a few options. The first option is to use bank pins to measure the amount of erosion occurring over time. This is probably the most accurate method, but generally requires a long study time to be accurate. The second option is to use the Bank Assessment for Non-Point source Consequences of Sediment (BANCS) method created by Rosgen (2001). To do this, you must first conduct a Bank Erosion Hazard Index (BEHI) assessment, and then determine the Near-Bank Stress (NBS) on each site. Once the BEHI and NBS ratings are calculated they are used with the BANCS model to derive annual streambank erosion rates. It is important to note that the rating curve that is used to calculate the amount of erosion is not extremely accurate for Minnesota, but a regional curve is in the process of being developed by researchers at the University of Minnesota. It is also possible to use the BANCS method, and then compare with GIS or historic aerial imagery to determine if the amount of erosion that is occurring over time is accurate.

Low Priority: Calculate the amount of erosion and if it is less than 100ft cubic feet per year, assign the site a Low priority.

Moderate Priority: Calculate the amount of erosion and if it is between 100 and 500 cubic feet per year, assign the site a Moderate priority.

High Priority: Calculate the amount of erosion and if it is between 500 and 1000 cubic feet per year, assign the site a High priority.

Very High Priority: Calculate the amount of erosion and if it is more than 1000 cubic feet per year, assign the site a Very High priority.

B.) Modified Pfankuch for Low-Gradient Streams Score (MPCA)

	Low Priority		Moderate Priority		High Priority		Very High Priority	
B. Modified Pfankuch for Low-Gradient Streams Score (Magner)	Excellent	2	Good	4	Fair	6	Poor	8

The Modified Pfankuch Stability Assessment (MPf) was modified from the Original Pfankuch Stablitity Index (OPf). The modified field form was developed by Asmus and Magner in 2008 to, “More accurately characterize geomorphic condition and channel stability in low to mid-gradient alluvial streams in the Midwest (MPCA, 2008).” The assessment has 14 metrics used to assess the stability of the upper banks, lower banks and channel bottom.

Low Priority: An Excellent score on the MPf.

Moderate Priority: A Good score on the MPf.

High Priority: A Fair score on the MPf.

Very High Priority: A Poor score on the MPf

C. Site's Potential for Water Storage:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
C. Site's Potential for Water Storage (i.e. Potential for oxbow /floodplain reconnection, interceptor wetland,etc)	Low; No potential for water storage (Land is too flat; no oxbow presence, or channel is too entrenched, water won't be able to get over banks)	2	Moderate; 1 storage features present with slight entrenchement. Water can reach storage feature during low flooding event	4	High; 1-2 storage features present with little to no channel entrenchment. Water can reach storage feature during low flooding event.	6	Very High; More than 2 storage features present, with little to no channel entrenchment; water can reach storage feature during low flooding event.	8

This metric assesses the site's potential to store water. Because an increase in stream flow causes erosion, this is an important metric to assess. Look at the site conditions and determine if there is potential to store water either through the reconnection of an oxbow to use during high flows, or if there is a depressional area on-site that could be used as an interceptor wetland. Also look to see if it would be possible to reconnect the channel to the floodplain, as this would help reduce the amount of water in the channel during high flows.

Low Priority: Low; No potential for water storage (Land is too flat; no oxbow presence, etc). Channel is too entrenched for water to reach storage feature during low flood event.

<u>Moderate Priority:</u> Moderate; 1 storage feature present with only slight entrenchment. Water can reach storage feature during low flooding event.

<u>High Priority:</u> High; 1-2 storage feature(s) present with only slight entrenchment. Water can reach storage feature during low flooding event.

<u>Very High Priority:</u> Very High; More than 2 storage features present with only slight entrenchment. Water can reach storage feature during low flooding event.

<u>D. Adjacent Riparian Buffer Width</u>

	Low Priority		Moderate Priority		High Priority		Very High Priority	
D. Adjacent Riparian Buffer Width	Riparian Buffer Area immediately adjacent to streambank is at 95 feet wide	2	Riparian Buffer Area immediately adjacent to streambank is 50-95 feet wide	4	Riparian Buffer Area immediately adjacent to streambank is 25-50 feet	6	Riparian Buffer Area immediately adjacent to streambank is 0-25 feet wide	8

Riparian vegetation plays a critical role in bank stability. Roots hold soil in place and litter slows overland water movement. When vegetation is removed, banks are more susceptible to erosion. Using general guidelines for the management of riparian buffer strips, describe in Hydrology and Watershed Management, (Brooks et al., 2003), this metric assesses the width of the adjacent riparian buffer. Generally, streams with a large riparian buffer are going to be more stable than those with a narrow riparian buffer. Please note when assessing this metric that the riparian buffer should be one that would work to protect stream stability by providing root strength and ground cover.

Low Priority: If there is a large, healthy riparian area adjacent to the stream, it is likely that the stream bank will not be in danger of significant erosion due to the root strength, interception and evapotranspiration of the riparian plants.

Moderate Priority: A site should be given this ranking if there is a 50-95 foot riparian area near the stream. This riparian buffer may be protecting the stream from erosive forces and therefore would not be a very high priority.

High Priority: A site should be given a high priority ranking if there is a 25- 50 foot buffer present. The riparian area may be somewhat acting as a buffer, but there is a need for improvement to protect the eroding streambank.

Very High Priority: Rank a site as having very high priority if there is little to no buffer present. It is extremely important to have a healthy riparian buffer to protect the streambank from erosion.

E. Adjacent Riparian Buffer Vegetation

	Low Priority		Moderate Priority		High Priority		Very High Priority	
E. Adjacent Riparian Buffer Vegetation	Quality mix of forbs/grasses/trees	2	Some mix, but poor quality: mostly trees with few forbs and grasses	4	Poor mix of vegetation; mainly trees or grasses.	6	Poor vegetative mix: row crops or grazed grasses	8

The ideal layout of a buffer strip as described in the guidelines for management of riparian buffers (Welsch, 1991; Brookes et al., 2003) is made up of the following three zones. Zone-1 nearest to the stream channel would be a 15-foot zone of undisturbed forest. Zone-2 would be uphill from Zone-1 and would be comprised of managed forest. The last zone, Zone-3, would be used for runoff control and would be made up of vegetation that dispersed or flows and allows for infiltration. Because this is an ideal situation and not very common to see occurring in the highly altered landscape of the Blue Earth River Basin, metrics were assessed using the types of vegetation, rather than the zones. It is important to have a mix of vegetation types to provide soil stability and ground cover.

<u>Low Priority:</u> Quality mix of forbs/grasses/trees.

<u>Moderate Priority:</u> Some mix, but poor quality: mostly trees with few forbs and grasses.

<u>High Priority:</u> Poor mix of vegetation; mainly trees or grasses.

<u>Very High Priority:</u> Poor vegetative mix: row crops or grazed grasses.

F .) Adjacent Land Management:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
F. Adjacent Land Management	Forest or prairie with evidence of partial management	2	Non-managed Forest	4	Conventional grazing with the potential for rotational grazing	6	Intensively managed (row crop)	8

The adjacent land use is extremely important in determining the priority of a site. This metric was based on the, "General Guidelines for the Management of Riparian Buffer Stripes (Welsch, 1991)".Taking the adjacent land-use into consideration is central in determining what is needed to create a healthy riparian area.

Low Priority: If the land adjacent to the stream is a forest or prairie that has evidence of management, then assign this ranking. This would be a low priority, because this type of land use is conducive to a healthy stream site.

Moderate Priority: A non-managed forest would be assigned this ranking, because if there is no management, then there would be less understory available to reduce overland flow.

High Priority: Conventional grazing would be given a high priority, because grazing decreases infiltration and root strength and increases runoff. If there is a possibility of rotational grazing, that can improve the riparian area immensely.

Very High Priority: If the site is cropped up to the edge of the stream, this is a very high priority, because there is a lot of compaction, runoff and decreased litter.

G.) Stage of Channel Evolution Model:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
G. Stage of Channel Evolution Model	Type I: Pre-adjustment Or Type V: New Dynamic Equilibrium	2	Type II (Incising and/ or bank failure)	4	Type III (Incising and/or bank failure	6	Type IV: Re-stabilizing	8

The Channel Evolution Model (CEM) was created in 1984 by Schumm et al. to provide a guide for studying the stability of alluvial channels (Brooks, et al., 2003). Stream channels naturally migrate over time; however, man-made alterations to a watershed can cause stream channels to become unstable and degrade at an unnatural rate. If a restoration was done at a site that was in the middle of the CEM, it would require a much larger project to change the stream channel geometry than a site that was near the end of the CEM. The following is a modified CEM created in the MPCA's Guidance Manual for Assessing Geomorphic Condition and Stability and was used to determine the CEM stage at each stream site.

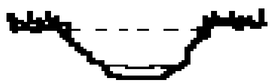
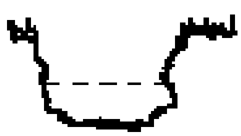
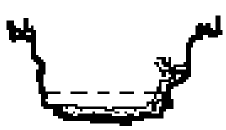
	**I. Pre-adjustment** – Channel exhibits little evidence of excessive bank erosion and cutting. For sinuous alluvial streams, the outside bends demonstrate some bank erosion and the inside bends some deposition; however, the degree of bank erosion and deposition remains in balance. The stream may demonstrate signs of lateral migration, but the degree of sinuosity and channel width remains relatively constant over time.
	**II. Degradation/incision/downcutting** – The process of incision may be instigated by many factors, including, but not limited to: a change in stream gradient due to mechanical channelization, bridge alignment, baselevel lowering of a main channel that causes knickpoint migration in tributaries and ravines, a change in the magnitude, duration, and frequency of high flows either due to a change in climate or anthropogenic change in watershed hydrology. As a knickpoint progresses upstream the bed incises and eventually the channel may disconnect from its floodplain. This results in a larger cross-section, where higher flows are now confined within the channel walls thereby increasing discharge and the potential for flow forces to dislodge bed and banks materials. Evidence of incision may include excessive bed scouring, steeper banks, and bank erosion along both the inside and outside bends. Note: Degradation may not be observed when coarse substrates are armoring the channel bottom. In this case, channel widening will be the dominant process (see CEM stage III below).
	**III. Widening and aggradation** – Banks have steepened to the point where they destabilize and collapse. This results in a wider cross-section with slower water velocities that allow suspended sediments to settle on the channel bottom. Evidence of widening may include trees observed leaning into the stream from one or both sides of the channel, midpoint bars, undercut banks as flows now erode banks below the rootline as a consequence of the deeper channel profile, grass matts or trees that have recently fallen into the stream, and reduced pool depth due to excess aggradation.
	**IV. Re-stabilizing** - During this stage, the stream may display evidence of the build up of sand bars along the inside bend thereby directing flows to the outside bend where the concentrated flow is now able to scour aggraded sediment. Consequently, a narrower, deeper channel (a thalweg) begins to form within the overwidened cross-section. During this transitional phase, some degree of cutting and bank collapse may still be observed along the outside bend as flows are directed against the channel wall (Thorne 1999).
	**V. New dynamic equilibrium** – Thalweg reformed, banks stable, and sand bars revegetated. Smaller floodplain within active channel.

Figure 3.2.1 Channel Evolution Stage from the following MPCA Guidance Manual for Assessing Geomorphic Condition and Stability

Low Priority: A Stage I or stable channel would be given a low priority ranking. A Stage V would also be a low priority, because the channel has already reached a new equillibrium

Moderate Priority: Assign this rank if the channel is a Stage II

High Priority: Assign this rank if the channel is a Stage III

Very High Priority: Assign a high priority if the channel is a Stage IV

H. Dominant Streambank Material

	Low Priority		Moderate Priority		High Priority		Very High Priority	
H. Dominant Streambank Material (That if eroded would contribute to turbidity and phosphorus in stream)	Loamy Sand	2	Cohesive Soil Mix	4	Silts	6	Silty Clay/Clay	8

In the Blue Earth River Basin, many streams are impaired for water quality. The impairments are a result of excess sediment, phosphorus, and nitrogen. When streamsbanks and bluffs erode, they can carry high amounts of nutrients into the waterbody. The amount of phosphorus varies widely by soil type. For example, clays are prone to carry much higher levels of phosphorus than sands. Different soil types also affect the level of turbidity.

Some soil particles can settle out much more quickly and do not remain suspended in the water column for a long period of time. Therefore, this metric assess the dominant streambank material that if eroded, would contribute high amounts of phosphorus and increase turbidity levels.

Low Priority: Loamy Sand.

Moderate Priority: Cohesive Soil Mix.

High Priority: Silts.

Very High Priority: Silty Clay/Clay.

I.) Instability Threatening Infrastructure or Loss of Land to Landowners:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
I. Instability Threatening Infrastructure or Loss of Land to Landowners	None present or Unlikely	0	Potentially; in a 5 or more years	4	Likely; in 1 year or less	8	Imminent; Already occurring or will occur within a year	12

An eroding stream can cause landowners to lose a substantial amount of land and can also threaten infrastructure, such as bridges, culverts, or homes, which can be dangerous and expensive if not dealt with. Therefore, a site would have a very high priority if the erosion occurring was threatening infrastructure or loss of land. When assessing this metric, look at the adjacent land use to determine what is near the eroding portion of the stream. It is important to compare the rate of erosion, with aerial imagery to determine how far the bank is retreating each year.

Low Priority: Stream is stable and not actively eroding. Stream could be eroding, but is not near any infrastructure, farm fields, or other property that would result in a loss of property value or structures.

Moderate Priority: Stream is eroding at a rate that is not going to cause damage to any property or infrastructure in the near future.

High Priority: Stream is actively eroding and will likely result in a high loss of profitable land or infrastructure within the next year.

Very High Priority: Damage due to erosion is imminent or already occurring. Especially important if infrastructure, such as a road, bridge or home is threatened.

Section Two: Variables affecting Cost to Restore:

Cost is the second section in the Stream Restoration Prioritization Score Sheet. It is extremely important to determine the metrics associated with this section because some restoration projects can be in the hundreds of thousands of dollars and are less likely to be carried out.

J.) Length of Eroding Streambank:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
J. Length of Eroding Streambank	More than 1000 Ft	0	500-1000Ft	4	100-500 Ft	8	Less than 100 Ft	12

The length of streambank needing to be restored is very important in predicting the cost of the project. A paper by Smith (2012), titled, "Stream Restoration Costs," analyzed data from over 300 stream restoration projects conducted in Minnesota. One of the variables that was used to determine the cost of the project was stream length. Over 350 past restoration projects were analyzed in the Smith (2012) paper and those lengths were used to determine these metric values.

Low Priority: Measure the stream length that is actively eroding at a site. A site with an length of more than 1,000 feet would be given this ranking.

Moderate Priority: If the streambank length needing restoration is 500-1000 feet assign this ranking.

High Priority: A bank length of 100-500 feet should be given this ranking.

Very High Priority: If the length is less than 100 feet, this would be given the ranking of Very High, because it is likely to be the cheapest to restore.

K.) **Amount of Wood, Woody Debris or Large Rock Available for Stabilization:**

	Low Priority		Moderate Priority		High Priority		Very High Priority	
K. Amount of Wood, Woody Debris or Large Rock Available for Restoration (See SRPSS Guidance Manual)	None Present	2	Few (1-3) Large Trees/Woody debris or rock present in-stream or in Riparian area.	4	Several (3-5) Trees/Woody debris or rock present in-stream or in Riparian area	6	Many (>5) Trees/Woody debris or rock present in-stream or in Riparian area	8

Wood and Woody debris can be very beneficial to a stream ecosystem by providing habitat and food for organisms. However, if too much wood or woody debris accumulates due to natural or unnatural causes, it can result in, "Flow deflection and debris jams that direct erosive flows into banks thereby further destabilizing the channel (MPCA, 2012)." Many times this woody debris can be used for stream restoration projects, such as log vanes or root wads. Review the stream site (In-stream or in the riparian area) and determine how much wood/woody debris is present that could be used for restoration projects. Generally the trees must be large enough to be able to be embedded in the bank and extend far enough out into the stream to deflect flow away from the eroding bank (A good sized tree is at least 12 inches in diameter and 25 feet in length). Also review the amount of boulders that could be used for bank stabilization. **Note: Do not include wood, woody debris, or rock that is firmly embedded in the bank and is contributing to bank stability!**

Low Priority: If there isn't any woody debris present, use this rating.

Moderate Priority: Few (1-3) Large Trees/Woody debris or rock present in-stream or in Riparian area.

High Priority: Several (3-5) Trees/Woody debris or rock present in-stream or in Riparian area.

Very High Priority: Many (>5) Trees/Woody debris or rock present in-stream or in Riparian area.

L.) Site Accessibility:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
L. Site Accessibility (Distance and Terrain)	None; no access by vehicle. Dense woods and/or difficult terrain	0	Somewhat; more than .5 mile to access and/or somewhat difficult terrain, while still being accessible	4	Mostly; less than .5 mile to access, easy terrain	8	Very, adjacent to road or field that can be easily accessed by a vehicle	12

The accessibility of a site makes a huge difference on how expensive it will be to restore. Therefore, this metric reviews the accessibility of a site.

Locate where the site is and determine what the adjacent land use is and where it is in relation to an access point.

Low Priority: No access by vehicle. Site is located in a very remote location that is in dense woods and large equipment would be unable to get there.

Moderate Priority: Location is somewhat remote (more than .5 mile to access) and somewhat difficult to access.

High Priority: Site is less than .5 miles to reach and is fairly easily accessible (No dense woods or other obstacles).

Very High Priority: Site is very accessible. It is adjacent to a road or field that can be accessed by a vehicle or large equipment.

M. Sod/ Willow Mat Availability:

	Low Priority		Moderate Priority		High Priority		Very High Priority	
M. Sod/ Willow Mat Availability	None present on landowner's property or available but poor quality because of grazing or >1mile away or not easily accessible. (or if readily available would cause significant disturbance if harvested)	0	On site and good quality: between 2000-5000 feet away and accessible by vehicle (Won't cause significant disturbance if harvested)	2	On-site and good quality: between 1000-2000 feet away and accessible by vehicle (Won't cause significant disturbance if harvested)	6	On-site and good quality: <1000 feet away and easily accessible by vehicle (Won't cause significant disturbance if harvested)	8

Many stream restoration projects require the application of organic material to protect an eroding bank. One tool is to use sod mats or Willows to stabilize an eroding bank. It is much more cost effective to have these materials on site and close-by. It is important to note that if sod mats or Willows are utilized that their use does not cause further harm if they are harvested.

> Low Priority: None present on landowner's property or available but poor quality because of grazing or >1mile away or not easily accessible. (Or if readily available would cause significant disturbance if harvested)
>
> Moderate Priority: On site and good quality: between 2000-5000 feet away and accessible by vehicle (Won't cause significant disturbance if harvested)
>
> High Priority: On-site and good quality: between 1000-2000 feet away and accessible by vehicle (Won't cause significant disturbance if harvested)
>
> Very High Priority: On-site and good quality: <1000 feet away and easily accessible by vehicle (Won't cause significant disturbance if harvested)

4. Testing the Stream Restoration Decision Support Tool: A Case Study:

After creating the Stream Restoration Decision Support Tool, it was important to test it to determine if it not only is repeatable, but if it also prioritizes the sites in a way that also allows agencies and other stakeholders to concentrate their efforts on areas with high erosion while also taking into account site conditions and other financial considerations. This case study of the decision support tool involves a total of 30 sites on 2 tributaries to the Blue Earth River to determine which sites have the highest priority for restoration. The repeatability of the tool was also tested by 15 researchers from the University of Minnesota.

4.1 Site Locations

4.1.1 Site 1: Elm Creek Basin: Background and Description

A total of 30 sites were selected on 2 tributaries to the Blue Earth River to field test the Decision Support Tool and determine which sites have the highest priority for restoration. The first stream, Elm Creek, is located in the Elm Creek Sub-Watershed of the Blue Earth River Basin, and runs through Martin and Jackson counties. “Elm Creek has one of the highest concentrations of suspended sediment (flow-weighted mean of 193 mg/l) of any tributary of the BER (Lenhart, 2008).” The ECB encompasses 700 square kilometres, with land-use being made up of 86% corn and soybean agriculture (Brooks et al., 2008). Historically, the area was made up of a prairie pothole landscape, with more than 30% of its area covered in wetlands and lakes (Lenhart, 2008; Quade, 2000; Meschke and Perrine, 2006). There are 165 miles of public drainage systems in the ECB and currently, only 2% of the ECB is made up of wetlands (Lenhart et Al., 2010, Leach and Magner, 1992; Quade 2000). This decrease in wetland storage has led to an increase in runoff and sediment delivery to Elm Creek. According to a study by Quade (2000) there is a potential to restore approximately 19,057 acres (32.2 percent) of the land in this sub-watershed to wetlands. Elm Creek also has a weighted stream gradient of approximately 3.2 ft/mile (Quade, 2000).

4.1.2 Site 2: Center Creek Basin: Background and Description

The second study site for this project is Center Creek, located in the Center Creek Sub-Watershed (CCB) of the BERB. The CCB is made-up of 121 square kilometers, and runs through the cities of Fairmont and Granada (Quade, 2000). The main land use in the CCB is agricultural cropland (76.5%), with corn and soybean rotation representing the main cropping type (Quade, 2000). With 77 miles of public drainage installed to increase crop production, only 4.1 percent of the wetlands remain in the CCB (Quade, 2000). The weighted stream gradient from Lily Creek to Center Creek is approximately 3.7 ft/mile in this sub watershed (Quade, 2000).

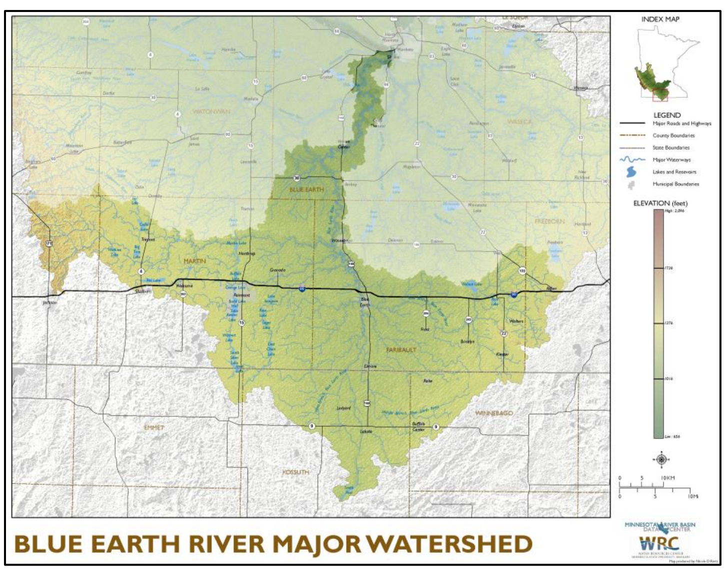


Figure 4.1.2: The Blue Earth River Basin (BERB) located in South-Central Minnesota. Map courtesy of MRB Data Center

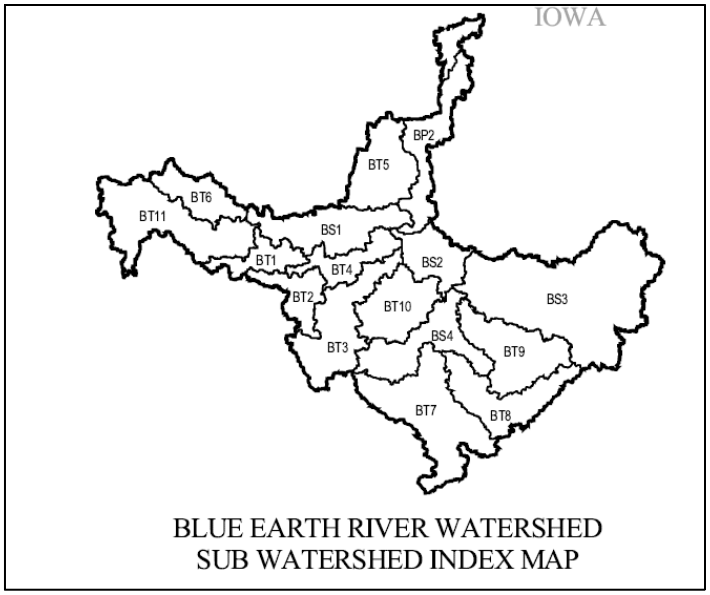


Figure 4.1.2a Center Creek Sub-Watershed is BT4. Elm Creek Sub-Watershed is BS1 Image Courtesy of Quade, 2000.

4.2 Step 1 in the Stream Restoration Prioritization Decision Support Tool: Site Selection: Methods and Criteria

The first step in the Stream Restoration Prioritization Decision Support Tool is to first locate sites with active erosion. In selection of potential restoration sites, it was important to work with the Martin County Soil and Water Conservation District (SWCD) and the Department of Transportation (DOT) to determine if there were any bridges, roads, or other infrastructure in danger due to stream bank/ bluff erosion. These were important to assess due to the high threat of economic damage.

Because the study creeks are relatively small, it was decided that a field reconnaissance of the stream via kayak would be conducted. This was done in October of 2010 to find locations threatening infrastructure and/or sites that are contributing sediment due high amount of bank/bluff erosion.

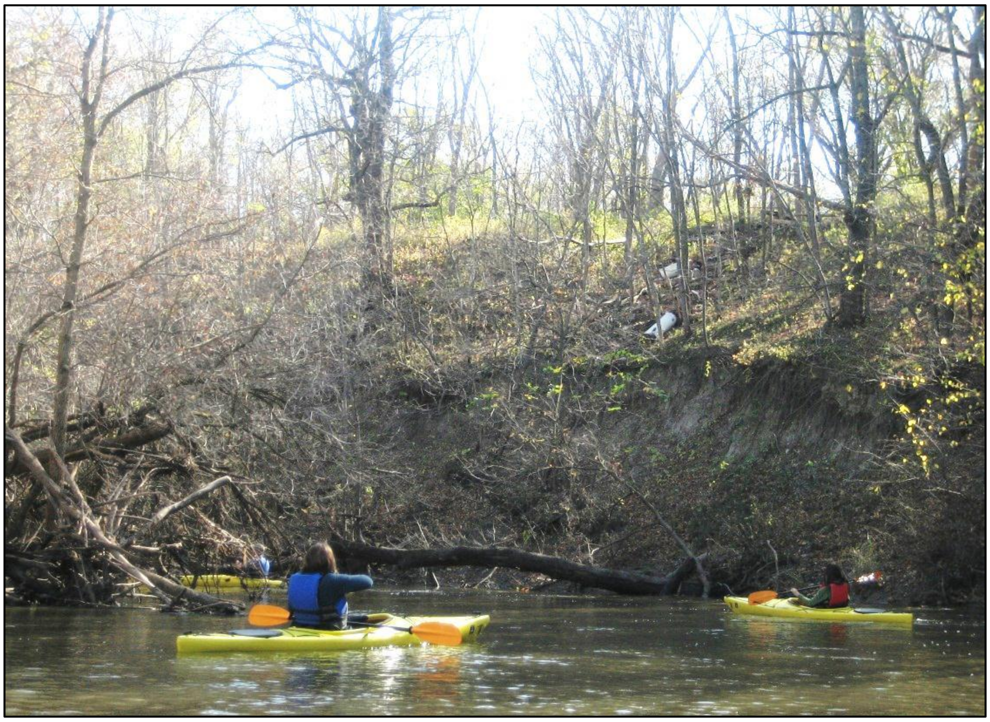


Figure 4.2: Kayak Reconnaissance to find sites with visual active erosion. Elm Creek, Fall, 2011. Photo by M. Presnail.

However, because of the high flow and numerous log jams, this was not a very safe or time effective method. Therefore, aerial photos on Google Earth™ were used to find sites that appeared to be eroding near roads, bridges or houses. Sites with high radii of curvature were also chosen, because this is generally an indication of high bank stress and erosion. Other potential sites were chosen in forested portion of the stream, where high amounts of channel blockage are likely. Locations were also chosen based on accessibility.

If the site was on private property, the land-owner was found using the Martin County Website, which lists landowner information and a letter was written requesting permission to go on their land and to see if they would be interested in participating in the study. Once potential sites were found, a list was comprised of site identification, coordinates, land-owner information, and the reason for site selection. In the end, a total of 30 sites were selected for this study. In this case, erosion rates were not calculated using LiDAR, since an in-depth estimate was going to take place.

4.3: Step 2 in the Stream Restoration Prioritization Decision Support Tool: On-site in-depth analysis and prioritization:

The next step was to do an on-site in-depth analysis using certain watershed assessment tools. In this project, the field watershed assessments used are the Bank Erosion Hazard Index (BEHI), the Near Bank Stress (NBS), and Modified Pfankuch (MPf) for Low to Mid-Gradient Streams. The purpose of these assessments are to evaluate the stability of the streambanks and help determine the amount of erosion occurring. The amount of erosion and the Modified Pfankuch scores will also be used as metrics in the Stream Restoration Prioritization Score Sheet (SRPSS).

The 30 field sites selected were visited between September 2011 and November 2011, during conditions of low-flow, where the majority of the streambanks were exposed. The field watershed assessments used in this project are the Bank Erosion Hazard Index (BEHI), the Near Bank Stress (NBS), and Modified Pfankuch (MPf) for Low to Mid-Gradient Streams, and the Channel Evolution Model (CEM). Data was entered on field forms and later entered into an Excel spreadsheet. Photo documentation, channel drawings, written comments and observations were also recorded at each site. The information collected at these sites will also be used to rank certain metrics in the Stream Restoration Prioritization Score Sheet.

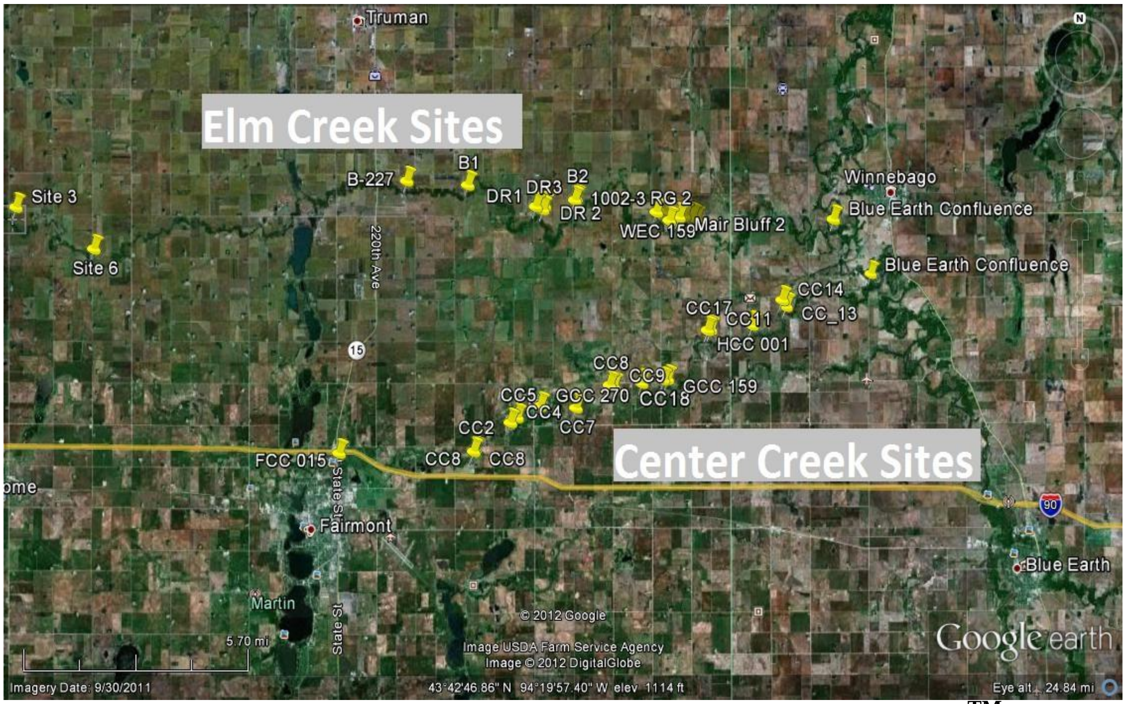


Image 4.3 Site Locations on Elm and Center Creeks using Google Earth™.

4.3.1 Stream Channel Stability Assessments

Watershed assessments provide information necessary to identify and prioritize restoration actions (Beechie et al., 2008). It is important to determine where erosion is occurring and the extent. The assessment should also determine what restoration actions would be necessary to meet the goal of sediment reduction. Watershed assessments should also determine what restoration projects would have the most impact and any restraints (economic, land-use, etc) to the projects (Beechie et al., 2008). In order to reduce the amount of sediment entering the Blue Earth River, it is important to identify stream reaches that are experiencing high streambank instability. Using qualitative and quantitative streambank stability assessments are useful in determining the state of stability of a streambank or stream reach (Suppes, 2009). The stability assessments were also done to collect information that will be used in the Stream Restoration Prioritization Score Sheet, which is part of this Decision Support Tool.

4.3.2 Modified Pfankuch Stability Index for Low-Gradient Streams (MPf)

The Modified Pfankuch Stability Assessment (MPf) was modified from the Original Pfankuch Stablitity Index (OPf), which was developed in 1975 for use in mountainous streams in the western United States. The modified field form was developed by Asmus and Magner in 2008 to, “More accurately characterize geomorphic condition and channel stability in low to mid-gradient alluvial streams in the Midwest (Asmus and Magner, 2008).” The assessment has 14 metrics used to assess the stability of the upper banks, lower banks and channel bottom. The assessment is based on visual observations, not physical measurements. Therefore, it is essential that the assessor have some training in fluvial geomorphology (Suppes, 2009). Once each metric is scored, the scores are summed to give an overall stability score and rating. Ratings range from Poor, Fair, Good, Excellent. MPf field form used in this study is shown in Appendix A.

4.3.3 The Bank Assessment for Non-Point Source of Consequences of Sediment (BANCS)

The Bank Assessment for Non-Point source Consequences of Sediment or BANCS model is used to evaluate streambank and channel changes to predict annual streambank erosion rates (Rosgen, 2008). The BANCS model uses two bank erosion estimation tools: The Bank Erosion Hazard Index (BEHI) and the Near-Bank Stress (NBS), both of which were used in this study.

4.3.4 Bank Erosion Hazard Index (BEHI)

The Bank Erosion Hazard Index or (BEHI) evaluates how susceptible a streambank is to erosion and integrates multiple metrics, including study bank height, bankfull height, root depth, root density, bank angle, and surface protection. Each of these metrics is then converted to a rating (Very Low-Extreme), which have values between 0 and 10. The BEHI scores are then added together and adjusted for bank material and stratification. This gives you an overall BEHI risk rating (Rosgen, 2008). The BEHI was created to quickly assess streambanks using visual observations. The user trains his or her eye to assess each of the metrics. Therefore, in order to make observations as consistent as possible for this study, all sites were assessed by the same observer. In addition, certain variables, such as rooting depth, bank height, bankfull height and bank angle were physically measured. Field forms used for this study and BEHI results can be found in the Appendix.

Image 4.3.4 Researchers gathering measurements. Photo by M. Presnail, Fall, 2011.

The following flow chart developed by Rosgen, helps to show the process to determine the Bank Erosion Hazard Index on a site:

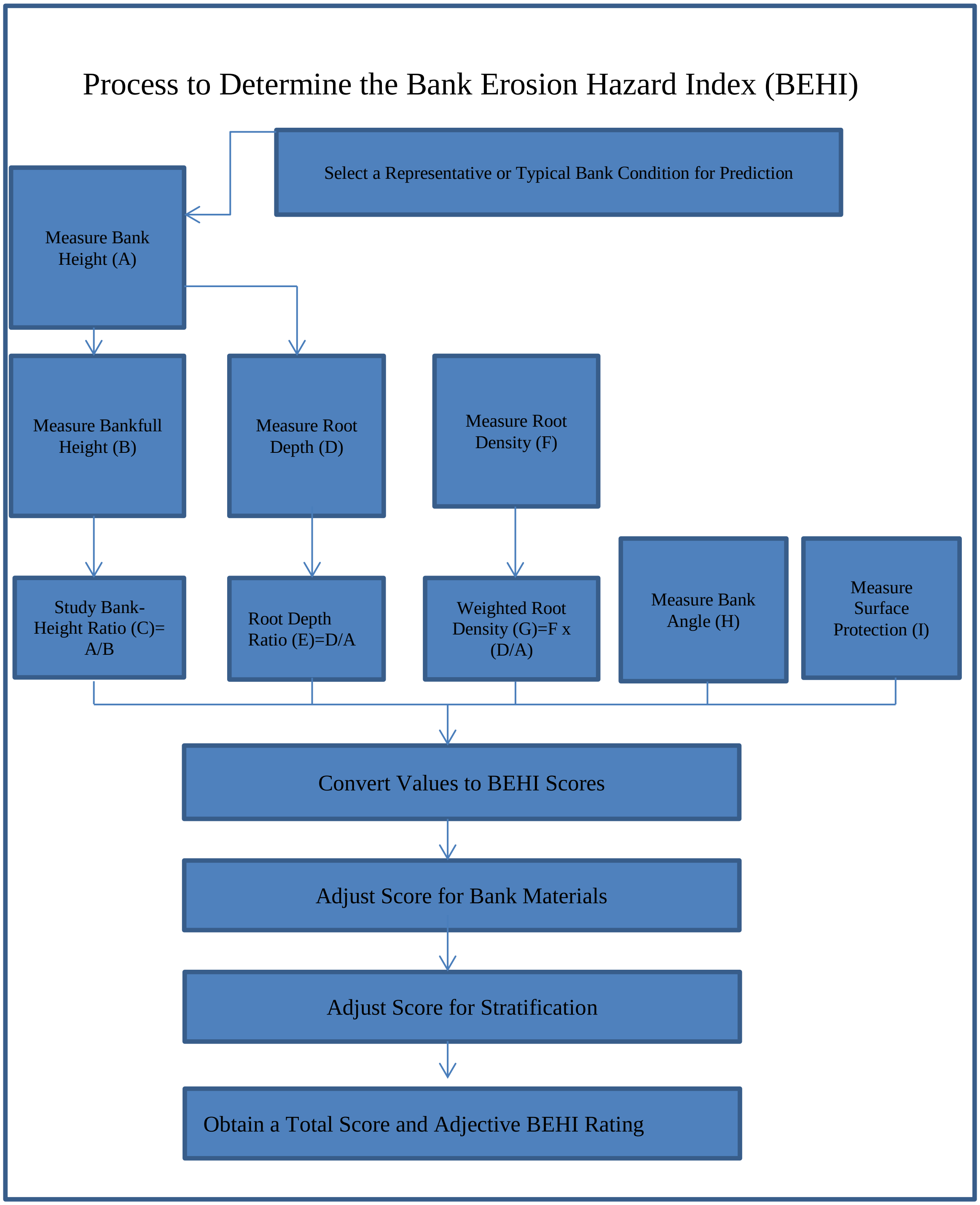


Figure 4.3.4 Flowchart depicting the BEHI Process. Figure by Rosgen, 2008, recreated by M. Presnail.

4.3.5 Near-Bank Sheer Stress

To predict annual erosion rates using the BANCS model, a Near-Bank Stress assessment must be included to determine the amount of energy distributed against the streambanks (Rosgen, 2008). One of seven methods can be used to determine an NBS rating (From Rosgen, 2008):

1. Channel pattern, transverse bar or split channel/central bar creating NBS or high velocity gradient
2. Ratio of radius of curvature to bankfull width
3. Ratio of pool slope to average water surface slope
4. Ratio of Pool slope to riffle slope
5. Ratio of near-bank maximum depth to bankfull mean depth
6. Ratio of near-bank shear stress to bankfull shear stress
7. Velocity of profiles/isovels/velocity gradient

In this project, latitudinal and longitudinal surveys were not conducted; therefore, many methods are unable to be used. However, because the bankfull width was measured at each site, Method 2 was generally used, with the radius of curvature being found from aerial images. Method 1 was also used if field observations showed, “Features that create a disproportionate energy distribution in the near bank region. (Rosgen, 2008).” Once an NBS score was found, it was then converted to a NBS rating (Very Low, Low, Moderate, High, Very High, and Extreme). The

NBS field form used for this study and NBS results can be found in the Appendix.

4.3.6 Total Bank Erosion Calculation

Once the BEHI and NBS ratings are calculated they are used with the BANCS model to derive annual streambank erosion rates. The 2 different relationships for these rates are derived for streams found in sedimentary and/or metamorphic geology, or for streams found in alpine glaciation and/or volcanic areas (Rosgen, 2008). A regional curve specifically created for low-mid gradient alluvial streams has not been created (but is in the process by UMN researchers), so the relationship for sedimentary geology was used to estimate erosion rates in this study. It is important to note, however, that erosion rates on the Lower Elm Creek were calculated by Lenhart (2008) and exceeded the BANCS estimates by 2-3 times. This is because the Lower Elm is an alluvial channel, comprised of sandy – loamy materials, which are easily transported compared to rock lined channels in Colorado or Yellowstone (Lenhart, email correspondence, 2012). For this study, the BANCS curve was still used to estimate the amount of erosion. It is also important to consider that the same method was used on all the sites, thus they will all be equally underrepresented. Once the new regional curve is developed for low to mid-gradient alluvial streams, then future estimates will be more accurate. The form showing the relationship of BEHI and NBS to predict annual streambank erosion rates for streams found in sedimentary geology is shown in Appendix B.

4.3.7 Stream Restoration Prioritization Score Sheet

Once the watershed assessments were complete, the next step was to fill out the, "Stream Restoration Prioritization Score Sheet." As stated in Chapter 3, this score sheet uses 13 metrics that will help to prioritize the need, ease and cost for restoration. The "Guidance Manual for the Stream Restoration Prioritization Score Sheet" was used as a step by step guide to determine score sheet rankings. See score sheet results in Chapter 5 Results and Discussion.

Image: 4.3.7 Researchers filling out the SRPSS on a site on Elm Creek. Photo by M. Presnail, Fall, 2012.

5. Results and Discussion

5.1 Statistical Analysis:

Since the goal of the project is to reduce sediment loading to the Blue Earth River in a productive, cost-effective way, it is important to determine if the amount of erosion is similar if sites are prioritize used the SRPSS or by erosion amounts alone . It is also imperative that the decision support tool be repeatable by different researchers. Statistical analysis was used to test research questions that include whether or not the SRPSS is repeatable, and if there is a correlation between erosion amounts based on different prioritizations methods.

5.1.1 Testing Correlation Between Prioritization Method and Amount of Erosion:

The first research question in this project is: Will sites ranked as having high priority for restoration in the Stream Restoration Prioritization Score Sheet have similar erosion rates if sites were prioritized by erosion amounts alone? To test this question, the 30 sites visited were prioritized based on 2 methods. Method 1 is prioritizing based on the amount of erosion and Method 2 is prioritizing using the Stream Restoration Prioritization Score Sheet. The mean erosion amounts at each of the top 10 sites using these different methods were compared using a paired T-test to test the following hypothesis:

H_0: $\bar{x}$ method 1erosion amounts = $\bar{x}$ method 2 erosion amounts
H_a: $\bar{x}$ method 1 erosion amounts $\neq$ $\bar{x}$ method 2 erosion amounts

Using the statistical program R, a paired T-test was conducted to determine whether or not the null hypothesis would be rejected. See code below:

```
> mean(dat)
Erosion.Method   SRPSS.Method
       9482.9        5835.0
> sd(dat)
Erosion.Method   SRPSS.Method
    13448.006      9930.857
>  t=9482.95835.0/sqrt(1344/.006^2/10+9930.857^2/10)
> t
[1] 9481.318
> 2*pt(T,df=10-1)
[1] 1.656564
```

Figure 5.1.1: R-output from paired T-test for erosion amounts using 2 methods of prioritization.

With such a large P-value, we do not reject the null hypothesis that the means are different. This shows that the means are similar enough between different methods and that using the score sheet will give you similar erosion amounts in the highest scored sites as if prioritized based on erosion alone.

5.1.2 Comparison of SRPSS Scores from Different Field Assessors

The second research question in this project is: Will the Stream Restoration Prioritization Score Sheet be repeatable by different researchers? To test this question, a single user used the SRPSS at 4 different sites and had 15 other researchers fill out the SRPSS at the same 4 sites. The mean scores at each site were compared using a paired T-test to test the following hypothesis:

H_0: $\bar{x}$ single user = $\bar{x}$ multiple users

H_a: $\bar{x}$ single user $\neq$ $\bar{x}$ multiple users

Using the statistical program R, a paired T-test was conducted to determine whether or not the null hypothesis would be rejected.

```
> mean(dat)
Single Multiple
93.73333 91.06667
> sd(dat)
Single Multiple
1.830951 7.850993
> t=93.733-91.066/sqrt(1.830^2/15+7.85^2/15)
> t
[1] 49.97668
2*pt(T, df=15-1)
[1] 1.755531
```

Figure 5.1.2: R-output from paired T-test for SRPSS repeatability assessment.

With such a large P-value, we do not reject the null hypothesis that the means are different. This shows that the means are similar enough between different users and that the score sheet is repeatable.

One important point to note is that Metric A was changed after this repeatability test was done. Metric A at the time was Landowner Willingness to Participate. It has since been changed to “Amount of Erosion.” However, the BANCS method was used to calculate erosion in this decision support tool and has been tested for repeatability by other researchers.

6. Stream Restoration Prioritization Score Sheet Results and Recommendations:

6.1 SRPSS Results and Discussion:

The Stream Restoration Prioritization Score Sheet (SRPSS) was created for this project and field tested on 30 sites to be used to prioritize restoration on two tributaries to the Blue Earth; Elm and Center Creek. The data was entered into the following Excel spreadsheets:

Center Creek SRPSS Results:

	CC2	CC4	CC5	CC7	CC8	CC9	CC10	CC11	CC12	CC13	CC14	CC17	CC18	FCC 015	GCC270
Erosion Amounts	0	8	12	12	4	4	4	12	4	8	12	4	12	0	8
MPF	4	8	6	6	4	8	8	8	6	6	6	8	8	6	8
Water Storage	2	6	4	2	2	2	2	0	4	6	0	0	0	0	0
Buffer width	4	8	6	8	8	2	8	4	8	8	2	2	4	8	2
Buffer Vegetation	2	8	6	8	8	6	8	4	8	8	8	4	6	8	4
Adjacent Land Mgmt	0	8	4	8	8	4	6	4	8	6	8	4	4	6	4
CEM stage	6	4	4	4	4	4	4	4	4	4	4	4	4	6	4
Streambank Material	8	8	2	2	2	8	8	2	2	2	2	2	2	2	8
Instability Threat	0	4	0	12	0	0	0	4	4	12	4	0	0	0	0
Length of eroding streambank	8	8	8	4	4	8	8	4	4	4	4	4	4	4	4
amt of woody debris	8	8	8	4	8	8	8	8	8	8	8	8	8	0	8
site accessibility	8	12	8	12	8	4	12	8	12	12	12	4	12	12	8
sod/willow mat availability	8	0	0	0	0	6	0	0	0	0	0	0	0	0	0
Total Score	58	90	68	82	60	64	76	62	72	84	70	44	64	52	58

Table 6.1 Center Creek SRPSS Results

Elm Creek SRPSS Results:

	Site 3	REC-06	1002-3	RG1	RG2	DR1	DR2	DR3	B-227	B1	WEC-159	Mair 1	Mair Bluff	Mair Bluff 2	HEC-300
Erosion Amounts	0	4	8	12	12	4	8	12	12	8	0	0	12	8	4
MPF	8	8	8	8	8	8	8	8	8	8	6	6	8	8	8
Water Storage	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Buffer width	4	2	8	8	8	2	8	8	6	2	4	8	8	8	8
Buffer Vegetation	6	6	8	8	8	6	8	8	6	4	6	6	8	8	6
Adjacent Land Mgmt	4	4	6	8	8	4	8	8	4	4	0	0	6	6	6
CEM stage	6	4	4	4	4	4	6	6	4	4	6	6	4	4	4
Streambank Material	2	6	2	2	6	6	4	6	2	2	6	6	4	2	6
Instability Threat	0	0	12	12	4	4	12	12	12	4	0	0	8	4	4
Length of eroding streambank	4	0	4	4	4	4	8	12	8	4	4	12	8	8	12
amt of woody debris	8	8	8	8	8	8	6	8	8	8	6	4	8	4	8
site accessibility	8	8	12	12	12	12	8	8	12	12	12	12	8	8	12
sod/willow mat availability	0	0	0	2	2	6	2	8	6	8	8	6	0	2	2
Total Score	52	52	82	90	86	70	88	106	90	70	60	68	84	72	82

Table 6.1(a) Elm Creek SRPSS Results

Once all the information from the SRPSS was entered into the Excel Spreadsheet, the next step was to enter each of the sites and the subsequent SRPSS scores, and then rank them from largest to smallest. The following table is the prioritized list of all 30 stream sites that were assessed. The highest priority will be a 1 and the lowest priority will be a 30.

Stream	Site ID	SRPSS Score	Priority Ranking
Elm	DR3	106	1
Elm	RG1	90	2
Elm	B-227	90	3
Center	CC4	90	4
Elm	DR2	88	5
Elm	RG2	86	6
Elm	Mair Bluff	84	7
Center	CC13	84	8
Elm	1002-3	82	9
Elm	HEC-300	82	10
Center	CC7	82	11
Center	CC10	76	12
Elm	Mair Bluff 2	72	13
Center	CC12	72	14
Elm	DR1	70	15
Elm	B1	70	16
Center	CC14	70	17
Elm	Mair 1	68	18
Center	CC5	68	19
Center	CC9	64	20
Center	CC18	64	21
Center	CC11	62	22
Elm	WEC-159	60	23
Center	CC8	60	24
Center	CC2	58	25
Center	GCC270	58	26
Elm	Site 3	52	27
Elm	REC-06	52	28
Center	FCC 015	52	29
Center	CC17	44	30

Table 6.1(b) Stream Restoration Prioritization Score Sheet results and rankings

7. Study Conclusions

The purpose of this project was to reduce sediment loading to the Blue Earth River Basin by reducing streambank and bluff erosion. A decision support tool was created to prioritize the eroding sites. The tool was field tested on two tributaries to the Blue Earth; Elm and Center Creek. The field test of the tool helped choose potential restoration locations based on different ranked metrics.

After testing 2 different prioritization methods, the tool was found to have similar erosion rates compared to prioritizing by erosion rates alone. The repeatability of the tool was also tested and found to have similar scores from different researchers.

The information on the sites with the highest priorities will now be given to local officials to determine the appropriate restoration actions for each site. Hopefully, this tool can then be used throughout the BERB to help prioritize restoration throughout.

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9. Appendix

Appendix A: List of Field Sites and Locations

The following is a list of the 30 sites visited during this project. The list includes Site ID, Coordinates, the date the site was evaluated, the watershed, and which side of the bank the site is on (looking downstream).

Site ID	Latitude	Longitude	Date Evaluated	Watershed	Left or Right Bank
CC2	43°40'30.19"N	94°22'47.06"W	8/25/2011	Center Creek	R
CC4	43°41'4.25"N	94°21'41.39"W	8/25/2011	Center Creek	L
CC5	43°41'10.68"N	94°21'29.26"W	8/25/2011	Center Creek	L
CC7	43°41'22.26"N	94°19'41.39"W	8/25/2011	Center Creek	R
CC8	43°41'50.53"N	94°18'41.80"W	8/25/2011	Center Creek	R
CC9	43°41'49.07"N	94°18'32.56"W	8/25/2011	Center Creek	R
CC10: Sam	43°41'57.73"N	94°16'50.69"W	8/25/2011	Center Creek	L
CC11	43°42'58.92"N	94°15'34.67"W	9/24/2011	Center Creek	L
CC12/HCC	43°43'5.51"N	94°14'16.23"W	9/24/2011	Center Creek	R
CC13	43°43'11.61"N	94°13'26.47"W	9/24/2011	Center Creek	R
CC14	43°43'28.52"N	94°13'19.65"W	9/24/2011	Center Creek	L
CC17	43°42'58.87"N	94°15'39.83"W	9/24/2011	Center Creek	L
CC18	43°41'57.69"N	94°17'0.38"W	9/24/2011	Center Creek	R
FCC 015	43°40'28.07"N	94°26'58.15"W	9/24/2011	Center Creek	L
GCC 270	43°41'26.53"N	94°20'45.79"W	9/24/2011	Center Creek	R
Site 03	43°45'33.33"N	94°36'46.03"W	8/30/2011	Elm Creek	R
REC 06	43°44'41.06"N	94°34'23.25"W	8/30/2011	Elm Creek	L
1002-3	43°45'40.46"N	94°19'42.48"W	10/15/2011	Elm Creek	R
RG 2	43°45'14.78"N	94°16'49.38"W	10/29/2011	Elm Creek	R
RG 1	43°45'24.82"N	94°16'53.37"W	10/29/2011	Elm Creek	L
DR1	43°45'32.03"N	94°20'54.73"W	10/15/2011	Elm Creek	R
DR2	43°45'32.50"N	94°20'37.29"W	10/15/2011	Elm Creek	L
DR3	43°45'29.77"N	94°20'41.11"W	10/15/2011	Elm Creek	R
B-227	43°46'5.50"N	94°24'50.22"W	10/15/2011	Elm Creek	R
B1	43°45'59.59"N	94°22'58.51"W	10/15/2011	Elm Creek	R
WEC 159	43°45'25.24"N	94°17'13.03"W	10/29/2011	Elm Creek	L
Mair 1	43°45'18.99"N	94°16'7.28"W	8/30/2011	Elm Creek	R
Mair Bluff	43°45'20.39"N	94°16'21.63"W	10/29/2011	Elm Creek	R
Mair Bluff	43°45'18.89"N	94°16'31.67"W	10/29/2011	Elm Creek	R
HEC 300	43°45'16.54"N	94°15'59.74"W	10/29/2011	Elm Creek	L

Table A.1 List of Field Site Locations

Appendix B: Field Assessment Forms

B.1. Modified Pfankuch Stability Index for Low-Gradient Streams (MPf)

Below is the field form used for the Modified Pfankuch Stability Index (MPf) for low to mid-gradient streams. This form was modified from the Original Pfankuch Stablitity Index (OPf), which was developed in 1975 for use in mountainous streams in the western United States.

The modified field form below was developed by Asmus and Magner in 2008 to, "More accurately characterize geomorphic condition and channel stability in low to mid-gradient alluvial streams in the Midwest (MPCA, 2008)." The assessment has 14 metrics used to assess the stability of the upper banks, lower banks and channel bottom.

Appendix B.1: Field form of the Modified Pfankuch Stability Assessment for low- gradient streams (MPf) (Asmus and Magner, 2008)

	Metrics	Excellent (38-45)		Good (45-76)		Fair (77-113)		Poor (114-152)	
1. Upper banks	a. Landform slope	Bank slope gradient <30%	2	Bank slope gradient 30-40%	4	Bank slope gradient 40-60%	6	Bank slope gradient 60%+	8
	b. Mass wasting or failure	No evidence of past events of mass wasting into channel	3	Infrequent &/or very small. Mostly healed over	6	Moderate frequency & size, with some raw spots eroded by water during high flows	9	Frequent or large, causing sediment nearly yearlong, bluffs present	12
	c. Riparian debris contribution	Essentially absent from immediate channel area	2	Present but mostly small twigs & limbs	4	Present, volume & size are both increasing	6	Moderate to heavy amounts, predominantly larger sizes	8
	d. Vegetative bank protection	90%+ plant density. Trees or thick grasses dominate; deep roots cover most	3	70-90% density. Fewer trees & deep rooted grasses. Roots 5-10"	6	50-70% density; bare ground visible but spotty. Roots shallow (1.5 –	9	<50% density, bare ground between plants common. Plants or	12

		of upper banks. Roots >10" deep, generally		deep, generally		5") or discontinuous		grasses with very shallow roots (<1.5"), easily pulled	
2. Lower banks	e. Bank-full channel capacity	W/D ratio < 5-9, 1.5-yr RI Peak Flows contained or valley flooded	1	W/D ratio 7-17, little evidence of bank sediment deposition	2	W/D ratio 15-25, evidence of over-bank deposition, roots buried, some midchannel bars	3	W/D ratio >25, channel blow-outs, many or large midchannel bars	4
	f. Bank rock content	65%+ large, angular boulders 12"+. Or, if no boulders observed, bank is made of cemented clay	2	40-65%, mostly small boulders to cobbles 6-12". Dense mixture of clay with some sand & gravel.	4	20-40%, with most in the 3-6" diameter class. Friable mixture of clay & sand, somewhat resistant to crumbling	6	<20% rock fragments of gravel sizes, 1-3" or less. Crumbles easily to the touch when dry	8
	g. Obstruction/ Flow deflectors/ Sediment traps	Rocks & old logs firmly embedded. Flow pattern without cutting or deposition. Pools & riffles stable	2	Some present, causing erosive cross currents and minor pool filling. Obstructions & deflectors newer & less firm	4	Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting & filling of pools	6	Frequent obstructions & deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring	8
	h. Hydraulic, geotech-nical failure, cutting	Infrequent raw banks less than 6" high w/ Little or no evidence of undercutting or seepage	4	Some, intermittently at outcurves & constrictions. Raw banks may be up to 12" or some toe slope erosion	8	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident or GW driven failure	12	Almost continuous raw bank over 24" high to bank top. Clear toe slope erosion	16
	i. Percent of relatively new deposition	If point bars present, no sediment accumulation. No mid-channel bar growth.	4	Some new increase in bar formation. Some evidence of mid-channel deposits. 1-25%	8	Moderate deposition of new sand on old & some new bars. Deposition may be on inside & outside bends. 25-75%	12	Extensive, predominantly fine-grain particles. Accelerated active bar development. >75%	16
3. Bottom	l. Consolid-ation or Particle packing (vertical)	Bed firmly packed. Probe depth 0-1" (0-2.5 cm)	4	Bed moderately packed. Probe depth 1-5" (2.5-13 cm)	8	Loose bed sediment. Probe depth 5-8" (13-20 cm)	12	Unconsolidated actively mobile bed. Probe depth >8" (>20cm)	16
	m. Percent stable materials (horizontal)	High density cohesive (HDC) >80%	3	HDC <80%, but > 50%	7	Wide-ranging mixture	10	Loose uniform sand >80%	13
	n. Water gradient	Extremely low; no apparent water flow at base-flow (0-0.1 ft/s)	1	Very low; water movement slow at base-flow (0.1-0.2 ft/s)	3	Low; water movement slow, but apparent at base-flow (0.2-0.4 ft/s)	6	Moderately low; water movement apparent (>0.4 ft/s)	9
	o. Evidence of bed movement via scouring & deposition.	Less than 5% of the bottom affected by scouring & deposition	6 7	5-30% affected. Scour at constrictions & where grades steepen.	10 12	30-50% affected. Deposits & scour at obstructions, constrictions, & bends. Some infilling of pools	14 17	More than 50% of the bottom is in a state of flux or change. Pools filled with sediment	18 22

	(If p. NA, then increase score for o.)		Some deposition in pools		
	p. Clinging aquatic vegetation (If NA, then increase score for o. as indicated)	Abundant. Algae clinging to material. Rooted plants visible in swifter waters 1	Common. Algal forms in low velocity & pool areas. Some rooted plants swifter waters 2	Present but spotty, or mostly in backwater areas 3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present 4

Appendix B.2: BANCS Model to Predict Streambank Erosion by Rosgen (2006)

The Bank Assessment for Non-Point source Consequences of Sediment or BANCS model is used to evaluate streambank and channel changes and annual erosion changes. The BANCS model uses two bank erosion estimation tools: The Bank Erosion Hazard Index (BEHI) and the Near-Bank Stress (NBS).

Appendix B.3 Bank Erosion Hazard Index (BEHI) by Rosgen (2006)

The following field form is used to record BEHI variables used for the erosion prediction model. All the variables in this experiment were measured directly, not estimated. Appendix B.2 courtesy of Rosgen (2008).

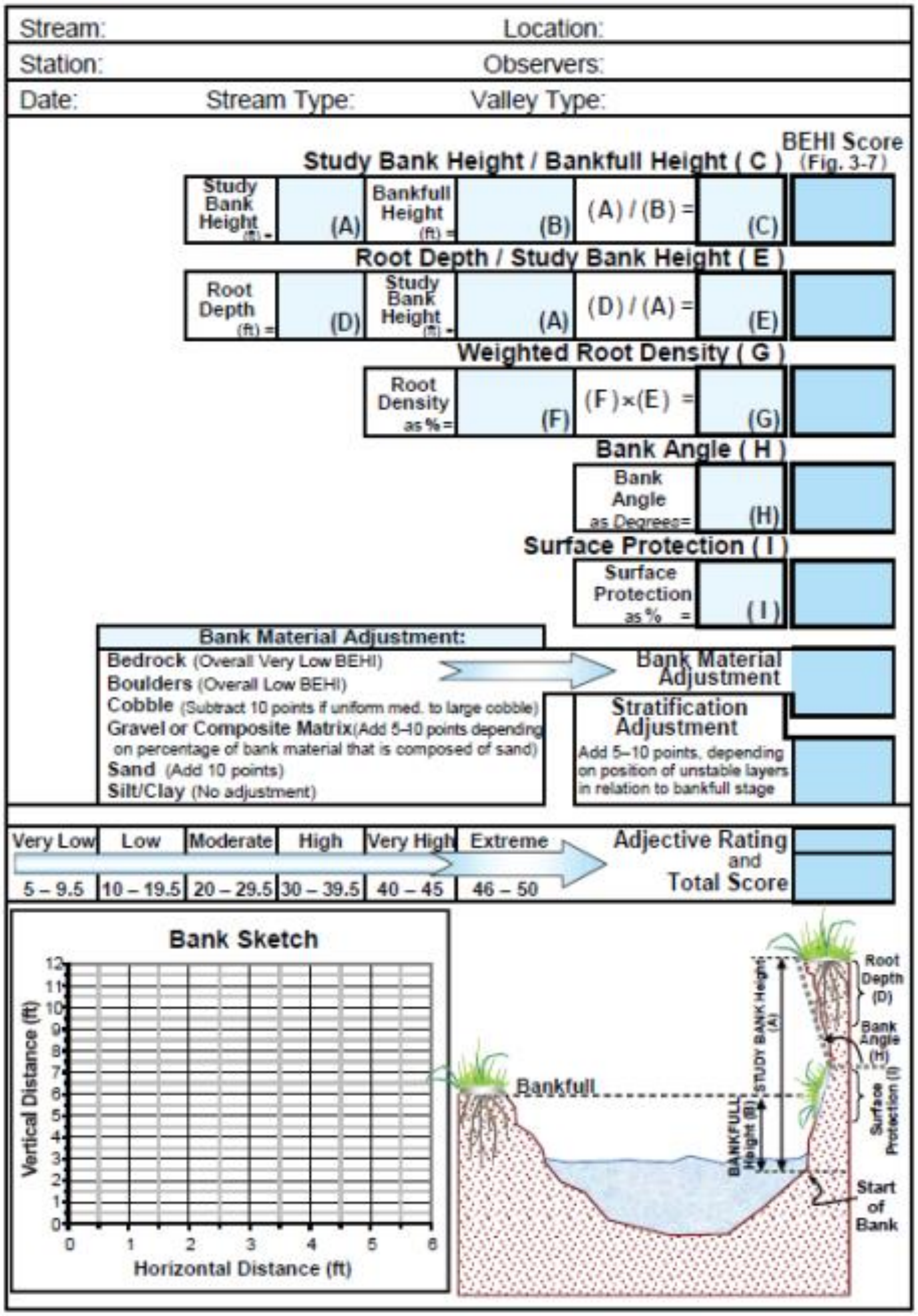

Figure B.3 Bank Erosion Hazard Index (BEHI) by Rosgen (2006)

Appendix B.4 BEHI Rating Curves by Rosgen (2008)

Each of the variables collected in the form under Appendix B.2 are converted to a BEHI rating using the relationship in the following figure. The ratings are between Very Low to Extreme and are totaled and adjusted to obtain an overall BEHI risk rating (Rosgen, 2008). The following figure is courtesy of Rosgen, 2008).

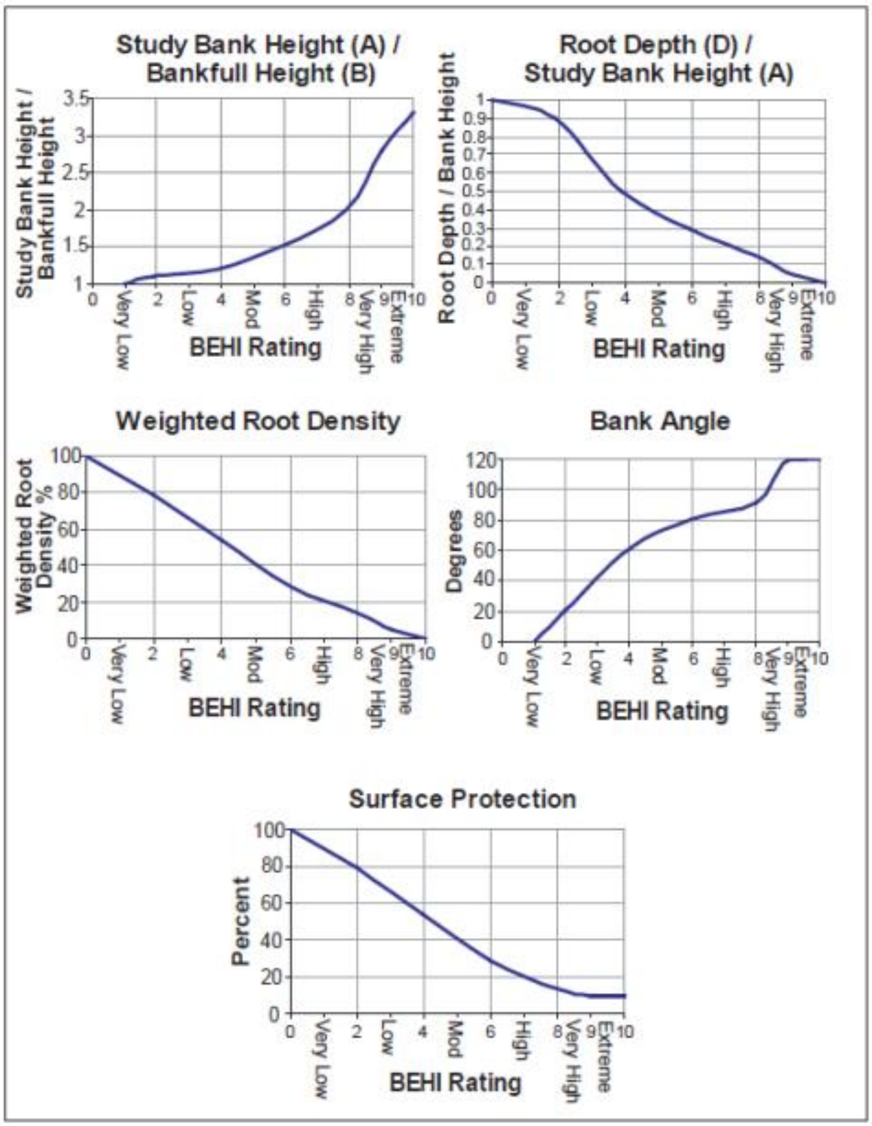

Figure B.4 BEHI Rating Curves by Rosgen (2008)

Appendix B.5 Near Bank Stress by Rosgen (2008)

To predict annual erosion rates using the BANCS model, a Near-Bank Stress assessment must be included to determine the amount of energy distributed against the streambanks (Rosgen, 2008). One of the seven methods in Worksheet 3-12 can be used to determine an NBS rating. Ratings range from Very Low to Extreme. Appendix B.5 courtesy of Rosgen (2008).

Worksheet 22A. Various field methods of estimating Near-Bank Stress risk ratings for the calculation of erosion rate.

Estimating Near-Bank Stress (NBS)

Stream:			Location:		Date:		Crew:	

Methods for Estimating Near-Bank Stress

(1) Transverse bar or split channel/central bar creating NBS/high velocity gradient: **Level I - Reconnaissance.**

(2) Channel pattern (Rc/W): **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	Method								
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 (Figure X). NBS = Extreme							
Level II	(2)	Radius of Curvature Rc (feet)	Bankfull Width W_{bkf} (feet)	Ratio Rc/W	Near-Bank Stress				
	(3)	Pool Slope S_p	Average Slope S	Ratio S_p/S	Near-Bank Stress		Dominant Near-Bank Stress		
	(4)	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p/S_{rif}	Near-Bank Stress				
Level III	(5)	Near-Bank Max Depth d_{nb} (feet)	Mean Depth d (feet)	Ratio d_{nb}/d	Near-Bank Stress				
	(6)	Near-Bank Max Depth d_{nb} (feet)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d (feet)	Average Slope S	Shear Stress τ (lb/ft^2)	Ratio τ_{nb}/τ	Near-Bank Stress
Level IV	(7)	Velocity Gradient (ft/s/ft)		Near-Bank Stress					

Converting Values to a Near-Bank Stress Rating

Near-Bank Stress Rating	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N/A	>3.0	< 0.20	< 0.4	<1.0	<0.8	<1.0
Low		2.21 - 3.0	0.20 - 0.40	0.41 - 0.60	1.0 - 1.5	0.8 - 1.05	1.0 - 1.2
Moderate		2.01 - 2.2	0.41 - 0.60	0.61 - 0.80	1.51 - 1.8	1.06 - 1.14	1.21 - 1.6
High	See (1) Above	1.81 - 2.0	0.61 - 0.80	0.81 - 1.0	1.81 - 2.5	1.15 - 1.19	1.61 - 2.0
Very High		1.5 - 1.8	0.81 - 1.0	1.01 - 1.2	2.51 - 3.0	1.20 - 1.60	2.01 - 2.3
Extreme		< 1.5	> 1.0	> 1.2	> 3.0	> 1.6	> 2.3

Overall Near-Bank Stress Rating

Figure B.5 Near Bank Stress by Rosgen (2008)

Appendix B.6. Prediction of Annual Streambank Erosion Rates

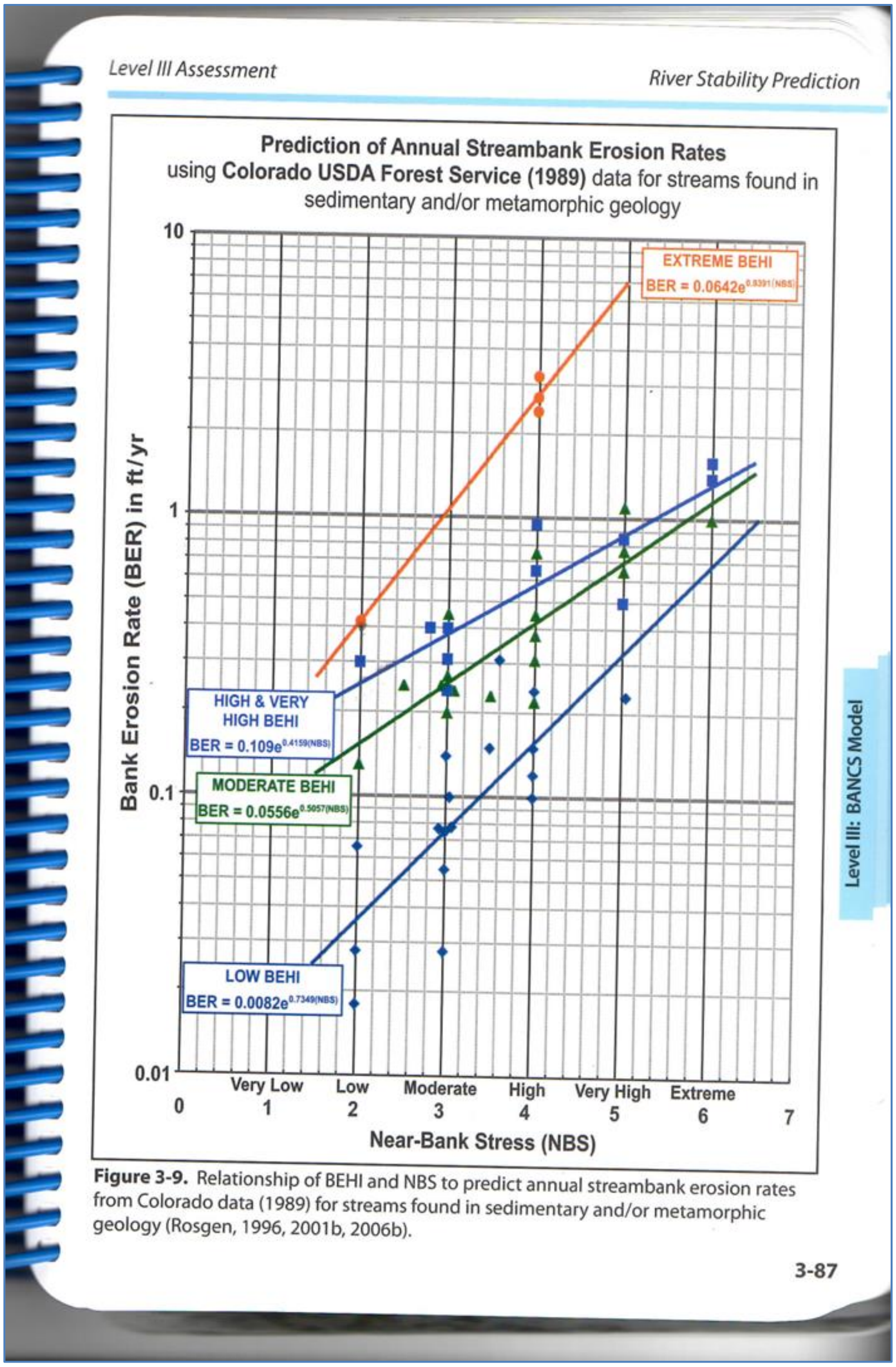

Figure B.6. Prediction of Annual Streambank Erosion Rates

Appendix B.7 Total Erosion Calculation Sheet

Worksheet 23. Total Bank Erosion Calculation

Stream:	Total Bank Length:	Stream Type:
Observers:	Date:	Graph Used:

	Station (ft)	BEHI (adjective)*	Near Bank Stress (adjective)	Erosion Rate (ft/yr)*	Length of Bank (ft)	Bank Height (ft)	Erosion Sub-Total (ft^3/yr)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

I. Sum erosion sub-totals for each BEHI/NBS combination	Total Erosion (ft^3/yr)	
II. Divide total erosion ($feet^3$) by 27 $feet^3/yard^3$	Total Erosion (yd^3/yr)	
III. Multiply Total Erosion ($yard^3$) by 1.3 (conversion of yd^3 to tons for average material type)	Total Erosion (tons/year)	
IV. Calculate erosion per unit length: divide total erosion (ton/year) by total length of stream (ft) surveyed	Total Erosion (tons/yr/ft)	

*Use numerical category spread to predict rates. (i.e. 21 = Moderate but at start of category, where as 28 is on upper end of relation - use prediction values appropriate to numerical rating).

Figure B.7 Total Erosion Calculation Sheet

Appendix C: Data from Field Forms

C.1. Modified Pfankuch Field Data

The following table summarizes the MPf data that was collected on the 30 stream sites. The scores for each of the 3 bank positions as well and the total and adjective ratings are given.

Site ID	Upper Banks	Lower Banks	Bottom	TOTAL	Adjective Rating
CC2	23	30	27	79	Good
CC4	36	45	61	142	Poor
CC5	25	33	52	110	Fair
CC7	33	31	49	113	Fair
CC8	21	24	26	71	Good
CC9	33	32	51	116	Poor
CC10: Sam	35	42	41	118	Poor
CC11	36	42	41	119	Poor
CC12/HCC	30	32	33	95	Fair
CC13	22	28	41	91	Fair
CC14	32	32	33	97	Fair
CC17	40	48	50	138	Poor
CC18	38	51	49	138	Poor
FCC 015	17	27	39	83	Fair
GCC 270	37	39	43	119	Poor
Site 03	37	45	35	117	Poor
REC 06	40	35	47	122	poor
1002-3	33	41	58	132	Poor
RG 2	38	49	55	142	Poor
RG 1	38	51	58	147	Poor
DR1	37	36	45	118	Poor
DR2	40	49	46	135	Poor
DR3	37	50	41	128	Poor
B-227	28	51	58	137	Poor
B1	35	49	58	142	Poor
WEC 159	19	29	37	85	Fair
Mair 1	24	22	41	87	Fair
Mair Bluff	34	45	51	130	Poor
Mair Bluff	36	41	39	116	Poor
HEC 300	35	43	46	124	Poor

Table C.1: All Modified Pfankuch data collected from each of the 30 stream sites.

C.2. Bank Erosion Hazard Index Field Data

The following table represents all the BEHI data that was collected from the 30 study sites. Each of the metrics are shown, as well as the total score and adjective rating.

Site ID	Study Bank Height (A) ft	Bankfull Height(B) ft	C=A/B	Root Depth(D) ft	E=D/A	Root Density (F) ft	G=F*E	Bank Angle (H) degrees	Surface Protection (I) percent	Bank Material Adjustment	Strat Adj.	Total Score	Adjective Rating
CC2	8.67	3.67	2.36	2	0.23	80	18.4	90	90	10	0	38.6	High
CC4	6.42	3	2.14	1.5	0.23	10	2.3	100	0	10	0	52	Extreme
CC5	6.5	3	2.16	6.5	1	80	80	90	70	10	0	31	High
CC7	6.58	3.16	2.29	0.75	0.16	20	3.2	120	40	10	0	49.7	Extreme
CC8	6.5	3.2	2.03	6.5	1	50	50	90	30	10	0	33	High
CC9	7.16	3	2.35	0.5	0.12	5	0.6	65	5	10	0	49	Extreme
CC10: GCC 059	8	3	2.67	0.91	0.11	3	0.33	110	30	5	10	56.5	Extreme
CC11	18	5	3.6	9	0.5	40	20	70	25	10	0	44	Very High
CC12/HCC 001	10.5	3.5	3	2	0.19	0.19	30	90	50	10	0	49	Extreme
CC13	6.4	3.5	1.82	4	0.625	70	43	90	90	10	0	35	High
CC14	24	3	8	0.5	0.02	5	0.1	90	30	10	10	64.5	Extreme
CC17	8.5	3.2	2.65	2.5	8.5	25	7.25	65	0	10	10	56.5	Extreme
CC18	7	4.25	1.65	3	0.43	7	3.01	55	5	10	0	44.5	Very High
FCC 015	5.58	4.25	1.31	5.58	1	85	85	60	90	5	0	16.95	Low
GCC 270	6.17	3.42	1.8	1	0.16	4	0.64	60	5	0	5	44	Very High
Site 03	6.8	4	1.7	2.9	0.426	20	8.6	110	80	7	0	38	High
REC 06	7.6	4.2	1.8	4.4	0.57	50	29	120	30	5	5	41	Very High
1002-3	10.67	4.67	2.28	2	0.43	30	12.9	90	0	10	0	50	Extreme
RG 2	12.8	4.9	2.9	1	0.08	2	0.16	90	30	5	0	48.5	Extreme
RG 1	23	3.5	6.57	1	0.05	1	0.05	80	3	10	0	53	Extreme
DR1	10	4.17	2.39	4	0.4	70	28	100	0	0	0	37.1	High
DR2	20.42	5.42	3.76	3	0.15	30	4.5	95	5	0	0	46	Extreme
DR3	9	4.25	2.11	1.42	0.16	5	0.79	90	0	5	5	54	Extreme
B-227	27	3.5	7.7	23	0.85	60	51	70	10	5	0	35.5	High
B1	7.33	3.75	1.95	3	0.41	70	28.7	70	100	boulders=lov	0	15	Low
WEC 159	5.5	3.3	1.67	5.5	1	90	90	55	70	5	0	19	Low
Mair 1	10.2	4.7	2.17	5	0.49	40	19.6	90	50	5	0	36	High
Mair Bluff	23	3.6	6.3	0.5	0.02	1	0.02	90	2	10	0	58.5	Extreme
Mair Bluff 2	23	3.5	6.57	0.5	0.02	2	0.04	90	40	10	0	53.5	Extreme
HEC 300	10.5	3.3	3.21	0.5	0.05	2	0.09	80	10	5	0	49.5	Extreme

Table C.2: BEHI data from all field sites.

C.3 Near Bank Stress Field Data

The following data summarizes the NBS data that was collected on the 30 stream sites. Radius of curvature was calculated from aerial photography.

Site ID	Radius of Curvature ft	Bankfull Width ft	Ratio Rc/B.F.W	NBS Score
CC2	95	33	2.9	Low
CC4	92	46	2.02	moderate
CC5	83.86	54.66	1.53	very high
CC7	65	40	1.62	Very High
CC8	395	44.6	8.8	Very Low
CC9	404	31	13	Very Low
CC10: Sam	1429	42	34	Very Low
CC11	500	34	14.7	Very Low
CC12/HCC	305	44	6.93	Very Low
CC13	361	47	7.7	moderate
CC14	65	46	1.43	Extreme
CC17	152	41.2	3.6	Very Low
CC18	90.8	47.42	1.91	High
FCC 015	162	37	4.3	Very Low
GCC 270	650	40	16.25	Very Low
Site 03	211	69.5	3.035971	Very Low
REC 06	109	56	1.95	high
1002-3	411	57.16	7.19	Very Low
RG 2	110	58	1.9	High
RG 1	54.4	67	0.8	Very High
DR1	111.9	37.33	3	Very Low
DR2	148	47.5	3.11	Very Low
DR3	56.7	37	1.53	Very High
B-227	145	53	2.7	Low
B1	69.6	51.42	1.35	Extreme
WEC 159	341	51.3	6.6	Very Low
Mair 1	324	71	4.5	Very Low
Mair Bluff	157	56.9	2.7	Low
Mair Bluff	445	48	9.2	Very Low
HEC 300	218	67.4	3.2	Very Low

Table C.3: Table of all NBS data collected on the 30 study sites.

C.4 Estimated Erosion Rates

Erosion rates were calculated using the BANCS method, which uses data from the BEHI and NBS to calculate erosion rates. The estimated amount of erosion in cubic feet/yr is listed for each site. Note: As mentioned in Chapter 2: These numbers are likely to be underestimated based on regional data.

Site ID	Erosion Rate (ft/yr)	Length of Bank (ft)	Bank Height (ft)	Erosion (Ft^3/yr)
CC14	10	150	24	36000
RG 1	8	180	23	33120
RG 2	3	200	12.8	7680
DR3	8	100	9	7,200
B-227	0.25	500	27	3,375
CC5	1	300	6.5	1950
CC7	4	100	4.58	1832
Mair Bluff	0.04	160	23	1472
CC18	0.8	200	7	1120
CC11	0.2	300	18	1080
DR2	0.2	240	20.42	980.16
CC4	1	150	6.42	963
1002-3	0.2	450	10.67	960.3
B1	0.5	250	7.33	916.25
CC13	0.4	300	6.4	768
Mair Bluff 2	0.2	150	23	690
GCC 270	0.2	500	6.17	617
REC 06	0.6	95	7.6	433.2
CC8	0.2	300	6.5	390
CC9	0.1	450	7.16	322
CC10 GCC 059	0.1	400	8	320
DR1	0.1	315	10	315
CC12/HCC 001	0.1	270	10.5	283.5
CC2	0.2	140	8.67	242.76
CC17	0.1	200	8.5	170
HEC 300	0.2	70	10.5	147
Site 03	0.1	142	6.8	96.56
Mair 1	0.1	40	10.2	40.8
WEC 159	0.02	300	5.5	33
FCC 015	0.02	200	5.56	22.24

Table C.4: Estimated Erosion Rates Using the BANCS Method