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A Bank Erosion Hazard Index (BEHI) Study of Dry Run Creek, Cedar Falls, Iowa

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A BANK EROSION HAZARD INDEX (BEHI) STUDY OF DRY RUN CREEK, CEDAR FALLS, IOWA

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ABSTRACT

Dry Run Creek is a watershed located in Cedar Falls, Iowa and it is on a list of the state's impaired waterways. One reason it may be impaired is that there is excessive erosion in the stream. This study assessed the Bank Erosion Hazard Index of portions of the creek to determine erosion hotspots. The majority of the banks in all the branches had a Low score, meaning that the BEHI was less than 11.9. The minimum BEHI score is 0 and the maximum score is 40. The lower the score, the better the condition of the bank. Portions of the University, East, and West branches of Dry Run Creek were studied. All assessed stretches in the West Branch were found to have a Low BEHI rating, indicating that they are in good condition and are in little danger of erosion. The highest BEHI found in the West Branch was 10.3, putting all of the stretches in the Low category. Stretches of the stream with a Moderate or High BEHI rating were found in the University and East Branches. Most of these scores were well above 15. These areas could be considered areas with high erosion potential that should be monitored and treated with measures to prevent erosion.

INTRODUCTION

The purpose of this study was to assess the Bank Erosion Hazard Index (BEHI) of the banks of Dry Run Creek as a starting point for providing aid to areas of the stream that are being heavily eroded. The BEHI will give the Watershed Conservationists of Black Hawk County and the Natural Resource Conservation Services an idea of which stretches of the stream are in critical condition and which banks are not in danger of excessive erosion. This study assessed the stability of key stretches of the stream channel banks by looking at plant root depth and density, surface protection, bank angle, and bank material. Areas with a high BEHI will become areas of focus for future bank protection projects and improvement programs.

Bank Erosion

Erosion of a bank is a gradual process in which bank material is removed or disintegrated by the forces of wind, water, or ice. According to the Iowa DNR (Anonymous, 2006), streams in Iowa are subject to fluctuations in flow depth and velocity, which occur over a period of years due to seasonal changes and individual storms. Increase in flow depth and velocity causes an increase in the force of the water flowing along the bank of the stream. This increased force removes soil and ultimately causes more erosion to occur. If high flows continue over an extended period of time, several feet of bank can be eroded annually (Anonymous, 2006). Erosion can also occur due to runoff from adjacent fields or rain falling directly on banks. If tributary drainage systems have an outlet in areas with unstable banks, this can also lead to greater amounts erosion (Anonymous, 2006).

Bank erosion is related to three major types of processes. These processes include fluvial entrainment, mass wasting, and the weakening and weathering of bank materials. Bank material weathering encourages the entrainment and mass wasting processes (Thorne, 1982). Mass wasting is the bulk transfer of earth materials downslope by gravity. Fluvial entrainment is the removal of sediment from the bank surface by corrasion, the abrasive forces produced by the flow of water in a river. Friction and cohesion hold a bank in place. When the forces of flowing water and the downslope component of the mass of particles overcome the cohesion and friction forces, erosion occurs. Properties of the bank determine the rate at which corrasion occurs. These properties include grain size, mineralogy, cohesion of bank material, and the type, density, and root system of vegetation on the bank (Thorne, 1982). The rate of bank erosion depends mainly on the characteristics of the bank materials and often depends little on the river itself (Hadley, 1961).

Rates of corrasion are also affected by seasonal changes. Freeze-thaw processes weaken the bank material by breaking soil aggregates apart, making them more susceptible to erosion. As a result, erosion rates during the winter are often higher than during the summer at the same location (Prosser, Hughes, and Rutherford, 2000). Bank weakening is more important in upstream areas where stream flow cannot erode bank sediment by corrasion unless particles have been loosened. Bank heights are relatively low in these areas, so mass wasting processes are not as important here. These processes become more important further downstream where bank heights tend to be higher (Lawler et. al, 1999).

Bank erosion is essentially the lateral movement of a stream bank. According to Calvin Creech, an engineer with the US Army Corps of Engineers, there are two factors that affect bank erosion: erodability and erosivity. Bank erosion is proportional to the erodability and erosivity, as can be seen in Figure 1. The erodability is the resistive capability of a bank, which is affected by the angle of the bank, the composition material of the bank, and the presence of vegetation. A BEHI study gives a measure of the erodability of a bank. The erosivity is a driving force of erosion, and it is the amount of near bank stress acting on the bank (Creech, 2010). Near bank stress is related to the hydraulic forces of the flow energy of the water, which create shear stress that acts on the bank surface, causing it to erode (Simon and Rinaldi, 2006). In summary, erosion is caused by the erosive forces of outside stressors that act on the bank, but the bank can resist the erosive forces based on its erodability properties.

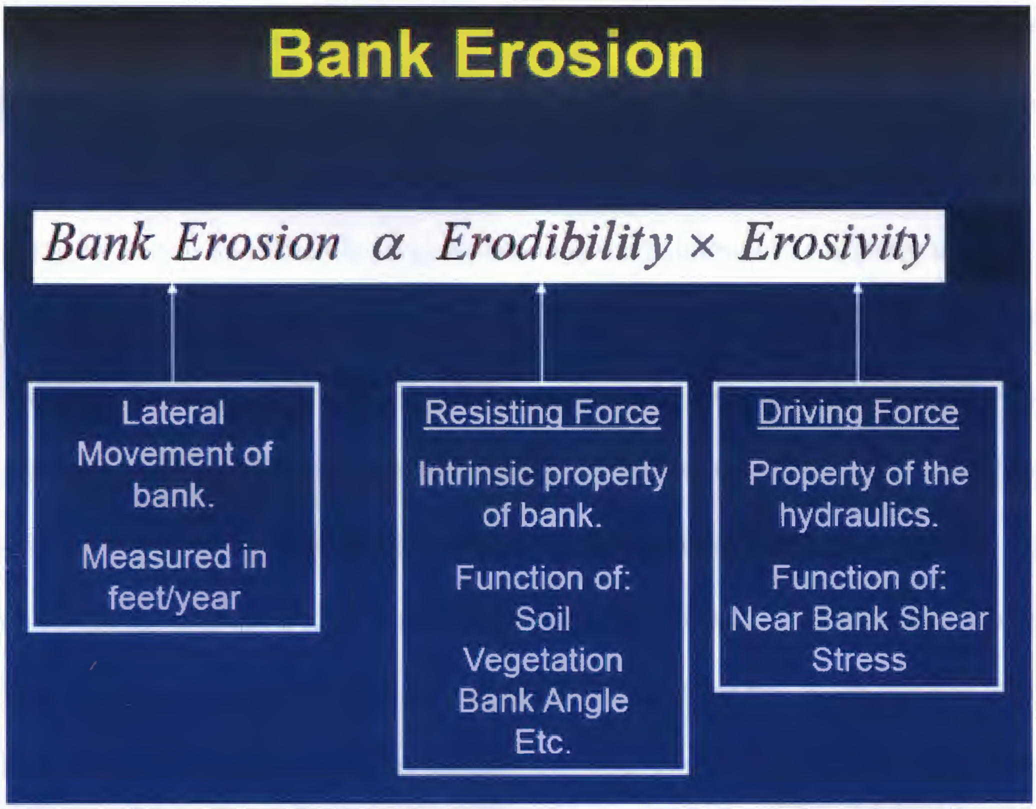

Figure 1. The relationship between bank erosion, erodibility, and erosivity (Creech, 2011).

Erosion can have natural or anthropogenic sources. Streams form naturally over time due to erosion and downcutting of the surface of the land. This channel incision is a natural part of landscape evolution and occurs because of an imbalance between sediment supply and sediment transporting power (Simon and Rinaldi, 2006). Incision of channels naturally involves bank erosion as the channels widen and the stream matures. The rate of bank erosion depends on factors including properties of the soil, freeze-thaw processes, bank stratigraphy, type and density of vegetation, and sediment grain size at the bottom of the bank (Posner and Duan, 2012). Bank erosion is a process that involves several stages. Bed scouring first steepens banks, causing banks to collapse. Bank material is then deposited at the bottom of the bank. Finally, the loose sediment is carried off by the stream (Posner and Duan, 2012). Bank erosion is a natural phenomenon that occurs with or without human influences.

The anthropogenic influences on bank erosion are important to understand so as to try to limit the effect we have on streams. Anthropogenic sources of erosion include dam construction, urbanization, agriculture, land use change, tourism, mining, and industrial development (Vadnais et al., 2012). These types of sources have rapid effects on the environment. According to a study by Simon and Rinaldi, large anthropogenic disturbances compress the time it takes for incision to occur and speed up the stages of erosion due to the imbalances they create between sediment delivery and transportation capabilities of streams. Stream formation that may occur naturally over millennia can take place in tens or hundreds of years due to anthropogenic fluvial disruptions (Simon and Rinaldi, 2012). The Simon and Rinaldi study also cited programs of channelization in the United States as having major effects on streams, some of which were done in Iowa. Channelization programs began about 150 years ago when the area was settled. Large areas of land were cleared for agriculture before and after the Civil War. Grasses and woody vegetation were removed from watersheds for agriculture, and this led to a reduction in the amount of water that could be stored in the soil, increasing the amount of runoff to streams. Rates of surface runoff have increased 2-3 times compared to pre-settlement rates. Downcutting increased dramatically and erosion affected the channel capacity of streams, prolonging floods (Simon and Rinaldi, 2012). Human effects on the environment can be drastic and can have unforeseen consequences.

BEHI Assessment

The BEHI assessment was created by Dave Rosgen of Wildland Hydrology, Inc (Rosgen, 2001). The purpose of the BEHI is to make a distinction between banks that are eroding naturally and those that are eroding unnaturally from changes in watershed hydrology. Points are assigned to aspects of bank condition, which gives an overall rating that is helpful when inventorying bank conditions in large areas so as to prioritize banks for improvement efforts. The full BEHI standard operating procedure (SOP) includes the determination of the ratio of bank height to bankfull height. This can be difficult for an inexperienced worker to identify, so it is left out of the modified BEHI procedure. The BEHI SOP that was used in this study is modified from Rosgen's original procedure (Rosgen, 2001) in that the scores are simplified to a single score for each metric. This helps to remove subjectivity from the field work, which makes it easier to obtain an accurate score for a novice BEHI assessor.

Study Area

Dry Run Creek is located in Black Hawk County, Iowa and drains 15,177 acres of agricultural, commercial, and residential property. This watershed includes 85% of the City of Cedar Falls and runs directly through the campus of the University of Northern Iowa. There are about 24.5 miles of stream in the system, and there are four main branches. These include the University, East, West, and Southwest branches. The watershed is 35% urban, and 65% is rural (Anonymous, 2012). With the help of the Watershed Conservationists of Dry Run Creek, portions of the University, East, and West branches were selected for this study. All of these branches are in close proximity to the University of Northern Iowa, as can be seen in Figure 2.

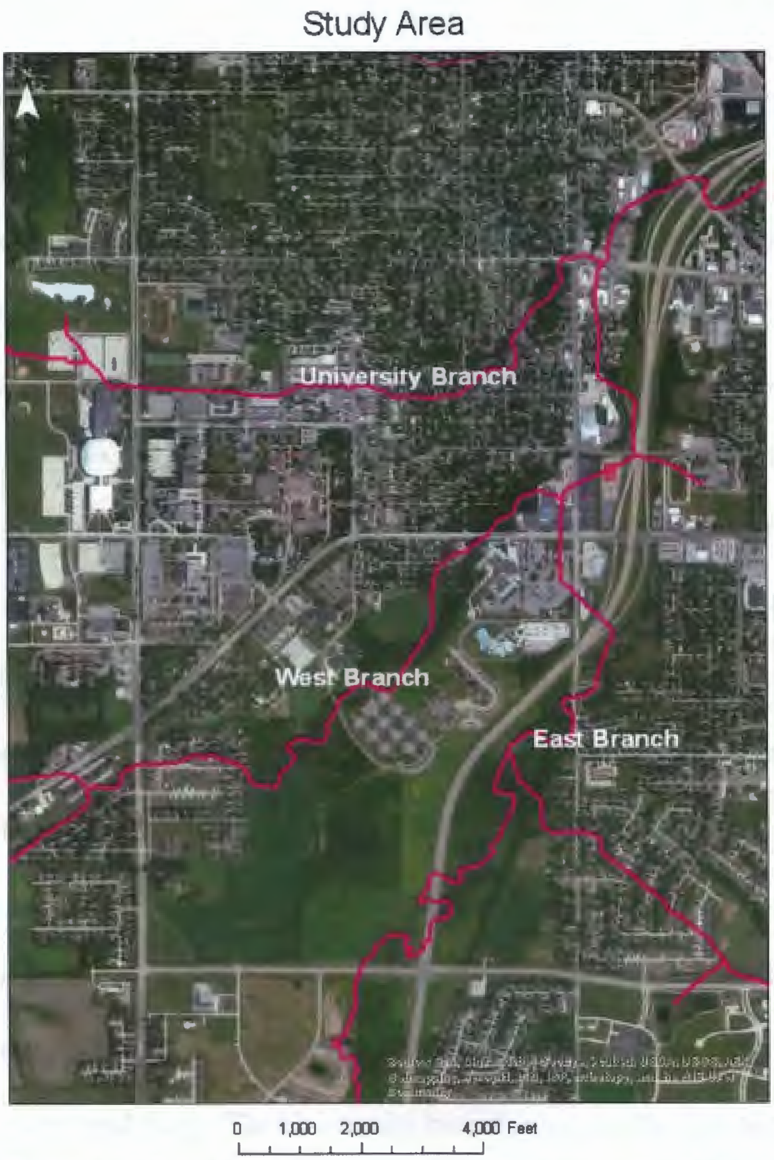

Figure 2. Map of Dry Run Creek near the University of Northern Iowa.

Dry Run Creek Present Conditions

Dry Run Creek was put on an impairment list by the Department of Natural Resources (DNR) in 2002 for lack of abundance and diversity in aquatic life. It received a subsequent impairment listing due to excessive levels of bacteria (Anonymous, 2012). According to the Water Quality Improvement Plan for Dry Run Creek (Palmer and Buyck, 2011), there are three factors causing these issues with the creek. They include increased amounts of bedded sediment, reduced habitat availability, and increased storm water input in the creek. This increased amount of water causes erosion, which destroys aquatic habitats. Alterations to the stream flow have lasting impacts, including reducing meander, increasing the stream gradient, shortening stream length, and decreasing sediment storage capacity. Increased pollution is also affecting life in the stream. Erosion is a major issue primarily due to storm surges, and excessive erosion can threaten the biological and physical functions of the stream (Palmer and Buyck, 2011). Reducing erosion would help improve the health of Dry Run Creek.

An official BEHI study of Dry Run Creek has never been conducted before. The bank material, bank stability, and bank height were assessed for all branches of Dry Run Creek by the 2005 Environmental Geology class at the University of Northern Iowa (Beason et al., 2005). This group used the Stream Corridor Assessment Worksheet, which is a much more detailed survey than the Modified BEHI Field Form used in this BEHI assessment.

Past Work with Dry Run Creek

It is important to know the material that banks are composed of as grain size and mineralogy affect the susceptibility of the bank to erosion. The Environmental Geology group (Beason et al., 2005) found that 95.27% of the bank material was sand or silt and 4.53% was gravel and rock. The University branch contains the coarsest material, much of it being larger than silt. There are also several stretches of cobble. The areas of the East and West branches that I assessed are primarily composed of fine-grained silts and sands (Beason et al., 2005).

Bank height is a component of the BEHI in that it is needed for the ratio of root depth to the bank height metric. The bank height was also assessed by the Environmental Geology group. They divided the banks into urban and rural categories, and it was found that over half of urban streams have banks 5-9.9ft in height. Rural streams were found to be divided nearly equally into three categories. About one third were 0-2.4ft, one third 2.5-4.9ft, and one third were 5-7.4ft (Beason et al., 2005). Overall, urban banks were taller than rural banks.

The most relevant aspect that the Environmental Geology class examined is the bank stability. They determined the stability based on many factors including vegetation, bank slope, herbaceous canopy, bank material, livestock access, and land use. They classified the banks as stable, moderately stable, moderately unstable, unstable, and artificially stable. Rural areas were found to have the most stable banks. Bank stability in the lower East Branch and eastern University Branches where I conducted the BEHI assessment were found to have the most unstable banks. The West Branch was found to be generally stable, as was the northern East Branch (Beason et al., 2005).

Once the BEHI is assessed, it can be a useful tool. The Arkansas Department of Environmental Quality used a BEHI to help develop a graphical model to estimate stream bank erosion rates and annual sediment load due to increased erosion for the West Fork White River Watershed. Estimates like these are valuable in understanding the condition of streams in order to improve their health. Models may be effective for predicting bank erosion rates of the assessed stream and for areas similar to those used to determine the BEHI (Van Eps et al., 2004).

METHODS

To conduct this study, I used the Modified BEHI Procedure, as described in the BEHI Standard Operating Procedure (Rosgen, 2001). The form used to record these measurements can be found in Appendix A. This method includes determining the measurements for the following metrics: ratio of root depth to bank height, root density, bank angle, and surface protection. I used the worksheet provided in the SOP for collection of data in the field. For every 100ft of straight bank, I collected BEHI data. The SOP recommends taking assessments of 200ft stream stretches (Anonymous, 2008), but Dry Run Creek meanders greatly, so I attempted to assess every 100ft. If there was not a fairly straight 100ft stretch, I did a slightly smaller stretch, or omitted the section, depending on the degree of meander. I also omitted any area containing artificially stabilizing material. If the artificial material was only covering one bank, I indicated this and did the assessment on the bank free of debris. I used a GPS unit to record the latitude and longitude of the beginning and end of each stretch so as to be able to create a map of the data.

BEHI Metrics

The ratio of root depth to bank height is expressed as a percentage, and it is the average root depth of the entire bank that is used for the root depth metric. I used a trowel to dig out vertical sections of the bank to better examine the root depth. The root density is the percentage of the stream bank that is covered with plant roots. Figure 3 shows how root density and root depth are estimated in the field. In this example, roots extend about half of the way down the bank, and they cover about 30% of the bank surface. In the field, if roots could be found from the top of the bank to the bottom, I considered the root depth to be 100%. Collection of most of the data took place while some beds were dry or water levels were very low. Regardless of the water level, the root depth was measured compared to the existing water level at the time of data collection.

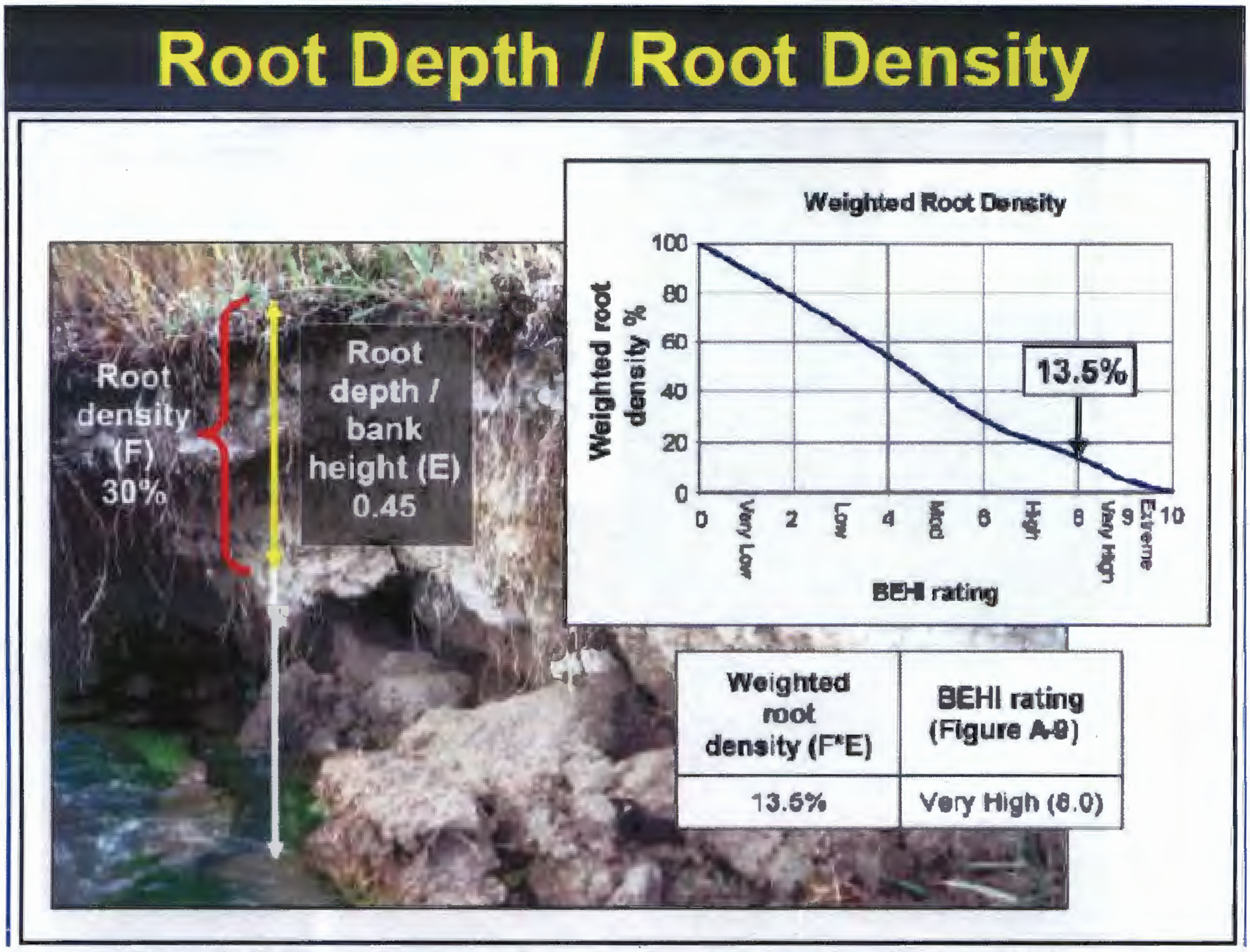

Figure 3. Example of the measurement of root depth and root density (Creech, 2011).

The surface protection is the percentage of the bank covered by roots, logs, rocks, or any other material that is protecting the bank from erosion. If there are no rocks or logs, I put the same value for the root density and surface protection. Figure 4 gives clear examples of different levels of surface protection found in the field. The greater the surface protection, root depth, and root density, the lower the BEHI score for that bank.

Surface Protection

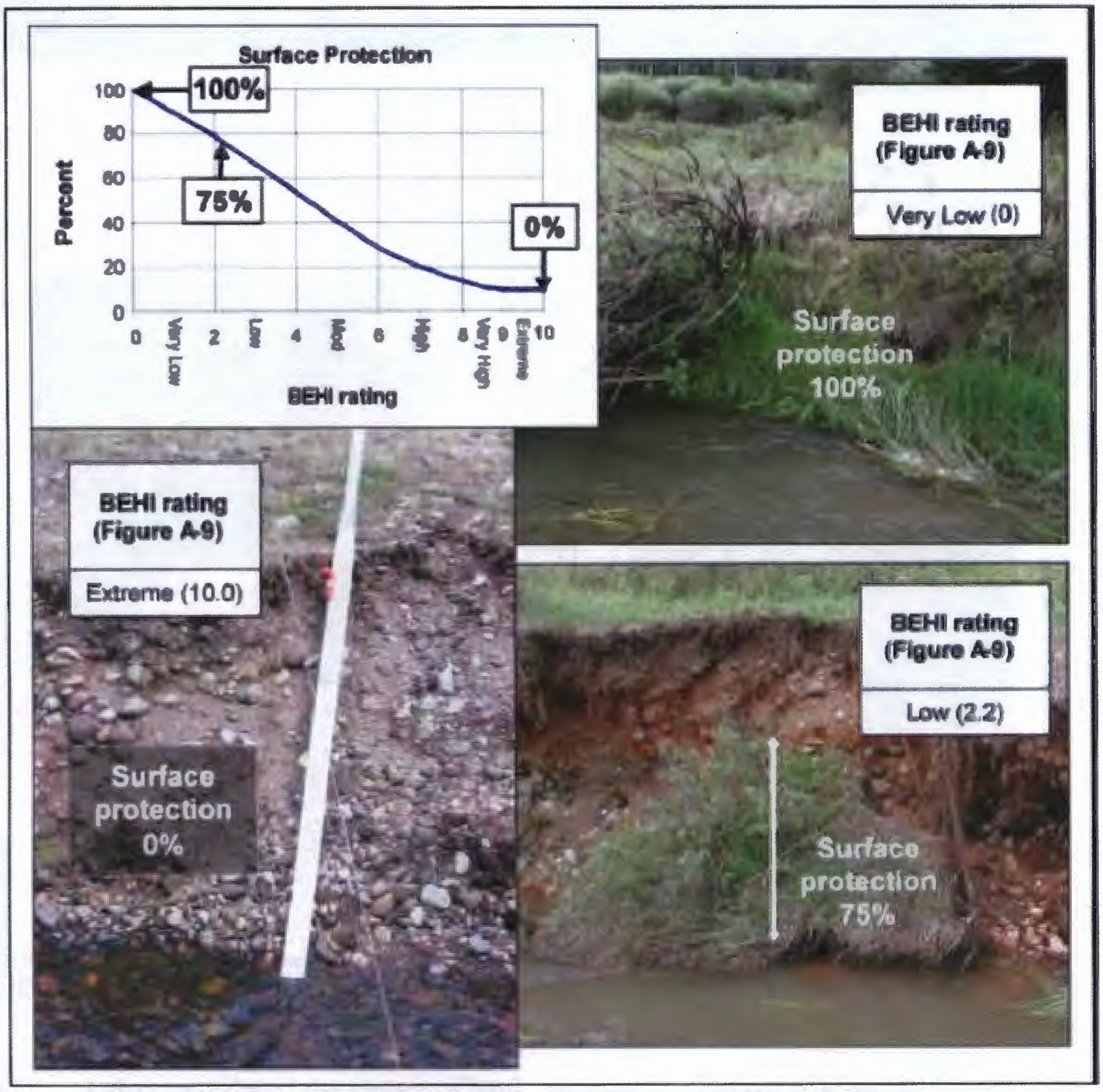

Figure 4. Examples of the measurement of surface protection (Creech, 2010).

The bank angle is the angle of the lower bank, from the waterline to the top of the bank. I used a clinometer to get an accurate reading of the angle instead of estimating by sight. Figure 5 shows how bank angle is measured in the field. The greater the angle, the higher the potential for erosion and therefore the higher the BEHI score will be.

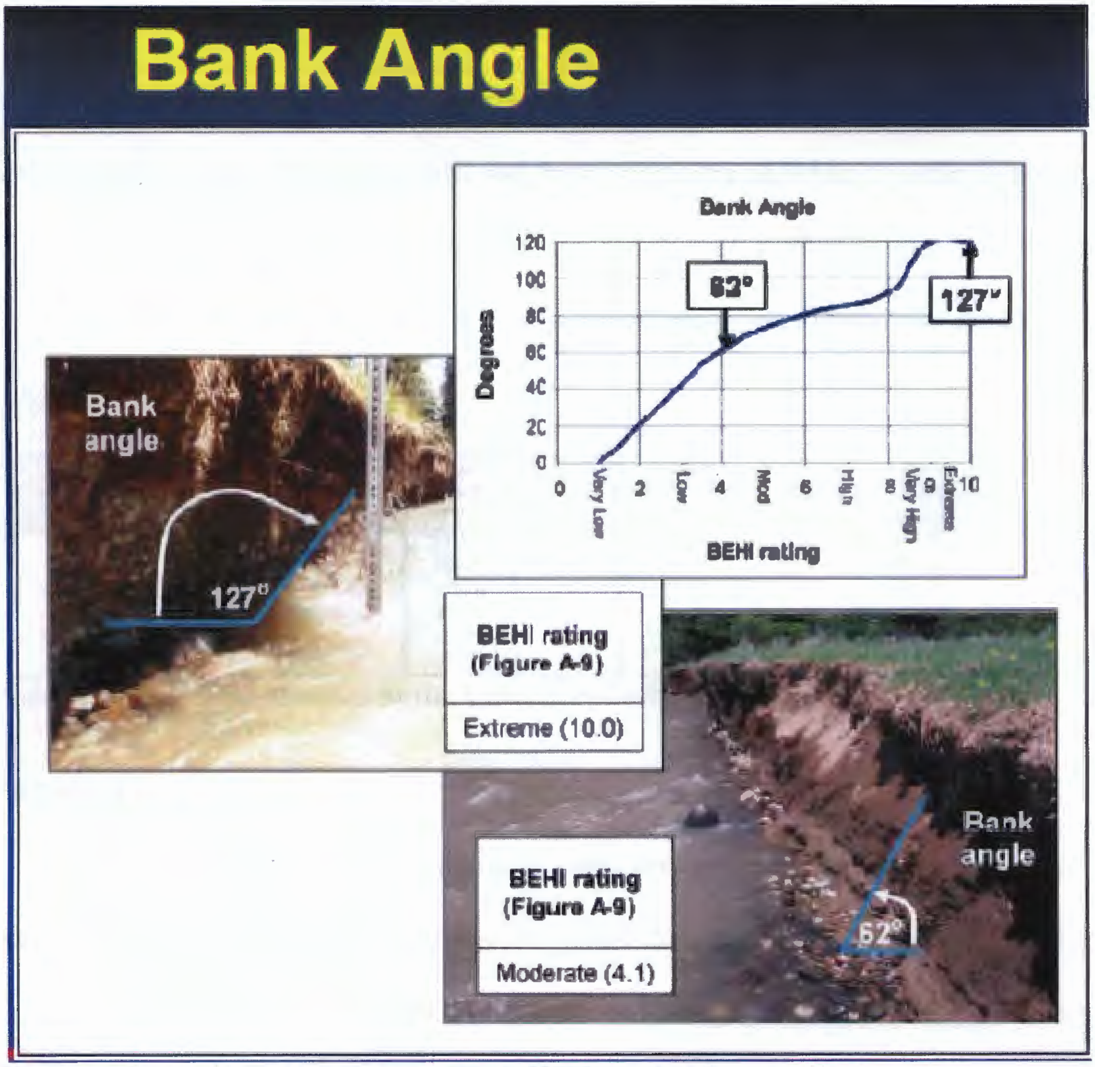

Figure 5. Examples of the measurement of bank angle (Creech, 2011).

I also considered the nature of bank composition, which adjusted the score of the BEHI in a limited number of stretches. These additional considerations are described in Rosgen's method of determining stream bank erosion rates (Rosgen, 2001). If the bank material is bedrock, an automatic rating of very low is given. For boulders, an automatic rating of low is given. If the material is cobble-sized, 10 points are subtracted. Gravel adds 5-10 points, depending on the amount of sand (Anonymous, 2008). Sand adds 10 points and silt or clay results in no adjustment. As mentioned previously, several sections of Dry Run Creek are known to have been artificially stabilized. I did not assign a BEHI score to these sections.

In order to calculate a BEHI score, each metric is put into a range that is determined in the field. Once the ranges are all determined, Table 1 is used to score each bank. The range converts into a score for each metric, and these scores are added up in order to give a composite BEHI score. The resulting BEHI rating assigns each bank a category that describes how much each bank is in danger of being eroded. The categories are very low, low, moderate, high, very high, and extreme.

BEHI Category	Root Depth Values	Root Depth Scores	Root Density (%)	Root Density Scores	Surface Protection (Avg. %)	Surface Protection Scores	Bank Angle (degrees)	Bank Angle Scores	Total Score, by Category
Very low	90-100	1.45	80-100	1.45	80-100	1.45	0-20	1.45	≤ 5.8
Low	50-89	2.95	55-79	2.95	55-79	2.95	21-60	2.95	5.8 – 11.8
Moderate	30-49	4.95	30-54	4.95	30-54	4.95	61-80	4.95	11.9 – 19.8
High	15-29	6.95	15-29	6.95	15-29	6.95	81-90	6.95	19.9 – 27.8
Very high	5-14	8.5	5-14	8.5	10-14	8.5	91-119	8.5	27.9 – 34.0
Extreme	< 5	10	< 5	10	< 10	10	> 119	10	34.1 - 40

Table 1. Scores for the Modified BEHI (Anonymous, 2008).

RESULTS

The following tables give numerical data for the scoring and classification of each metric considered in the BEHI study. Tables 2, 3, and 4 define the name of the stretch, BEHI metric scores, bank material, and overall BEHI score and category for each stretch in its respective branch. Further description and pictures of stretches can be found under the subheading of the respective branches. All pictures were taken looking downstream. Table 5 gives the GPS locations of the beginning and ending point of each stretch, which was used to create a GIS map of the data.

Data

University Branch

Stretch	Root Depth	Root Density	Surface Protection	Bank Angle	Material	BEHI Score	Category
U1	15-29%	55-79%	55-79%	21-60°	Clay/silt	15.8	Moderate
U2	15-29%	30-54%	30-54%	21-60°	Clay/silt	19.8	Moderate
U3	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
U4	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low

U5	90-100%	80-100%	80-100%	0-20°	Clay, <50% sand	15.8	Moderate
U6	90-100%	30-54%	30-54%	21-60°	Clay/silt	14.3	Moderate
U7	50-89%	55-79%	55-79%	21-60°	Clay/silt	11.8	Low
U8	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
U9	90-100%	55-79%	55-79%	21-60°	Clay, 25% sand	10.3	Low
U10	90-100%	55-79%	55-79%	21-60°	Clay, 10% sand	10.3	Low
U11	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
U12	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low

Table 2. University Branch BEHI data and scores.

West Branch

Stretch	Root Depth	Root Density	Surface Protection	Bank Angle	Material	BEHI Score	Category
W1	90-100%	80-100%	80-100%	0-20°	Clay/silt	5.8	Low
W2	90-100%	80-100%	80-100%	0-20°	Clay/silt	5.8	Low
W3	90-100%	80-100%	80-100%	0-20°	Clay, minimal sand	5.8	Low
W4	90-100%	80-100%	80-100%	21-60°	Clay/silt	7.3	Low
W5	90-100%	55-79%	55-79%	21-60°	Clay, 10% sand	10.3	Low
W6	90-100%	55-79%	55-79%	21-60°	Clay, 10% sand	10.3	Low
W7	90-100%	55-79%	55-79%	21-60°	Clay, 25% sand	10.3	Low
W8	90-100%	55-79%	80-100%	21-60°	Clay/silt	8.8	Low
W9	90-100%	55-79%	80-100%	21-60°	Limestone	8.8	Very Low
W10	90-100%	55-79%	55-79%	21-60°	Clay and limestone	10.3	Low
W11	90-100%	55-79%	80-100%	21-60°	Clay/silt	8.8	Low
W12	90-100%	55-79%	55-79%	21-60°	Clay, 25% sand	10.3	Low
W13	90-100%	80-100%	80-100%	21-60°	Clay/silt	7.3	Low

Table 3. West Branch BEHI data and scores.

East Branch

Stretch	Root Depth	Root Density	Surface Protection	Bank Angle	Material	BEHI Score	Category
E1	50-89%	30-54%	30-54%	21-60°	Sand, little mud	25.8	High
E2	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
E3	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
E4	90-100%	55-79%	55-79%	91-119°	Clay/silt	15.85	Moderate
E5	90-100%	55-79%	55-79%	21-60°	Clay, 20% sand	10.3	Low
E6	90-100%	30-54%	30-54%	81-90°	Clay, 5-10% sand	18.3	Moderate
E7	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
E8	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
E9	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
E10	90-100%	55-79%	55-79%	21-60°	Clay, 20% sand	10.3	Low
E11	90-100%	55-79%	55-79%	81-90°	Clay/silt	14.3	Low
E12	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low
E13	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low

E14	90-100%	80-100%	80-100%	21-60°	Clay/silt	7.3	Low
E15	90-100%	55-79%	55-79%	21-60°	Clay/silt	10.3	Low

Table 4. East Branch BEHI data and scores.

Location Data

Stretch name	Date	Start point	End point
U1	10/21/2012	N42°31.164', W92°27.909'	N42°31.152', W92°27.895'
U2	" "	N42°31.153', W92°27.858'	N42°31.168', W92°27.851'
U3	" "	N42°31.156', W92°27.811'	N42°31.155', W92°27.801'
U4	" "	N42°31.156', W92°27.782'	N42°31.158', W92°27.763'
U5	" "	N42°31.149', W92°27.632'	N42°31.146', W92°27.603'
U6	" "	N42°31.160', W92°27.296'	N42°31.155', W92°27.257'
U7	" "	N42°31.166', W92°27.226'	N42°31.150', W92°27.212'
U8	11/18/2012	N42°31.156', W92°27.202'	N42°31.151', W92°27.175'
U9	" "	N42°31.133', W92°27.032'	N42°31.133', W92°27.004'
U10	" "	N42°31.187', W92°26.877'	N42°31.185', W92°26.856'
U11	" "	N42°31.185', W92°26.856'	N42°31.186', W92°26.821'
U12	" "	N42°31.187', W92°26.877'	N42°31.185', W92°26.856'
W1	11/2/2012	N42°30.389', W92°27.881'	N42°30.394', W92°27.862'
W2	" "	N42°30.404', W92°27.845'	N42°30.408', W92°27.837'
W3	" "	N42°30.408', W92°27.837'	N42°30.412', W92°27.811'
W4	" "	N42°30.412', W92°27.707'	N42°30.420', W92°27.687'
W5	11/18/2012	N42°30.396', W92°27.531'	N42°30.380', W92°27.513'
W6	" "	N42°30.448', W92°27.418'	N42°30.447', W92°27.422'
W7	" "	N42°30.531', W92°27.299'	N42°30.539', W92°27.289'
W8	" "	N42°30.564', W92°27.178'	N42°30.550', W92°27.175'
W9	" "	N42°30.550', W92°27.175'	N42°30.561', W92°27.147'
W10	" "	N42°30.617', W92°27.099'	N42°30.618', W92°27.077'
W11	" "	N42°30.696', W92°27.026'	N42°30.700', W92°27.028'
W12	" "	N42°30.856', W92°27.002'	N42°30.820', W92°27.978'
W13	" "	N42°30.920', W92°26.804'	N42°30.937', W92°27.803'
E1	11/18/2012	N42°30.135', W92°26.993'	N42°30.144', W92°27.001'
E2	" "	N42°30.137', W92°27.031'	N42°30.141', W92°27.042'
E3	" "	N42°30.141', W92°27.042'	N42°30.142', W92°27.046'
E4	" "	N42°30.158', W92°27.060'	N42°30.162', W92°27.048'
E5	" "	N42°30.237', W92°27.932'	N42°30.222', W92°27.920'
E6	" "	N42°30.232', W92°27.908'	N42°30.227', W92°27.885'
E7	" "	N42°30.268', W92°27.848'	N42°30.278', W92°27.841'
E8	" "	N42°30.291', W92°27.833'	N42°30.305', W92°27.827'
E9	" "	N42°30.334', W92°27.811'	N42°30.357', W92°27.795'
E10	" "	N42°30.528', W92°27.708'	N42°30.543', W92°27.663'
E11	" "	N42°30.545', W92°27.643'	N42°30.549', W92°27.624'

E12	" "	N42°30.573', W92°27.594'	N42°30.588', W92°27.594'
E13	" "	N42°30.629', W92°27.583'	N42°30.635', W92°27.557'
E14	" "	N42°30.502', W92°27.502'	N42°30.502', W92°27.497'
E15	" "	N42°30.535', W92°27.402'	N42°30.542', W92°27.387'

Table 5. Location and date data for each DRC stretch.

University Branch

Figure 6. Stretch U2

Stretches U1 and U2 were similar in that they were in an urban area, had root density and surface protection of 30-79%, were composed of clay/silt, had a bank angle of 21-60°, and had root depth of 15-29%. Figure 6 represents conditions at U1 and U2. These stretches had a Moderate BEHI score.

Figure 7. Stretch U4

Figure 7 represents the conditions at U3 and U4. These stretches had a Low BEHI score, and were in an urban area. A drainage pipe was located in the middle of stretch U3. These stretches had a bank angle of 21-60°, surface protection and root density of 55-79%, and root depth of 90-100%. The banks were composed of clay/silt.

Figure 8. Stretch U5

Stretch U5 had a Moderate BEHI score due to composition of the bank, which was greater than 50% sand. This adds 10 points to the BEHI score. The other properties of the bank make it resistant to erosion, and can be seen in Figure 8. These include a bank angle of 0-20°, root density and surface protection of 80-100%, and root depth of 90-100%. This stretch was located in an urban area.

Figure 9. Stretch U6

Stretch U6 had a surface protection and root density of 30-54%, putting it into the Moderate BEHI category. The minimal vegetation cover can be seen in Figure 9. The bank angle was 21-60° and root depth 90-100%. The bank was composed of clay/silt and located in an urban area.

Figure 10. Stretch U9

Figure 10 represents the Low BEHI score conditions at U7, U8, U9, U10, U11, and U12. U9 and U10 were composed primarily of clay/silt and less than 25% sand, which did not affect their score. The rest of these stretches were composed of clay/silt. All had a bank angle of 21-60°, root density and surface protection of 55-79%, and root depth of 90-100%.

West Branch

Figure 11. Stretch W1

Figure 11 represents the Low BEHI conditions at W1, W2, and W3. These stretches had a bank angle of 0-20°, root depth of 90-100%, and surface protection and root density of 80-100%. W3 contained an insignificant amount of sand in its banks, and W1 and W2 were composed of clay/silt. There was a drainage pipe located at the end of W3. They were located in a semi-urban area.

Figure 12. Stretch W4

W4 had a bank angle of 21-60°, root depth of 90-100%, and surface protection and root density of 80-100%. These properties can be seen in Figure 12. This stretch had a Low BEHI score, and was composed of clay/silt. The location was semi-urban.

Figure 13. Stretch W6

Figure 13 represents stretches W5, W6, and W7. These stretches were in a rural area, and had a Low BEHI score. All had root depth of 90-100%, root density and surface protection of 55-79%, and bank angle of 21-60°. They also all contained small amounts of sand, but were primarily composed of clay/silt.

Figure 14. Stretch W8

Stretch W8 was in a rural wooded area, and the BEHI score was Low. The bank was composed of clay/silt. As can be seen in Figure 14, a significant amount of rock coverage provided high surface protection of 80-100%. The root density was 55-79%, root depth 90-100%, and bank angle 21-60°.

Figure 15. Stretch W9

Stretch W9 was unique in that the bank was composed primarily of limestone bedrock. This created an automatic BEHI rating of Very Low. As can be seen in Figure 15, the surface protection in this stretch was 80-100%. The root density was 55-79%, root depth 90-100%, and bank angle 21-60°.

Figure 16. Stretch W10

Figure 16 represents the conditions at W10 and W11. Both had a BEHI rating of Low, and were located in a rural area. W10 was primarily composed of clay/silt, but also contained some limestone float. W11 was composed of clay/silt, but had more rock coverage on its banks resulting in higher surface protection than W10. Both had bank angles of 21-60°, root density of 55-79%, and root depth 90-100%.

Figure 17. Stretch W12

W12 had a Low BEHI score, and was located in a rural area. The bank was composed primarily of clay/silt and contained a small amount of sand. As can be seen in Figure 17, the bank angle was 21-60°, root depth 90-100%, and it had surface protection and root density of 55-79%.

Figure 18. Stretch W13

W13 was located in a more urban area, and had a Low BEHI score. It had surface protection and root density of 80-100%, bank angle of 21-60°, and root depth 90-100%. Only the left bank could be considered as the right bank was covered with rip rap to stabilize it artificially.

East Branch

Figure 19. Stretch E1

Due to the high sand content of the banks and the low surface protection and root density of 30-54%, E1 was determined to have a BEHI rating of High. The root depth was 50-89% and bank angle was 21-60° at this location. E1 was in a rural area.

Figure 20. Stretch E2/E3

Figure 20 represents the conditions of E2 and E3, which were adjacent stretches. As can be seen in Figure 20, they have a root depth of 90-100%, bank angle of 21-60°, and surface protection and root density of 55-79%. They had a BEHI score of Low, and were located in a rural area. The composition of the banks was clay/silt.

Figure 21. Stretch E6

E6 was unique in that the bank was nearly vertical at 81-90°. The vertical nature of the bank can be seen in Figure 21. The root density and surface protection for the rest of the bank was 30-54%, but the roots were 90-100%. The bank was approximately 5-10% sand, but it was composed primarily of clay/silt. The overall BEHI rating was Moderate.

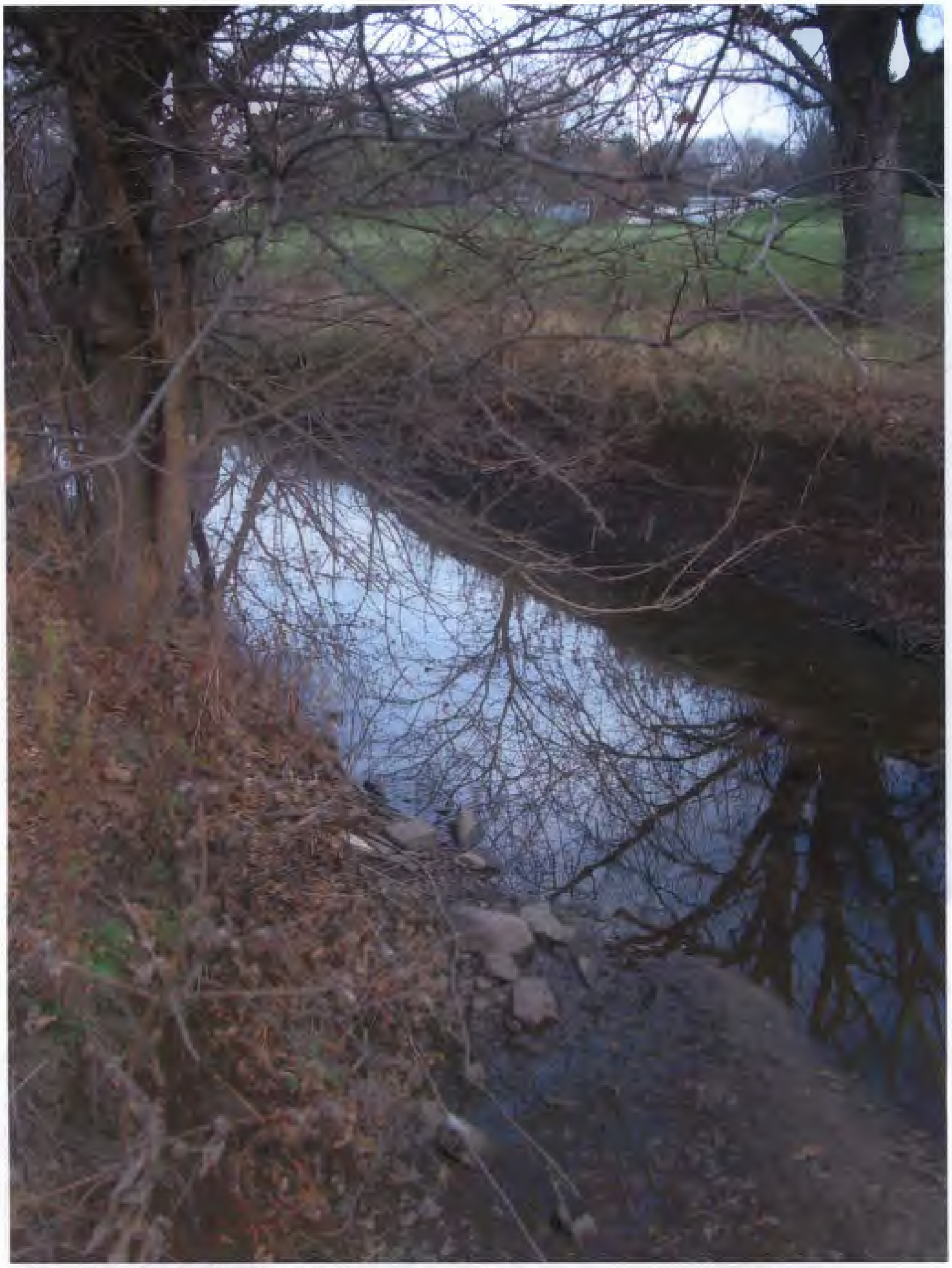

Figure 22. Stretch E9

Figure 22 represents all of the Low BEHI score stretches between E7 and E13. These stretches all had root depth of 90-100% and root density and surface protection of 55-79%. E10 had a considerable amount of sand, but not enough to affect its BEHI. The rest of the bank stretches were composed of clay/silt. E11 had a bank angle of 81-90°, and the rest were 21-60°. Most of the stretches were in a semi-urban or urban area.

Figure 23. Stretch E14

Figure 23 shows the dry bed conditions that were encountered in many stretches of the stream due to the dry fall conditions. E14 had a Low BEHI score, and was in an urban area. The root density and surface protection were 80-100%, the bank angle 21-60°, and the root depth 90-100%. The bank was composed of clay/silt.

Figure 24. Stretch E15

E15 had a Low BEHI score, and was located in an urban area. The bank was composed of clay/silt and the root depth was 90-100%. The root density and surface protection were 55-79% and the bank angle was 21-60°. As can be seen in Figure 24, the left bank was covered in rip rap, so only the right bank was considered.

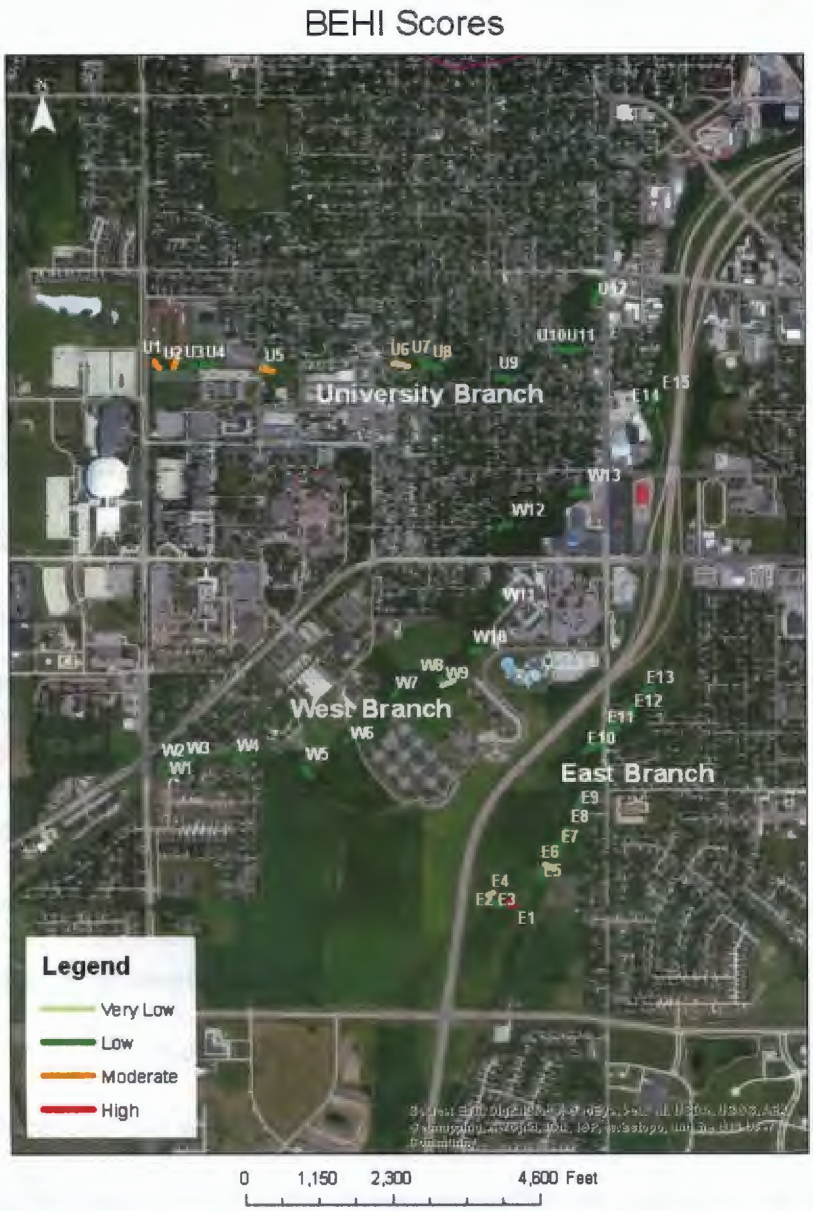

Figure 25. Locations of assessed stretches and the BEHI represented by color.

Figure 25 shows the locations of the assessed stretches on a map of Cedar Falls. Ratings are represented by color. Green stretches have a Low BEHI, orange stretches have a Moderate BEHI, and red stretches have a High rating.

DISCUSSION

The Environmental Geology group (Beason, et al., 2005) found that urban areas did not have as stable banks as rural areas. Developing land without including proper drainage and infiltration practices increases the amount of runoff in urban areas. The increase in runoff increases the erosivity of the bank, which would lead to more bank erosion.

The University Branch is primarily urban, which is likely why there are areas with a Moderate BEHI score. This is in agreement with the results of the Environmental geology group. These stretches are near the beginning and middle of the branch, and the rest of the branch appeared to be very resistant to erosion. Many areas of this branch were covered in rip rap to artificially stabilize the bank, limiting the number of stretches that could be assessed. Stretches with Moderate BEHI score included U1, U2, U5, and U6. U1 and U2 had shallow root depth. U5 was composed of a significant amount of sand. U6 had limited surface protection and root density. These areas could be considered erosion hotspots for the University Branch and should be monitored further.

The West Branch was located mostly in rural areas, and had a Low BEHI rating at all locations that were assessed. Like the results of the University Branch, this agrees with the conclusions drawn by the Environmental Geology group in that rural areas are more stable than urban areas. No areas in the West Branch could be considered hotspots for erosion, and it had the overall lowest ratings of the three assessed branches.

The East Branch contained the most extreme BEHI scores and unique banks. E1, E4, and E6 could be considered areas with high erosion potential, E1 having a High rating and the others having a Moderate rating. E1 was very sandy and had little surface protection. E4 and E6 had very steep banks. Pictures were not taken of several of these banks, such as the undercut E4 bank. These findings did not follow the general trend that rural areas have more stable banks. The more urban areas in this branch had Low BEHI ratings.

Although it does not fit with the general trend, it does make sense that banks are eroding in rural areas as well as urban areas. Urbanization is one anthropogenic source of erosion, however agriculture and land use change are also key sources of anthropogenic erosion (Vadnais et al., 2012). Therefore, it is not unusual for the rural areas of the East Branch to have High and Moderate BEHI scores. Excessive runoff caused by nearby farming practices could be having an effect in certain areas, such as E1. The trend in Dry Run Creek of urban areas having less stable banks than rural areas could be due to the good runoff management and infiltration practices of farmers with land near the creek.

Remedial actions should be taken in the High and Moderate BEHI stretches. The Iowa DNR (Anonymous, 2006) suggests several erosion control measures that could be effective at stabilizing these banks. One of the most practical actions would be to seed the streambank which involves planting grasses to reinforce banks with limited surface protection. Another option would be live stakes, which involves the placement of woody plants and tree cuttings on to a bank so that they with grow and stabilize the bank with their roots and surface growth. A similar method would be tree revetment, which is the planting of trees on the banks (Anonymous, 2006). These would be good options for U1, U2, U6, and E1, all of which scored low on surface protection or root depth. A different method is that of Iowa vanes. With this method, vanes are placed in the streambed which redirect the flow of water, allowing sediment to be recollected on the eroding bank (Anonymous, 2006). This may be a better choice for E4 and E6, which are steep banks that could use more sediment deposited on them to possibly create a gentler grade. U5 and E1 may also benefit from Iowa vanes as they are composed of significant amounts of sand. New sediment deposits could add more clay/silt to those banks.

CONCLUSIONS

The majority of the stretches of Dry Run Creek examined in this study were found to have Low BEHI scores, which indicates that most banks are in good condition. The "typical" bank had nearly 100% root depth to bank height ratio, root density and surface protection between 55-79%, and a bank angle around 40°. This resulted in a score of 10.3, putting it in the Low BEHI category. The sections that were found to have a Moderate and High score could be considered hotspots. Monitoring these areas and implementing remedial actions could help improve the health of the stream, as well as provide more information of current erosion rates.

This BEHI assessment shows that most of the banks in Dry Run Creek are stable and not in danger of excessive erosion. This is significant in that it shows that erosion is not the primary cause of the unhealthy bacteria levels and other problems with the creek that resulted in it being put on impairment lists. It could also show that many of the stabilizing efforts that have already been put in place, such as best management practices to reduce runoff or the addition of rip rap, are effective at controlling erosion rates. Stabilizing the areas with a High or Moderate BEHI will only help the health of the creek, and could eliminate the problems all together. Erosion and excessive runoff play a part in destroying aquatic habitats, which is a problem in Dry Run Creek (Palmer and Buyck, 2011). Adding stability to all areas of the banks that are in danger of excessive erosion will reduce the amount of sediment entering the stream, and help banks stay intact during flooding.

Limitations to this BEHI study were primarily due to the season in which the study was done. Measurements were taken during the fall, which was a dry season in Iowa. Because of this, normal plant coverage might have been reduced so an accurate determination may not have been obtainable. Additionally, water levels in the creek were very low in some stretches during November. The level of the water formed the lower boundary of the bank height, so lower water levels increased the bank height. This may have affected the root depth metric, which compares the root depth to the total bank height. Greater bank height would make the root depth measurement smaller if the water level was lower than normal. Another limitation was that in the field, I did not make an attempt to distinguish between clay and silt. The only distinction that was made was between sand and fine-grained material, which limits the usefulness of this study in deeper analysis of bank material. Neither silt nor clay, however, had an effect on the final BEHI score.

A BEHI study gives an idea of the erodability of stream banks. Further study of Dry Run Creek is necessary to draw complete conclusions about the health of the stream. A Near Bank Stress (NBS) study would give information about the other component of bank erosion, erosivity. The metrics assessed for the NBS study are channel pattern, ratio of radius of curvature to bankfull width, ratio of pool slope to average water surface slope, ratio of pool slope to riffle slope, ratio of near-bank maximum depth to bankfull mean depth, ratio of near-bank shear stress to bankfull shear stress, and velocity profiles. Bank profiles are measured in part by using bank erosion pins. Bank pins are used to determine the rate and magnitude of bank erosion. The pins are installed and left for one year, then the lateral migration of the pins are determined (Creech, 2010). The BEHI and NBS studies complement each other, and together can be used to evaluate the Bank Assessment for Non-point source Consequences of Sediment (BANCS). The BANCS method is used to predict stream bank erosion rates (EPA, n.d.).

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APPENDIX A

Modified Bank Erosion Hazard Index (BEHI) Field Form

Date:______________________ **Personnel:**____________________________________

Location:____

(Circle one in each column)

Root Depth (% of BH)	Root Density (%)	Surface Protection (Avg. %)	Bank Angle (degrees)
90-100	80-100	80-100	0-20
50-89	55-79	55-79	21-60
30-49	30-54	30-54	61-80
15-29	15-29	15-29	81-90
5-14	5-14	10-14	91-119
< 5	< 5	< 10	> 119

Comments:

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