Deer Creek Bank Erosion Monitoring
Past, Present, and Future

Litzsinger Road Ecology Center
Missouri Botanical Garden

A project for completion of degree
MS Environmental Studies
Antioch University New England
Maisie Tyler Rinne
2013

"Sediment can cause great harm to aquatic habitats and is arguably the most pervasive and costly form of water pollution in North America (Osterkamp, 1998)" (Peacher, 2011)

Abstract

The Missouri Botanical Garden's Litzsinger Road Ecology Center (LREC) utilized data collected from surveys of streambank and streambed profile measurements, various visual assessments, and a bank erosion potential rating (BEPR) to develop stream profile graphs and maps and chart streambank changes over time due to accelerated streambank erosion of a 785 meter reach of Deer Creek located on LREC property in St. Louis County, Missouri. Deer Creek is a major contributing 4th order stream to the Deer Creek Watershed which flows through twenty-two municipalities of St. Louis County, Missouri (Deer Creek Watershed Alliance, 2013). The section of Deer Creek that flows through the LREC property in the city of Ladue is a unique, relatively untouched stretch of the creek and is the focus reach of this study (figure 1). Though streambank erosion, sedimentation, and meander migration does occur naturally and is an important process in the hydrologic/sediment cycle, the meanders present in this reach are likely the stream's response to watershed disturbances of upstream channelization and excessive bedload caused by urbanization (Intuition & Logic, 2005). Data collected in this study will be useful in tracking changes over time as further data is collected in the future using the replicable protocols created by Maisie Tyler Rinne, MS Candidate Environmental Studies, Antioch University New England with the advice of LREC Restoration Ecologist, Danelle Haake.

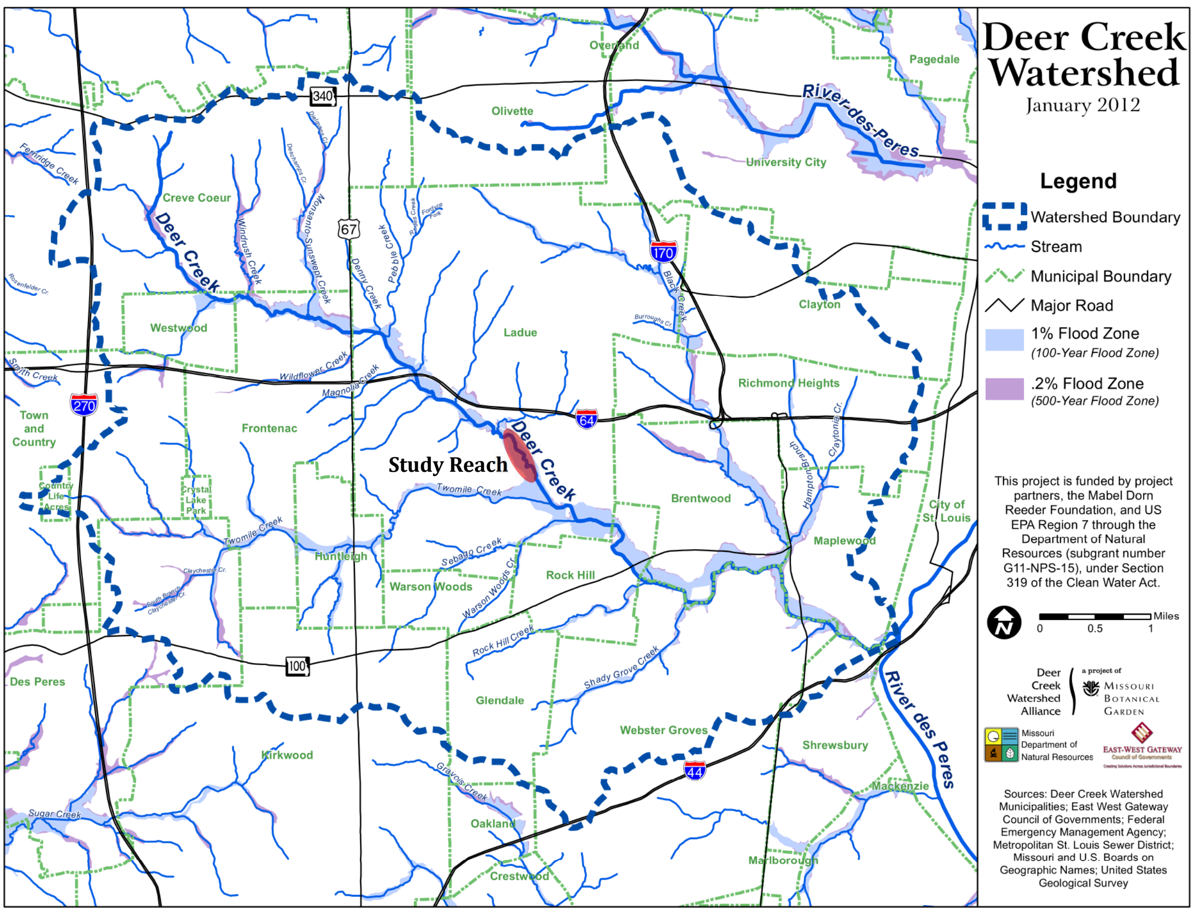

Figure 1: Map of study area within greater watershed (Deer Creek Watershed Alliance, 2013)

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Introduction

This study was initiated by Maisie Tyler Rinne with the help of Danelle Haake to create a comprehensive stream bank erosion monitoring protocol that would incorporate historical data and be informative, functional, and replicable. Data from this study was used to create streambank profile maps that can be compared over time and to rate the stream bank erosion potential according to Rosgen's (1993) Bank Erosion Potential Rating (BEPR). Additionally, photo monitoring at several points along the reach were conducted per past photo monitoring protocol and visual stream assessments were gathered and recorded to contribute to a holistic understanding of the dynamics of this study area.

Two different sets of reference points were used for data collection. A set of 39 points along the creek edge were used in the Bank Point method which provided general information on the location of the stream bank's edge that was charted in ArcGIS for change over time. A separate six reference points along the creek's edge were used to conduct intensive cross section surveys including bank profile, streambed profile, visual assessments, photo monitoring, and Bank Erosion Potential Ratings (BEPR). Table 1 displays the measurements conducted at each reference point and the outcomes, short-term and long-term goals of each.

Table 1: Logic Model

Reference Points Used	Data Collected	Outputs	Short Term Goals	Long Term Goals
39 Bank Points	Distance from bank point to bank edge Distance from bank point to gravel edge	Stream edge profile Gravel edge profile	Compare profile changes over time Collect data every 5 years; collect data at crucial points annually	Use mapped bank edge for educational purposes
6 Cross Section Points	Stake to Rod Bank to Rod (intervals) Bank Height Streambed Width Streambed Details Width of Wetted Area	Six detailed cross section profiles	Compare profile changes over time Collect data every other year to ensure continuation of methods.	Predict future erosion rates Understand bank erosion effects from upstream watershed adjustments
	Root Density % Bankfull Elevations Bankfull Angles Bank Composition	Bank Erosion Potential Rating (BEPR)	Utilize a widely accepted protocol Locate areas of concern	Prioritize future restoration efforts Utilize data for outreach and communications
	Weather Streambank Conditions Bed Composition Percent Embeddedness of Cobble Substrate Algae Coverage	Visual Assessment	Complete assessment of 6 sections of the stream	Contribute to a systems approach to understanding the dynamics of this waterway
	Photographs	Photographic Records	Comparative analysis	Educational tool

Background Information

Previous Deer Creek Studies

Several bank erosion studies of the reach of Deer Creek that flows through Litzsinger Road Ecology Center have been conducted in the past. These various studies were unearthed by Maisie Rinne and Danelle Haake and synthesized for current use.

The earliest study found was conducted by Julie Mann Edge, MS in 1996. She wrote a document titled “Riparian and Watershed Habitat Characteristics of Deer Creek” that can be found in the LREC files. In her study, Edge collected data for six cross sections of Deer Creek and took photographic records of these six sites. Though the study only included a handful of measurements and little mention of methods used, Edge was able to hand draw graphical depictions of the six cross sections which served as the foundation for the current study. In order to make Edge’s data useful in comparison with current records, Rinne created data points and digital graphs of Edge’s data which can now be found in the Cross Section Data document in the glass house shared drive. It appears that the photographic documentation at these six points continued to be recorded annually from this point forward.

In 2004, an intensive Cross Section Survey was conducted by Jennifer Brown and Malinda Slagle. Brown and Slagle utilized Edge’s six reference points to collect their data. Their report indicates that they were able to locate Edge’s six points based on photographic records. They then installed permanent markers at these six points for continued future reference. Brown and Slagle’s methods were clearly outlined and served as a valuable reference for the current study. Their methods were based on methods described in the “Streamkeeper’s Field Guide” (Murdoch et al. 1996). Rinne and Haake decided the 2004 methods could be improved to include more recorded data along the stream banks, which is evidenced in their methods. 2004 marks the date of the latest recorded cross section data before the current study.

The following year, a few studies of Deer Creek emerged. Starting in 2005, an intensive two-year mapping project was conducted by Susan Lambert and various volunteers. The data and methods utilized in this project are located in a manila folder at the desk of Danelle Haake titled “Creek Mapping.” To our best knowledge, the maps themselves were created by hand on large pieces of graph paper located in storage at the Glass House at Litzsinger. Though specific cross sections were not measured in this study, their work depicts the seemingly earliest record of Deer Creek mapped. The tools used for this study proved helpful in conducting the current study and can be found in a large plastic transparent bin in the Glass House.

Also in 2005, Intuition & Logic conducted a study of Deer Creek on the Litzsinger Property that aptly describes the watershed and the reach of creek that flows through LREC. It also introduces and explains concepts in fluvial geomorphology, which are useful in understanding this reach of Deer Creek as a piece of a larger system. The Intuition & Logic *Stream Study of Deer Creek* Executive Summary can be found on the Litzsinger Road Ecology Center website at http://www.litzsinger.org/streamstudies.html. Though the specific data recorded for this study has yet to be found, the Executive Summary proved useful in providing a context for the current study. The following excerpt from the Intuition & Logic *Stream Study of Deer* Creek Executive Summary explains the reach of Deer Creek that flows through the Litzsinger Road Ecology Center.

Deer Creek in Context

Excerpts from *Stream Study of Deer* Creek, Intuition & Logic. 2005

http://www.litzsinger.org/research/streamstudy.pdf

> This report addresses deposition and erosion management through the application of methods based in the science of fluvial geomorphology. Fluvial geomorphology is the discipline that describes how a stream or river changes the landform. As the quantity or timing of water introduced to streams change, so do the streams themselves. The flow of water is the driving force that is balanced by the resisting force of the streambed and channel geometry. It is the interaction between these two types of forces that determines how deposition and erosion occur. Therefore, a thorough understanding of both the driving and resisting forces is required for any successful management.
>
> Based on the results of our analysis, the study reach of Deer Creek is adjusting via meander migration or lateral planform adjustment. While meander migration is a natural phenomenon that occurs without anthropogenic influence, historic aerial photograph review and field reconnaissance data suggests that lateral meander migration along Deer Creek may have been provoked by channelization, a loss of channel sinuosity, and excessive bedload. Evidence of meander adjustment consists of aggradation of bed material along with a pattern of bank scouring and erosion occurring opposite wide, steep-sided point bars.
>
> Historic aerial photographs were examined for evidence of changes in the watershed that may have provoked the adjustments observed today. Digital aerial photographs were available from 1937 to 2002. The earliest aerial photographs reveal important background information about the watershed prior to widespread sub-urban development.
>
> Prior to 1953, much of the Deer Creek Watershed from Litzsinger Road north to Highway 40 was undeveloped forest. By 1968, increasing sub-urban development resulted in a conversion of the original forest cover to large residential lot development. The once meandering channel had been straightened or channelized to accommodate residential development south of Highway 40. Additional channelization occurred between 1968 and 1981, with the removal of a large meander loop immediately upstream of the Litzsinger Ecology Center property. The net effect of channelization from 1968 to 1997 was an estimated loss of nearly 1, 000 linear feet of channel, or a reduction in reach sinuosity (channel length/valley length) from 1.9 to 1.4.
>
> Based on our geomorphic analysis, the study reach of Deer Creek appears to be adjusting in planform via meander migration. Meander migration includes lateral channel shift, expressed as an annual rate of distance moved perpendicular to the channel centerline, and down-valley migration, the annual distance moved downstream along the river valley. While meander migration is a natural phenomenon that occurs without anthropogenic influence, it may be exacerbated by watershed disturbances such as land use changes or urbanization, bridge or culvert construction, or the removal of riparian vegetation. Lateral meander migration along Deer Creek may have been provoked by loss of channel sinuosity due to channelization and excessive bedload. Since the channel bed is relatively resistant to incision, with exposed bedrock observed throughout the study reach, the stream has responded to increased flows by decreasing its slope via meandering, thereby increasing

the channel length over the same change in elevation.

Evidence of meander adjustment includes the aggradation of bed material accompanied by the downstream progression of severe bank scouring opposite wide, steep-sided point bars. Erosion and mass wasting along meandering reaches occurs preferentially on the outside of meanders and extends downstream from the apex of the meander. Point bars are typically semi-consolidated, with steep downstream angles, and a bar width that exceeds the existing low flow channel width.

<u>Methods Old and New</u>

Methods used for this study were created based on previously used methods and researched methods. For the Cross Section points, it was important to use the existing reference points to maintain consistency with past data as well as use the 2004 methods as much as possible so as to be able to use that information in comparison with the current and future studies. (See the attached "Review of Streambank Erosion Monitoring Methods" for a synopsis of common and current methods). It was decided to make small improvements to the 2004 methods for the bottom of the streambed measurements so as to include more detailed information.

Changes in Protocol 2004-2013

Streambed Measurements: In 2004, the protocol was to take measurements along the bottom of the streambed every half-meter. The current protocol is to take measurements every approximate half-meter, making sure to include major features and streambed changes as well as precise wetted edges and thalwegs.

Bank Measurements: Current protocol is to measure bank to rod every approximate half meter starting from .2 meters from the bottom of the bank working up toward the top of the bank. The 2004 protocol for bank measurements was the same as its streambed measurements, recording height every lateral half meter. The new protocol allows for more information to be recorded including bank undercuts and other major features that would have been missed with the 2004 protocol.

Cross Section Location: Though cross section starting points are located using the permanent reference points located along the banks' edge, the 2004 protocol required a declination reading to find the opposite bank point. This was also the protocol used to record data for the current study. However, upon graphing the data and comparing the current cross sections with the 2004 cross sections, there seemed to be large discrepancies, which might be explained by inaccurate declination reading causing only minor errors toward the beginning for the cross section, but major differences further from the starting point. To minimize angle error, we later installed permanent posts opposite of every reference point to mark the exact opposite bank point for each cross section. Care was taken to ensure the posts were installed as near the point used in the current study as possible. In the future, these posts will serve as permanent opposite bank markers. They are green stakes marked with white paint and can be located using the recorded declinations on the data collection sheets.

String and Tape Method: To increase accuracy of height measurements along the streambed, the current protocol requires a taught, leveled string spanning from bank to bank from which height measurements on the surveyor's rod would be read. Underneath the string is a taught-as-possible tape measure to measure distance. It was noted in the 2004 protocol that the tape measure would sag but was still used to measure height. This change in protocol might explain some of channel depth differences evident in the comparison graphs.

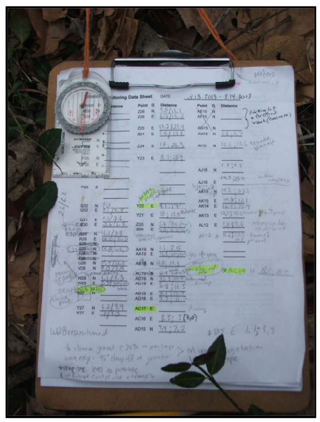
In addition to the above changes, methods were added to improve and standardize the visual assessment records at every cross section. A new method was also added to rate the bank erosion potential by using Rosgen's (1993) Bank Erosion Potential Rating protocol.

Methods previously used to collect Bank Point data were not recorded and therefore not replicable. However, previous data records exists for a handful of points in the years of 1995, 1996, and 2009. In 2010, the Bank Point grid system was updated to replace missing reference points and add new reference points in the southern section of the stream. The current recorded data is the first data on record for all 39 bank points with a replicable protocol. The protocol was created with the intention to mimic previously recorded data, to utilize existing reference points, to minimize insertion of reference points that might contribute to bank erosion, to be useful in creating a GIS-based map of the bank's edge, and to be easily replicable by staff, interns, or trained volunteers. It is recommended that in the future, reference points be added to the East side of Deer Creek and the protocol be updated to include East bank data.

2013 Study: Methods, Analysis, and Discussion

Bank Points

<u>Bank Point Locations</u>
Bank Point measurements were taken at 39 points along Deer Creek on the LREC property. Collected data was then used to create a stream profile in ArcGIS that can be charted over time. Bank points are permanently marked on the Litzsinger property by tagged metal rods. In cases where a rod had sunken over time, a piece of rebar was placed next to the tagged metal rod. Rods are 15 meters apart from one another and were originally created as a grid across the prairie and woodland as point markers for plant monitoring. Points used in this study are those listed on the data sheet.



<u>Bank Point Protocol</u>
Purpose: Record distance from permanent marker to bank edge and from permanent marker to the gravel edge in order to create a mapped profile of the bank and gravel edges.

Materials: Data sheet, Clipboard, Map of points, Print out of protocol instructions, Camera, Measuring tape in meters (could use transit instead), Compass, Pencils

Protocol:

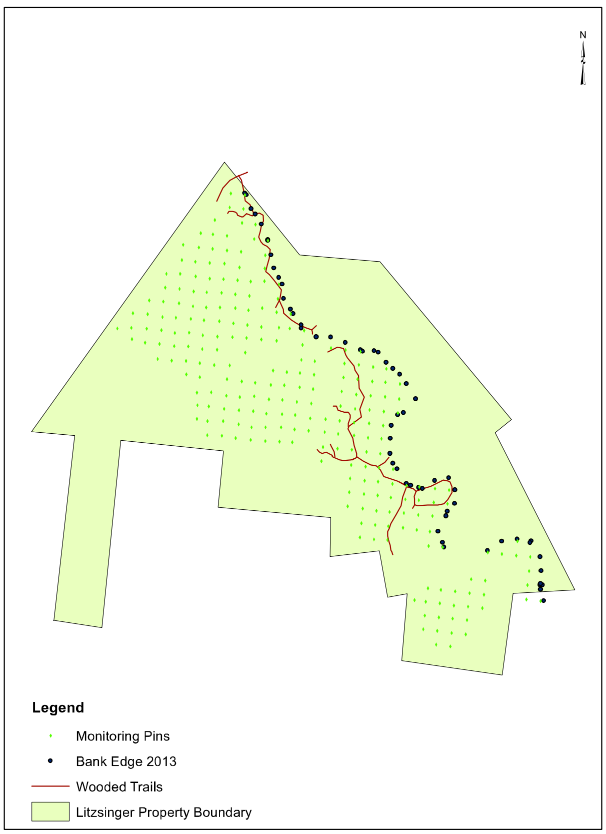
1. At each monitoring point listed on the data sheet, place one end of the measuring tape on the monitoring post (not the rebar).
2. Holding one end of the measuring tape in place, have a second person travel with the other end of the tape in the distance shown on the data sheet (N for north; S for south, etc).
3. Keeping the tape measure as level as possible, determine and record the distance in meters to:
    a. **The eroded edge** as defined by the point where the ground begins to slope at a 45 degree angle or greater.
    b. **The gravel edge** as defined by the first point where gravel presence is 25 percent or greater.

As monitoring posts are lost due to erosion, posts further into the site should be added to the data sheet to allow monitoring to be conducted along the entire stream corridor. Currently, monitoring posts are only located on the east side of Deer Creek. As posts are added on the west side of the creek, these should be added to the erosion monitoring data sheet. Monitoring of all points should be conducted every 3 years. Monitoring of the following key points should be conducted annually: Q31, W28, Y21, Z20, AC19, and AC16.

Bank Point Data Analysis
Collected measurements should be entered into the Excel spreadsheet in the glass house shared file titled “Bank Point Protocol.DataSheets.Recorded Data.” Start a new tab for the new data mimicking the 2013 data tab and also add the new data into the “Combined Data” tab for comparison.

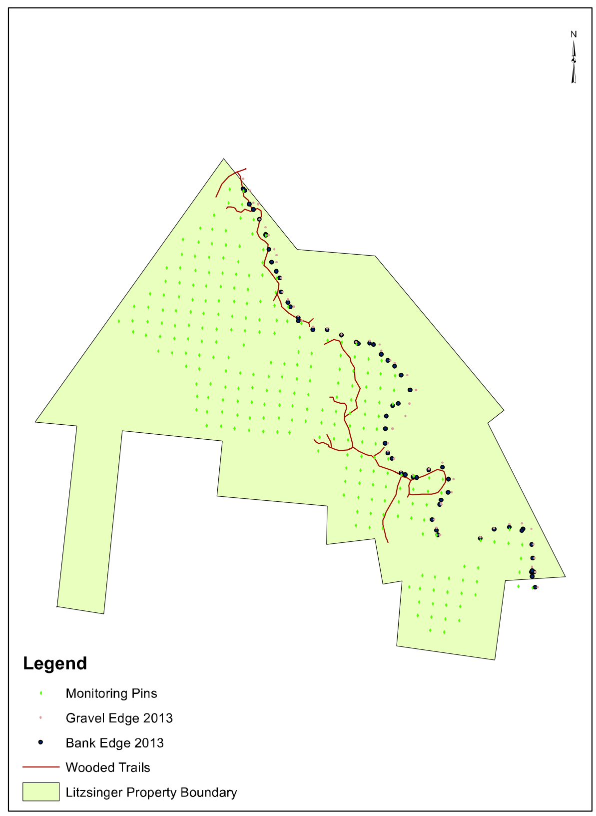
Data should then be entered into the Excel spreadsheet titled “Pin_Coortinates_Bank.” Create a new column for the year of your data collection and input data accordingly. These coordinates can then be imported into ArcGIS to create a profile drawing of the bank’s edge that can be used in comparison with previously recorded data. For instructions on inserting data in ArcGIS, visit http://www.uhh.hawaii.edu/~sdalhelp/docs/ht_xls_to_shp.pdf or view the pdf saved in the glass house shared drive in the folder titled “Maisie.” As future data is collected and imported into ArcGIS, the changes in bank and gravel edges should become visibly evident.

Litzsinger Road Ecology Center Deer Creek Bank Erosion Study



Created by Maisie Rinne, 2013

Litzsinger Road Ecology Center Deer Creek Bank Erosion Study



Created by Maisie Rinne, 2013

Bank Point Results and Discussion
It is the hope of this study that, with the addition of future data, these maps will be used for educational purposes, illustrating the changing bank edge over time. Though various bank points had been measured in the past (1995, 1996, 2009), methods used to collect this information was unrecorded and therefore not useful in comparing with current measurements. Therefore, this is the first full set of recorded data. In the future, all 39 points should be monitored every 3 years with crucial points monitored annually. Another recommended project for the future is to improve the visuals of the above maps.

Cross Sections

Cross Section Locations

An in-depth study of six cross sections of Deer Creek on the LREC property was conducted utilizing a combination of methods from various sources to best fit LREC's needs. The locations of the six cross sections used in this study were chosen based on the use of the same or similar locations in prior studies. In 2004, permanent stakes were inserted to mark these six locations which were approximated to be in the same locations as a 1996 study. The stakes are located at the following UTM coordinates on the banks of Deer Creek and are indicated by green metal stakes with white painted tips. For this study, bank side is determined by looking downstream, i.e., the right bank is on your right side as you are looking downstream. Across the creek from each reference point is another permanent stake (installed in 2013), indicating the exact opposite point for cross section data collection.

R1 – 728469E, 4278282N (on right bank)
R2 – 728366E, 4278328N (on right bank)
R3 – 728361E, 4278384N (on left bank)
R4 – 728328E, 4278458N (on right bank)
R5 – 728308E, 4278489N (on right bank)
R6 – 728200E, 4278586N (on right bank)

Cross Section Protocol

Purpose: Collect qualitative and quantitative data to contribute to an in-depth analysis of the streambank health and changes over time.

Materials: Data sheets, Clipboard, Pencils, Orange plastic stakes (2), Long Rebar (1), Tape measure in meters (2), Small levels (2), Surveyor's Rod, Rod level, String on spool, Compass, Waterproof boots/waders, Camera

Data Collected:

- Cross Section measurements
- Visual assessment
- Photographic records (protocol located in the glass house shared drive)
- Bank Erosion Potential Rating (optional)

Danelle Haake and Maisie Rinne measure the bank profile. 2013

Danelle Haake and Maisie Rinne record measurements along the streambed. 2013

Protocol:

1. Locate the permanent reference point and indicate your location on the data sheet as well as the date, time, and names of participants.
2. Note the recorded compass bearings on the data sheet and orient yourself from the permanent reference point to the Top of Bank (TB). Mark this point (TB) with an orange stake or piece of rebar. Since often you cannot place the stake directly on the bank's edge without further eroding the bank, place the stake a safe distance from the bank's edge. Measure and record the distance from the reference point (RP) to the stake you just placed to mark the Top of Bank (TB).
3. Use the recorded compass bearing on your data sheet to locate the permanent marker on the opposite bank.
4. Attach the measuring tape and then the string to the stake at the Top of Bank (TB) and walk them across the streambed to attach them to the permanent marker on the other side.
5. Using a level, ensure that the string is level across the channel and that one of the ends of the string is touching the ground. Secure the tape measure under the string as taught as possible, though it will sag a bit regardless (see figure 2).
6. Returning to the starting side, identify the Bottom of the Bank (BB) and place the surveyor's rod at this point, keeping it level using the rod level.
7. Record Bank Profile Measurements:
    a. Measure and record the distance from the TB to the actual Edge of Bank (EB).
    b. Measure and record the distance from the stake (TB) to the Surveyor's Rod.
    c. Starting about .2 meters from the Bottom of the Bank (BB), measure the distance from the bank to the Rod every approximate half meter up as indicated on the Rod until you are within .5 meters from the top. Use a level to ensure accuracy. Be sure to include major changes in the bank profile, regardless of the approximate .5 meter measurements.
    d. Measure the height of the Rod from the BB to the TB by reading the point at which the string (not the tape measure) crosses the Rod.
8. Record Streambed Profile Measurements:
    a. Moving the Rod approximately .5 meters across the channel at a time, record:
        i. Distance from Top of Bank (TB) to Rod
        ii. Height of bank as indicated on the Rod by the string
        iii. Depth of water (as appropriate)
    b. In moving the Rod across the streambed, make sure to stop at each wetted edge and the Thalweg and mark these points on your data sheet with WE for Wetted Edge and TW for Thalweg.
    c. Record streambed profile measurements until you reach the Bottom of the opposite Bank (BB). After you have recorded data at the opposite BB, keep the Rod at the BB to record the following data.
9. Record opposite Bank Profile Measurements
    a. Starting about .2 meters from the BB, measure the distance from the bank to the Rod every half-meter up as indicated on the Rod until you are within .5 meters from TB.
    b. Record the total distance from the starting point to the actual Edge of Bank (EB).
10. If there is a difference in bank heights, record the difference on the data sheet.
11. Record a rough sketch of the cross section on your data sheet.
12. Record Visual Assessment data as indicated on the qualitative data sheet.
13. Record Bank Erosion Potential data as indicated on the BEPR sheet.
14. Enter measurements into Xcel to make graphs and compare data with 2013 study.

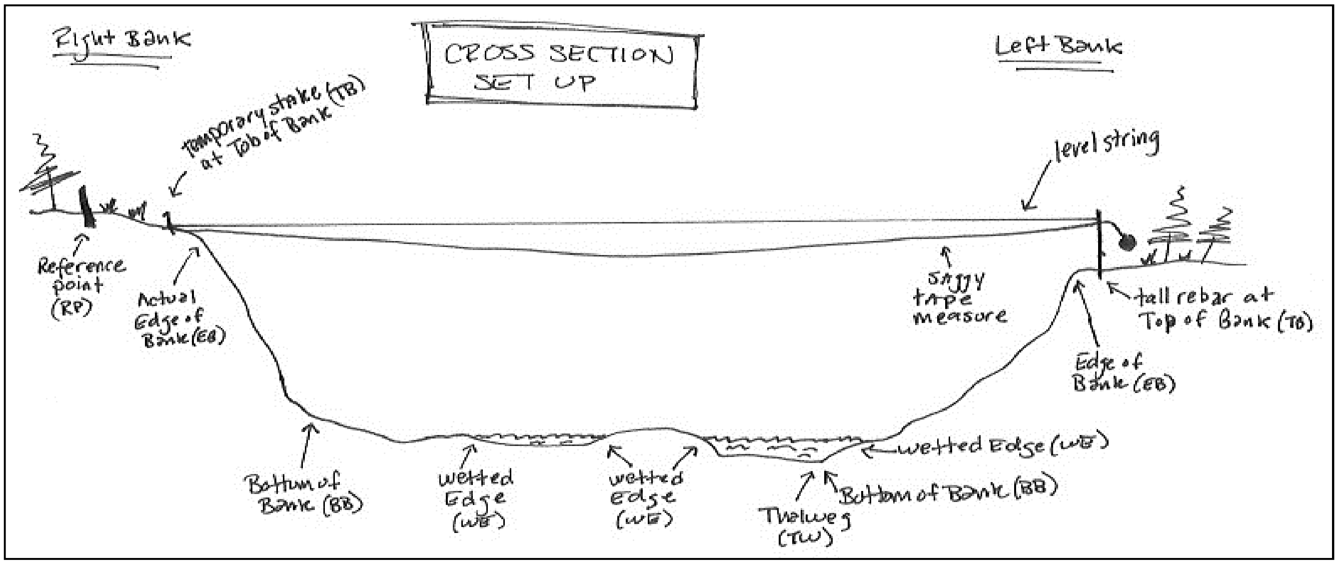


Figure 2

Definitions:

(BB) Bottom of Bank: The bottom edge of the bank where the ground begins to level

(EB) Edge of Bank: The point on the top of the bank at which the bank begins to slope down at a 45˚ angle or more

(LB) Left Bank: As indicated by looking downstream

(RB) Right Bank: As indicated by looking downstream

(RP) Reference Point: The six green posts with white paint on top permanently placed and marked R1-R-6.

(Rod) Surveyor's Rod: Expandable Surveyor's Rod

(TB) Top of Bank: The point where the tape measure starts, typically at the temporary stake

(TW) Thalweg: The deepest point of the streambed

(WE) Wetted Edge: The starting and ending points of the wetted area of the streambed

Bankful Height: The height of the lower bank from the thalweg to top of bank

Channel Width: The width of the channel at the height of the taller bank

Temporary Stake (aka TB): The point you determine to start cross section measurements. In most cases, you can't place the stake directly on the edge of the bank without causing further erosion, thus the need to measure from stake to Edge of Bank.

Measurements to take in the field:

1. Declination from RP to EB
2. Distance from RP to temporary stake at Top of Bank (TB)
3. Declination from EB to opposite bank
4. Distance from TB to EB
5. Distance from TB to Rod
6. Height from BB to TB
7. Distance from BB to Rod every vertical half meter
8. Height from bottom of streambed to string *and* Distance from TB to Rod every half meter across the streambed
9. Water depth when Rod is in wetted area
10. Distance from starting point to opposite BB
11. Height from BB to TB (on opposite side)
12. Distance from BB to Rod every vertical half meter (on opposite side)
13. Distance from starting point to opposite EB

<u>Cross Section Data Analysis</u>

Data for the six cross sections was collected over a period of two weeks in the Spring of 2013 and then transferred into an Excel document to create graphs of each cross section. The graphs were created so that the bank holding the permanent reference point served as zero on the x-axis. It was decided (after many different graphs were made) that the bank holding the reference point was the plane least likely to change. Therein, when future graphs are compared to the 2013 graphs, a change in streambed depth and width should both be evident. In order to compare data collected in 2004 with current data, I flipped the 2004 graphs so that the Y-axis was consistently the bank hosting the reference point. Data from the 1996 study was omitted from the comparison graphs due to insufficient data and methods. All graphs and data can be found in the glass house shared drive in the folder titled "Maisie" as well as in printed format in Danelle's files.

Site #1

The right bank, which marks the location for Reference Point #1, is much lower than the opposite bank at this point in Deer Creek. The right bank has easy access to its floodplain, has a moderate slope and fairly good coverage by plants. According to the Bank Erosion Potential Rating (BEPR) index, the right bank scored a 5.75 which indicates the bank is only at moderate risk for bank erosion. The bank's composition of mostly small materials (fine gravel, silt, and clay), make it the most suseptable to erosion.

The left bank at Reference Point #1 is much higher than the right bank and is terraced in several places. For this study, we determined the Top of Bank at a rather large terrace (about 2 meters wide) just less than a half meter taller than the right bank. However, the left bank continues to climb uphill another approximately 4 meters to the level of the rail trail. The difference in bank elevations has caused inscision in the left bank as bankfull elevations cut into the left bank while draining into the floodplain on the right bank. Note the undercut evident in Figure 3. The Bank Erosion Potential Ratign for the left bank is a 3.25, indicating it is at a high risk.

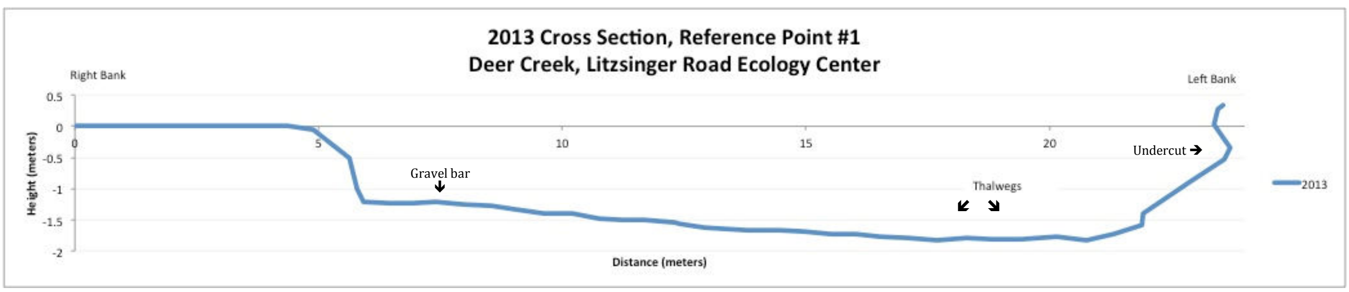


Figure 3

The Top of Bank for Cross Section #1 was located 4.35 meters from the permanent post at a 90° bearing. In the 2004 study, the Top of Bank was determined to be 9.9 meters from the reference point at the same angle. The difference in distance is most likely a combination of bank erosion and angle error. As evidenced in the comparison graph of the 2004 and 2013 studies (Figure 4), a little error in angle across a great distance can lead to dramatic differences.

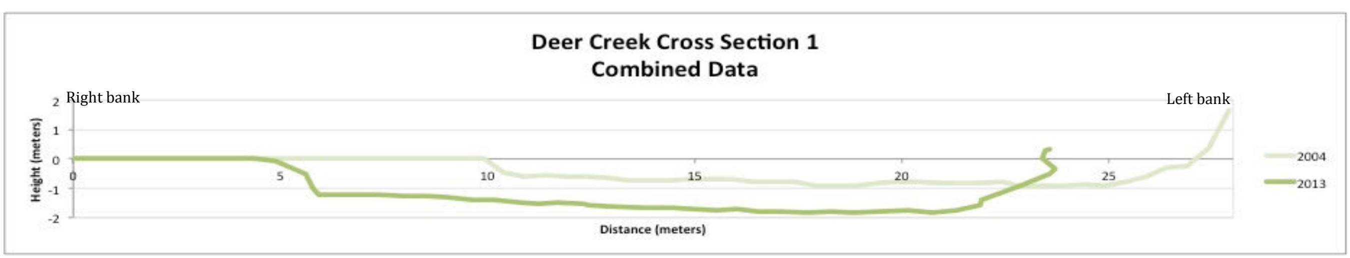


Figure 4

Site #2
The right and left banks at Reference Point #2 are rather even in height, angle, and composition with an overall Bank Erosion Potential Rating of 4.25 for the right bank and 4 for the left bank indicating both banks at a moderate to high risk for bank erosion. The main difference in these banks is how they are maintained. The right bank, being consistently maintained, is flush with native grasses, while the left bank, rarely maintained, is overgrown with bush honeysuckle. Both banks are composed mostly of clay and mud, though the right side of the channel hosts a gravel bar, whilst the majority of the streambed consists of mostly bedrock.

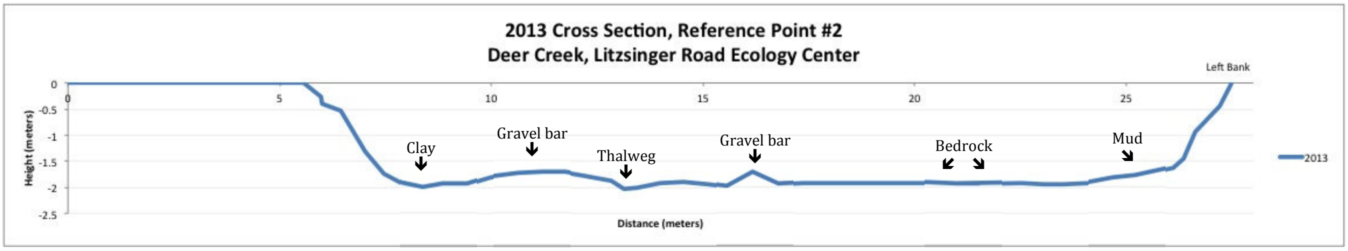


Figure 5

The Top of Bank for Cross Section #2 was located 5.55 meters from the reference point at a 90˚ bearing. In the 2004 study, the Top of Bank was determined to be 9.9 meters from the reference point at the same bearing. The difference in distance could be a combination of eroded bank and angle error. In 2004, the left bank was found to much higher than the right bank. A leveling of the two banks to near equal could possibly be another discrepancy in bank angle or methods.

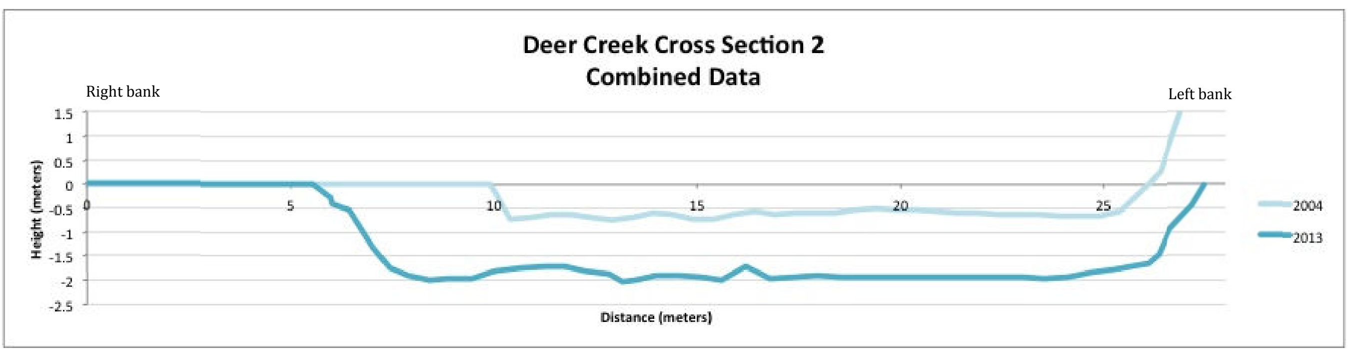


Figure 6

Site #3

Reference point #3 is the only reference point located on the left bank. At this particular location the left bank is far more stable than the right bank, thus the location of the reference point. Both left and right bank are fairly even in height, though the left bank is far more vegetated than the right bank and a bit steeper in slope. Near the center of the streambed is a large gravel bar that divides the waterway. The streambed depth on the left side of gravel bar has gotten noticeably deeper since 2004. Due mostly to poor composition, both banks are rated high on the Bank Erosion Potential index, the left bank scoring a 3, and the right bank, a 4.

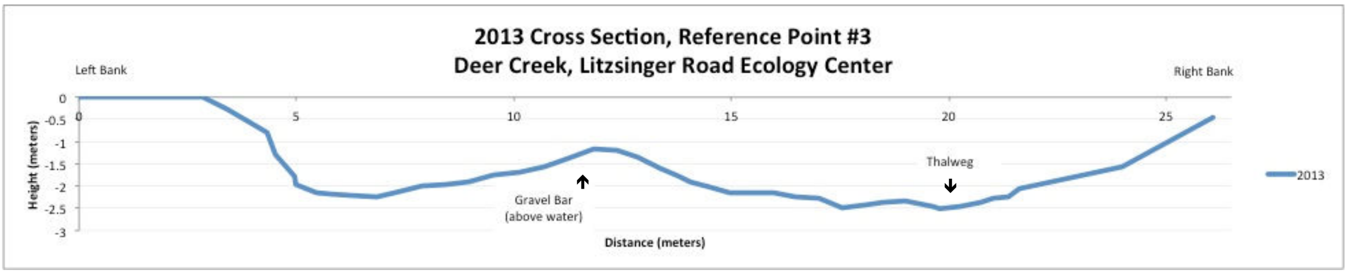


Figure 7

The Top of Bank was found to be 2.84 meters from the reference point on the left bank at a declination of 170˚. In 2004, the Top of Bank was determined to be 3.8 meters from the reference point at the same declination. However, due to the recent live-fall of a huge cottonwood on the right bank, the declination across the streambed was changed from 186˚ in 2004, to 170˚ in 2013 in order to properly access the right bank. Because of the intended change in angle, the two cross sections from 2004 and 2013 shouldn't be compared too closely, although they have been illustrated in figure 8 side by side.

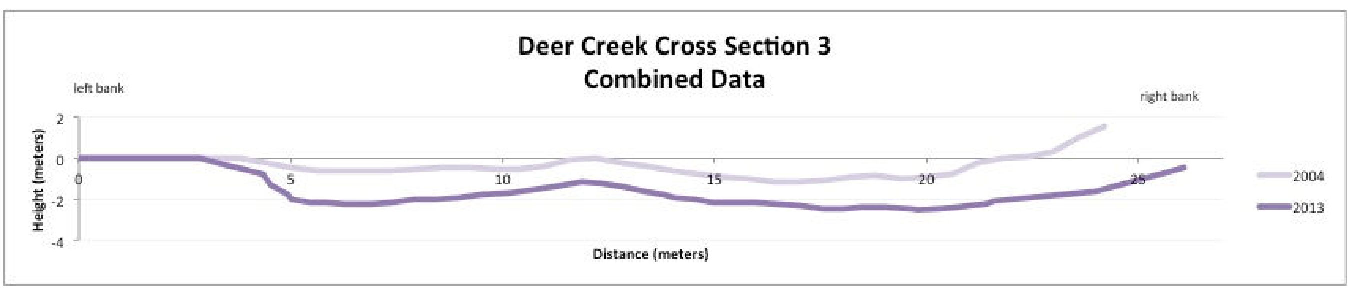


Figure 8

Site #4

The right and left banks at Reference Point #4 are fairly even in height, though vary greatly in slope, composition, and access to floodplain. The right bank at this juncture scored a medium-low Bank Erosion Potential Rating of 7.5, while the left bank scored an extremely high Bank Erosion Potential Rating of 2.25. The high potential of the left bank for erosion is mostly due to its composition (non-vegetated mud) and its steep slope. Unlike many of the other sites, this site lacks the presence of any bedrock or boulders and is mainly composed of gravel, cobble, mud, and sand.

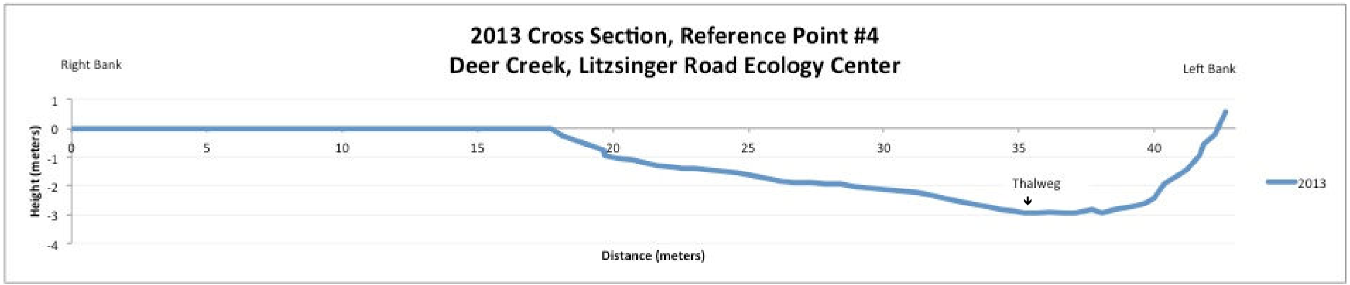


Figure 9

The Top of Bank at Reference Point #4 was found to be 17.7 meters from the permanent marker at a 130˚ declination. In 2004, the Top of Bank was determined to be 18.6 meters from the reference point at the same declination. With such a distance, we are certain there is much room for angle error, which could explain some of the discrepancies in the comparison graphs.

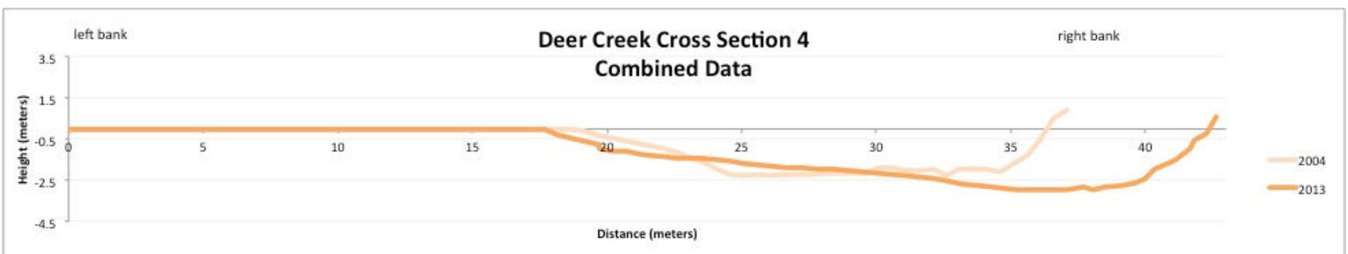


Figure 10

Site #5

The banks of Cross Section #5 were relatively similar in height, composition, and slope. The section scored a combined Bank Erosion Potential Rating of 5.25 on a spectrum of 1-10 indicating the site has only a moderate potential for bank erosion. Both banks were vegetated lightly with gravel present toward the bottom of their banks.

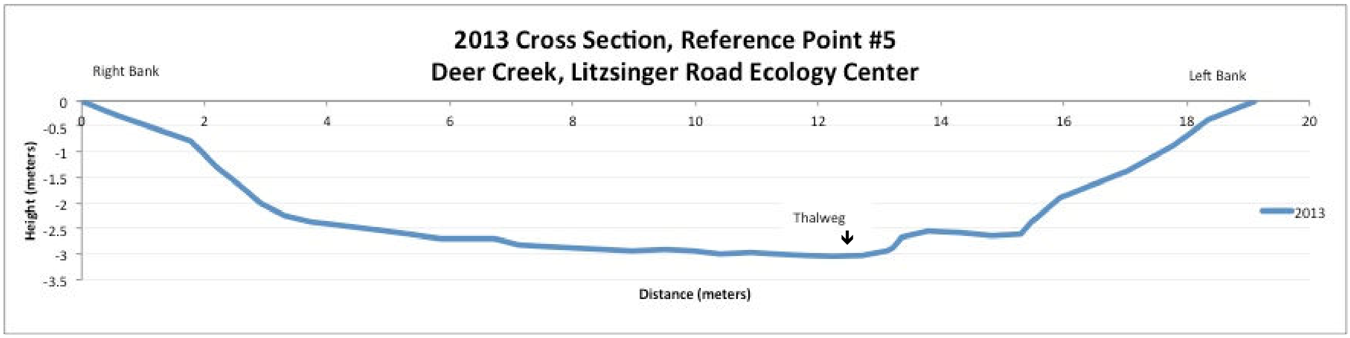


Figure 11

The Top of Bank was determined to be at the same point as the permanent marker reference point. However, in 2004, the Top of Bank was found 2.1 meters from the reference point at a bearing of 38˚. Based on observations by employees and volunteers, this bank has, indeed, eroded quite a bit in the past few years and it is possible that the Combined Data graph is fairly accurate. A bearing of 38˚ was used to find the location of opposite bank for both studies.

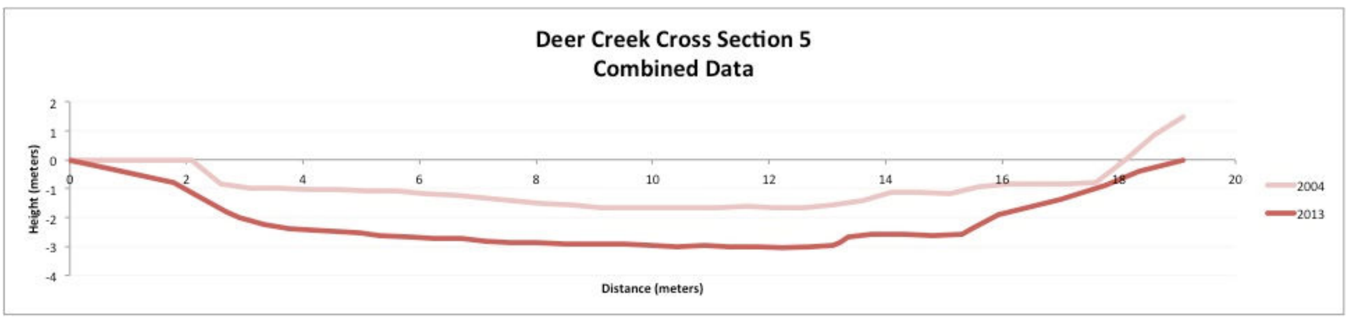


Figure 12

Site #6
The right and left banks at Cross Section #6 are quite different from one another. Most noticeably, there are two Hackberry trees jutting out from the right bank which is causing a bulge in the bank. Additionally, some stream mitigation has been performed upstream causing the stream flow to widen. However, the main flow of the creek at this point still undermines the right bank, as it was tending to do in 2004 as well. The left bank is slightly sloped, terraced, and well vegetated. In the center of the streambed is a wide gravel bar.

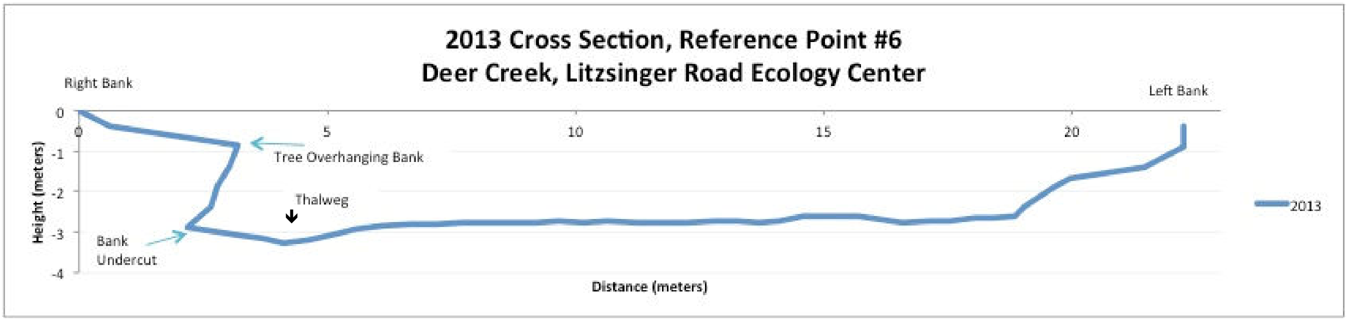


Figure 13

The Top of Bank was found to be at the same point as the reference stake in 2013. However, in 2004, the Top of Bank was determined to be 3.4 meters from the reference stake at a bearing of 44˚. After data was collected for this site, we determined that the 3.4 meter distance at the 44˚ declination was created to avoid the overhanging Hackberry tree which would give a more accurate bank reading. Both studies used a declination of 75˚ to determine the opposite bank point.

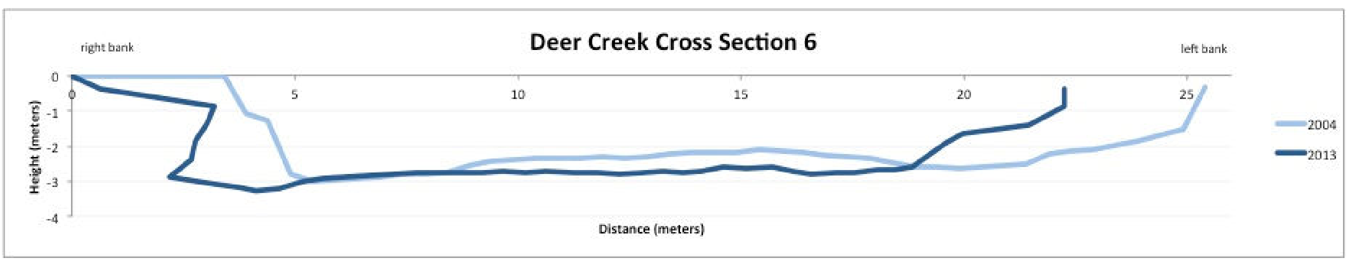


Figure 14

<u>Cross Section Results and Discussion</u>
Though comparison graphs of the 2004 and 2013 studies are shown in this document, it is not recommended that they be too closely compared due to discrepancies in angle measurements and minor changes in methods. The current protocol as written should be replicable and useful for future comparison studies. It is also recommended that Site #6 be redone during the summer of 2013, making the necessary adjustments to avoid the overhanging trees for a more accurate depiction of the right bank.

Conclusion

In the future, trained volunteers or interns should be able to replicate the current protocols and make adjustments as needed. It should be noted that Bank Point data of all 39 points could be easily collected over a period of two days though inputting the data into Excel and ArcGIS could take up to a week. Cross Section data of all six points could be collected over a period of two to three days, but it is from here on recommended that three of the points be surveyed, computed, and analyzed by summer interns every year so that by the end of two years, all six cross sections have been completed. This will ensure that the protocol does not go forgotten, that data stays updated, and that interns gain experiential education in fluvial geomorphology – how water changes landscapes.

The current protocols for the Bank Point mapping and the Cross Section graphing were both created to be replicable in the future and applicable to past studies. However, after the current data was synthesized, graphed, and compared to past data, it became clear that the current and past data were less than comparable. Small changes in protocol along with methods that were challenging to replicate made the data difficult to compare over time. With these considerations, improvements were made to the current protocol after the study was complete to avoid these problems in the future.

Herein, it is hoped that the current data and protocols will be useful in the future and will provide a basis for future comparisons as the channel changes over time. With the addition of future data, it is recommended that the changes over time be analyzed in accordance with the principles of Fluvial Geomorphology in order to better understand this reach of Deer Creek as a piece of the larger Deer Creek Watershed. It is also recommended that the graphical data be used for educational purposes to demonstrate how water changes its landscape over time and for discussion on various causes of those changes. It should also be interesting to note the rate of changes over time as our planet experiences climate change events at an exponentially growing rate.

References

Brown, Jennifer, and Malinda Slagle. 2004. *Cross Section Survey of Deer Creek*. Missouri Botanical Garden; Litzsinger Road Ecology Center.

Deer Creek Watershed Alliance. 2013a. "MBG: Deer Creek Watershed Alliance—Maps." *Deer Creek Watershed Alliance*. http://www.deercreekalliance.org/maps.aspx.

Edge, J.M., 1996. *Riparian and Watershed Habitat Characteristics of Deer Creek.* Field Ecology Grant; Missouri Botanical Gardens; Litzsinger Road Ecology Center.

Gordon, Nancy D., Thomas A. McMahon, and Brian L. Finlayson. 1992. *Stream Hydrology: An Introduction for Ecologists*. John Wiley & Sons Ltd.

Intuition & Logic. 2005. "Stream Study of Deer Creek". Intuition & Logic.

Leopold, Luna B., and Robert C. Stroh. 2012. *Fluvial Processes in Geomorphology*. Dover Publications.

Murdoch, T. *et al.* 1996. *Stream Keeper's Field Guide.* Everett, Washington; Adopt-A-Stream Foundation.

Peacher, Rachel. 2011. "Impacts of Land Use on Stream Bank Erosion in the Northeast Missouri Claypan Region." *Graduate Theses and Dissertations* (January 1). http://lib.dr.iastate.edu/etd/10395.

West Virginia Department of Environmental Protection Nonpoint Source Program. 2006. "West Virginia Nonpoint Source Program: Natural Stream Channel Design & Riparian Improvement Project Monitoring Protocol". West Virginia. http://www.dep.wv.gov/WWE/Programs/nonptsource/Pages/Nonpoint.aspx.

APPENDIX

Review of Modern Streambank Erosion Monitoring Methods
Litzsinger Road Ecology Center
Missouri Botanical Garden

Created by Maisie Tyler Rinne
In conjunction with *Deer Creek Bank Erosion Monitoring*
2013

<u>Overview</u>

There are many different methods to monitor streambank erosion with varying degrees of detail, accuracy, affordability, and time investment. This report summarizes various methods researched for the 2013 *Deer Creek Bank Erosion Monitoring* study. The methods reviewed below were considered when creating the 2013 protocol for Bank Point and Cross Section methods. Some of methods listed below could be useful for Litzsinger Road Ecology Center in the future, with the addition of substantial funding.

Brett Allen Connell of the University of Tennessee – Knoxville completed a study in 2012 in which he compared multiple streambank erosion and habitat assessments. The table below aptly compares some of the most commonly used methods and is borrowed from his report: *GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas*.

Table 1: Streambank Erosion and Habitat Assessment Comparison.

Assessment	BEHI	USDOT	EPIN	SEI	BEPI	QHEI	RBP	SVAP	RGA	SCA	PIBO
Bank Erosion/ Condition		X	X	X		X	X	X	X	X	X
Bank height / bankful	X				X						
Root depth / bank height	X										
Bank Angle	X	X		X	X				X		X
Vegetation/ Surface Protection	X	X	X	X	X	X	X		X	X	X
Riparian width						X	X	X		X	X
Bank Material		X		X	X						X
Root Density	X				X						
Velocity		X	X	X						X	
Sinuosity							X				X
Cause of Erosion				X							
Substrate Materials		X	X			X	X		X		X
Thalweg Location		X			X						X
Instream Cover						X	X	X		X	X
Degree of Incision / Constriction		X							X/X		
Pool Riffle Quality						X	X	X		X	X
Embeddedness						X	X			X	X
Deposition		X					X		X	X	X
Water Clarity								X			
Fish Barriers								X			

BEHI (Bank Erosion Hazard Index) developed by Rosgen (2001), USDOT (United States Department of Transportation) developed by Henderson)2006), EPIN (Erosion Potential Index Number) was developed by the Genesee/Finger Lakes Regional Planning Council (1998), SEI (Streambank Erosion Inventory) was developed by the Michigan Department of Environmental Quality (2001), BEPI (Bank Erosion Potential Index) was developed by The Wisconsin Division of Natural Resources (2010), QHEI (Qualitative Habitat Evaluation Index) was developed by Rankin (1989), RBP (Rapid Bio-assessment Protocol) developed by Barbour for the USEPA (1999), SVAP (Streambank Visual Assessment Protocol), RGA (Rapid Geomorphic Assessment) was developed by Simon (2006), SCA (Stream Corridor Assessment) developed by the Maryland Department of Natural Resources (2003). PIBO (PACFISH/INFISH Biological Opinion) developed by the USDA Forest Service.

Summary of Bank Erosion Assessment Methods

Summarized below are several of the assessment mentioned in Connell's table as well as a few other methods identified as useful when considering methods for Deer Creek.

Bank Erosion Hazard Index (BEHI)

"The Bank Erosion Hazard Index (BEHI) developed by Rosgen (2001) is part of a bigger, total river assessment/ classification that is widely used throughout academia and governmental agencies. The BEHI (Rosgen, 2001) focuses on just the erodibility of the actual bank and is one of the most widely accepted methods today" (Connell, 2012). The BEHI method is very in-depth and proven to be accurate in the prediction of soil erosion. It is a widely used bank erosion assessment to inventory stream banks to identify those of most concern. Those areas found to be most hazardous are then further surveyed. Variables include bank angle, bank height ratio, root density, root depth, percent of bank protected, and bank materials. BEHI risk rating categories include low, moderate, high, very high, and extreme.

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Montana Department of Envioronmental Quality. 2011. "Appendix E - 2007 Stream Bank Erosion Source Assessment - Bitteroot TMDL Planning Area". Montana. http://deq.mt.gov/wqinfo/tmdl/finalreports.mcpx.

Rathbun, Joe. 2008. "Standard Operating Procedure; Assessing Bank Erosion Potential Using Rosgen's Bank Erosion Hazard Index (BEHI)". Michigan Department of Environmental Quality. www.michigan.gov/documents/deq/wb-nps-BEHI-SOP_246873_7.doc.

Rosgen, David L. 2001. "A Practical Method of Computing Streambank Erosion Rate." Proceedings of the Seventh Federal Interagency Sedimentation Conference, Volume 1, II. Stream Restoration. Reno, NV. http://pubs.usgs.gov/misc/FISC_1947-2006/pdf/1st-7thFISCs-CD/7thFISC/7Fisc-V1/7FISC1-2.pdf.

US EPA, OW. 2013. "Bank Erosion Prediction (BEHI, NBS)." Accessed March 1. http://water.epa.gov/scitech/datait/tools/warsss/pla_box08.cfm.

Van Eps, M.A., S.J. Formica, T.L. Morris, J.M. Beck, and A.S. Cotter. 2004. "Using a Bank Erosion Hazard Index (BEHI) to Estimate Annual Sediment Loads From Streambank Erosion in the West Fork White River Watershed". EPA. http://water.epa.gov/scitech/datait/tools/warsss/resources_bank.cfm.

Bank Erosion Hazard Rating (BEHR)

This method us useful in identifying areas of concern along a stream reach. Using visual and written cues, a rating is given to right and left banks at specified points along a reach and an overall rating is given to the cross section based on an index number.

References

West Virginia Department of Environmental Protection Nonpoint Source Program. 2006. "West Virginia Nonpoint Source Program: Natural Stream Channel Design & Riparian Improvement Project Monitoring Protocol". West Virginia. http://www.dep.wv.gov/WWE/Programs/nonptsource/Pages/Nonpoint.aspx.

Bank Assessment for Non-Point source Consequences of Sediment (BANCS)

"This method as published by Rosgen (2001a) utilizes two bank erodibility estimation tools: the Bank Erosion Hazard Index (BEHI), and Near Bank Stress (NBS). The application involves evaluating the bank characteristics and flow distribution along river reaches and mapping various risk ratings commensurate with bank and channel changes. An estimate of erosion rate is made, and then multiplied times the bank height times the length of bank of a similar condition, providing an estimate of cubic yards and/or tons of sediment/year. This information can be compared to the sediment yield data to apportion the amount of sediment potentially contributed by streambanks" (US EPA 2013).

References

US EPA, OW. 2013. "Bank Erosion Prediction (BEHI, NBS)." Accessed March 1. http://water.epa.gov/scitech/datait/tools/warsss/pla_box08.cfm

PACFISH/INFISH Biological Opinion (PIBO)

"By far the most in depth habitat sampling protocol is the PACFISH/INFISH Biological Opinion (PIBO) used by the Fish and Aquatic Ecology Unit of the USDA Forest Service. Within each reach surveyed, there are 20 transects that have two different indices applied. First the stream channel attributes listed in Table 1 are measured, but also including water chemistry and macro invertebrates. Then an extremely detailed vegetation parameters index is applied to the riparian area. One of the objectives of PIBO is to determine if specific Designated Management Area practices related to livestock grazing are maintaining or restoring riparian vegetation structure and function" (Connell 2012, pg 12)

Resources

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Henderson, Richard C., Eric K. Archer, Boyd A. Bouwes, Marc C. Coles-Ritchie, and Jeffrey L. Kershner. 2005. "PACFISH/INFISH Biological Opinion (PIBO): Effectiveness Monitoring Program Seven-Year Status Report 1998 Through 2004". USDA Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/pubs/rmrs_gtr162.pdf.

Bank Stability and Toe Erosion Model (BSTEM)

Developed by Simon, et al. (2003), "this assessment predicts streambank retreat due to both fluvial erosion and geotechnical failure. This method is the most in-depth and complex method of computing erosion potential being used today. As a result, training and data collection to use BSTEM appropriately is higher in both cost and time compared to other methods. Parameters assessed are geometry, top of bank toe, bank layer thickness, flow parameters, bank material, and hydraulic data are all needed to run the program. The Factor of Safety outputs are failure width, failure volume, sediment loading and constituent load. Information output from BSTEM is very valuable but comes with a price of intensive field work and data entry" (Connell 2012, pg 9).

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Rapid Geomorphic Assessment (RGA)

"The Rapid Geomorphic Assessment (RGA), developed by Simon (2006) while working for the National Sedimentation Laboratory, evaluates stream stability by assessing primary bed material, degree of channel incision, degree of channel constriction, Simon's Channel Evolution Model, and several other factors. Each of these assessment protocols utilizes a series of questions that asks the investigator to determine the level of function of various habitat parameters by selecting from a series of possible answers (Simon, 2006)" (Connell 2012, pg 11).

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Heeren, D. M., A. R. Mittelstet, G. A. Fox, D. E. Storm, A. T. Al-Madhhachi, T. L. Midgley, A. F. Stringer, K. B. Stunkel, and R. D. Tejral. 2012. "Using Rapid Geomorphic Assessments to Assess Streambank Stability in Oklahoma Ozark Streams". American Society of Agricultural and Biological Engineers. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1221&context=biosysengfacpub.

Stream Visual Assessment Protocol (SVAP)

"The Stream Visual Assessment Protocol (SVAP) is an introductory level, assessment method for people who are unfamiliar with stream assessments. The protocol was developed as a tool to qualitatively characterize stream ecological conditions and to help facilitate the work of NRCS (2003) personnel who work with riparian landowners. Participation by the landowner in making assessments is encouraged. By participating, the landowner learns about stream processes, signs of impairment, and effects of land use activities on ecological health and integrity. The parameters used in the SVAP include channel condition, hydrologic alteration, riparian zone, bank stability, water appearance, and several other factors using a numeric value, quantitatively describing the rating from poor to excellent." (Connell 11).

SVAP collects more data than LREC was looking for – an overall stream health assessment. LREC already has water monitoring protocols set in place. The data collected in this survey may be combined with that data for a more full perspective on the watershed. SVAP provides a quality overall stream assessment but a much less detailed bank erosion assessment. SVAP might be a good tool to use in the future for educational purposes as it is relatively simple, necessitates little measurement and would teach about the steam as part of a larger system.

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

USDA. 1998. "NWCC Technical Note 99-1, Stream Visual Assessment Protocol". National Resources Conservation Service. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044776.pdf.

Stream Corridor Assessment Survey (SCA)

"The Maryland Department of Natural Resources (2003) developed the Stream Corridor Assessment Survey (SCA), a very in-depth and well explained habitat assessment that has been adopted by several other states and organizations as a standard. Instream cover, embeddedness, channel alteration, sediment deposition, velocity and depth combinations, channel flow status, bank vegetative protection, condition of banks, and riparian width are the habitat parameters…" (Connell 2012, pg 12)

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Yetman, Kenneth T. 2001. "Stream Corridor Assessment Survey: SCA; Survey Protocols". Annapolis, MD: Maryland Department of Natural Resources, Watershed Restoration Division. http://www.dnr.state.md.us/irc/docs/00005291.pdf.

Video Mapping

Connell (2012) developed GPS and video mapping technology to map streambeds and watersheds. "Using a sit-on-top kayak outfitted with above and underwater video cameras, depth sonar, and GPS, every second of video was fixed to a GPS location" (Connell 2012). "Creating river habitat maps with geo-referenced video is an emerging concept that shows great promise for a variety of reasons. Large, landscape-scale maps have been created and have attributed greatly to watershed management and monitoring. Attributes such as depth, and PRR (pool, riffle, and run) are assigned to each GPS point and habitat maps are made within ArcGIS. Information from this can be used for threatened and endangered species potential location or re- introduction."

Connell developed a Bank Erosion Susceptibility Index (BESI) method which was primarily based on the Bank Erosion Hazard Index (BEHI) (Rosgen, 2001). The BESI method "focuses on four attributes that can be easily seen from video. Several other erosion models and habitat assessments were evaluated and considered. The four parameters assessed by video analysis were bank angle, bank height, surface protection, and riparian diversity" (Connell 2012, pg 18). Connell also utilized the GPS-enhanced Streambank Video Mapping System (SVMS). "The SVMS and BESI served to be a valuable form of landscape-scale, erosion susceptibility mapping. Compared to traditional erosion assessments which tend be costly, inefficient, environmentally intrusive, and inaccurate due to extrapolation, the SVMS surveys more streambank, in less time, without laying a foot on any living thing or private property."

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Erosion Pins

A common method among universities, this method uses bank pins hammered horizontally into the side of the streambank at measured intervals to indicate changes in bank sediment load. It is cited as being both a common and inexpensive tool for monitoring bank erosion (Connell, 2012). This method has proven to be effective in accuracy, however, the bank pins have also been found to negatively affect the eroded streambank and it is recommended that this method be used for large study reaches that require well-spaced and few reference points.

References

Bartley, Rebecca, CSIRO Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef (Australia), and Land and Water. 2006. "Measuring the Rates of Bank Erosion and Channel Change in Northern Australia a Case Study from the Daintree River Catchment." http://nla.gov.au/nla.arc-69339.

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Rosgen, Dave. "Channel Monitoring Methodology". Wildland Hydrology. http://www.wildlandhydrology.com/assets/CHANNEL_MONITORING_METHODOLOGY.pdf.

West Virginia Department of Environmental Protection Nonpoint Source Program. 2006. "West Virginia Nonpoint Source Program: Natural Stream Channel Design & Riparian Improvement Project Monitoring Protocol". West Virginia. http://www.dep.wv.gov/WWE/Programs/nonptsource/Pages/Nonpoint.aspx.

Measuring Soil Loss Rates

Van Eps study (Van Eps et al. 2004) measured the volume of sediment generated due to erosion of individual streambanks by multiplying the predicted annual lateral erosion rate (using BEHI +) by the originally recorded length and height of the bank. Van Eps found the average lateral erosion of each individual streambank by calculating the average of the lateral streambank measurements. This study is summarized by Connell on pg 7 (Connell 2012).

References

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141

Van Eps, M.A., S.J. Formica, T.L. Morris, J.M. Beck, and A.S. Cotter. 2004. "Using a Bank Erosion Hazard Index (BEHI) to Estimate Annual Sediment Loads From Streambank Erosion in the West Fork White River Watershed". EPA. http://water.epa.gov/scitech/datait/tools/warsss/resources_bank.cfm.

References

Bartley, Rebecca, CSIRO Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef (Australia), and Land and Water. 2006. "Measuring the Rates of Bank Erosion and Channel Change in Northern Australia a Case Study from the Daintree River Catchment." http://nla.gov.au/nla.arc-69339.

Connell, Brett Allen. 2012. "GIS-Based Streambank Video Mapping to Determine Erosion Susceptible Areas". University of Tennessee. http://trace.tennessee.edu/utk_gradthes/1141.

Heeren, D. M., A. R. Mittelstet, G. A. Fox, D. E. Storm, A. T. Al-Madhhachi, T. L. Midgley, A. F. Stringer, K. B. Stunkel, and R. D. Tejral. 2012. "Using Rapid Geomorphic Assessments to Assess Streambank Stability in Oklahoma Ozark Streams". American Society of Agricultural and Biological Engineers. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1221&context=biosysengfacpub.

Henderson, Richard C., Eric K. Archer, Boyd A. Bouwes, Marc C. Coles-Ritchie, and Jeffrey L. Kershner. 2005. "PACFISH/INFISH Biological Opinion (PIBO): Effectiveness Monitoring Program Seven-Year Status Report 1998 Through 2004". USDA Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/pubs/rmrs_gtr162.pdf.

Montana Department of Envioronmental Quality. 2011. "Appendix E - 2007 Stream Bank Erosion Source Assessment - Bitteroot TMDL Planning Area". Montana. http://deq.mt.gov/wqinfo/tmdl/finalreports.mcpx.

Rathbun, Joe. 2008. "Standard Operating Procedure; Assessing Bank Erosion Potential Using Rosgen's Bank Erosion Hazard Index (BEHI)". Michigan Department of Environmental Quality. www.michigan.gov/documents/deq/wb-nps-BEHI-SOP_246873_7.doc.

Rosgen, Dave. "Channel Monitoring Methodology". Wildland Hydrology. http://www.wildlandhydrology.com/assets/CHANNEL_MONITORING_METHODOLOGY.pdf.

Rosgen, David L. 2001. "A Practical Method of Computing Streambank Erosion Rate." Proceedings of the Seventh Federal Interagency Sedimentation Conference, Volume 1, II. Stream Restoration. Reno, NV. http://pubs.usgs.gov/misc/FISC_1947-2006/pdf/1st-7thFISCs-CD/7thFISC/7Fisc-V1/7FISC1-2.pdf.

US EPA, OW. 2013. "Bank Erosion Prediction (BEHI, NBS)." Accessed March 1. http://water.epa.gov/scitech/datait/tools/warsss/pla_box08.cfm.

USDA. 1998. "NWCC Technical Note 99-1, Stream Visual Assessment Protocol". National Resources Conservation Service. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044776.pdf.

Van Eps, M.A., S.J. Formica, T.L. Morris, J.M. Beck, and A.S. Cotter. 2004. "Using a Bank Erosion Hazard Index (BEHI) to Estimate Annual Sediment Loads From Streambank Erosion in the West Fork White River Watershed". EPA. http://water.epa.gov/scitech/datait/tools/warsss/resources_bank.cfm.

West Virginia Department of Environmental Protection Nonpoint Source Program. 2006. "West Virginia Nonpoint Source Program: Natural Stream Channel Design & Riparian Improvement Project Monitoring Protocol". West Virginia. http://www.dep.wv.gov/WWE/Programs/nonptsource/Pages/Nonpoint.aspx.

Yetman, Kenneth T. 2001. "Stream Corridor Assessment Survey: SCA; Survey Protocols". Annapolis, MD: Maryland Department of Natural Resources, Watershed Restoration Division. http://www.dnr.state.md.us/irc/docs/00005291.pdf.