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Impacts of land use on stream bank erosion in the Northeast Missouri Claypan Region

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Impacts of land use on stream bank erosion in the Northeast Missouri Claypan Region

by

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Chapter 1. General Introduction

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). Suspended sediment impacts the entire aquatic ecosystem by interfering with the physiological and life history functions of all types of aquatic life, including fish, mussels, and aquatic insects (Simon & Darby, 1999). Sediment accumulation on bed substrate material causes the loss of benthic aquatic habitat, which is essential for fish spawning, and can completely bury mussels and other slow-moving animals (Simon & Darby, 1999). Excess phosphorus, which is often carried by sediment, can create imbalances that are detrimental to aquatic ecosystems and harmful to livestock and humans (Daniel et al., 1998).

Upland erosion and agricultural phosphorus supplements are often thought of as the primary culprits for sediment and phosphorus pollution, respectively, in streams. However, there is reason to believe that stream bank erosion may also be a significant non-point source (Simon and Rinaldi, 2000). As in-field soil conservation practices have become more widespread and erosion from upland sources has largely decreased, some researchers suggest that the main source of eroded materials in streams is shifting from upland sources to the erosion of gullies and stream channels (Simon and Klimetz, 2008; Wilson et al., 2008a,b). In general, there is a growing consensus in the literature that stream bank erosion is almost always a significant source of stream sediment (Nagle et al., 2007; Rondeau et al., 2000; Simon, 2008; Thoma et al., 2005; Sekely et al., 2002) and in many instances, it is the dominant source (Amiri-Tokaldany et al., 2003; Laubel et al., 1999; Laubel et al., 2003; Mukundan et al., 2010; Schilling and Wolter, 2000; Schilling et al., 2011; Simon and Rinaldi, 2006; Wilson et al., 2008a). Zaimes et al.(2008a) and Zaimes et al. (2008b) suggest that stream bank erosion may be an important source of phosphorus in watersheds, and a two-year grazing study (Schwarte et al., 2011) showed that the major source of the sediment and phosphorus in a pasture stream in Iowa is eroding stream banks and not surface runoff or fecal deposition.

Project Description

The cumulative goal of the studies described in this thesis is to gain a deeper understanding of stream bank erosion processes in order to confidently recommend current conservation practices or propose new ideas or changes to the current practices. The first study (Chapter 2) examines how land use, stream order, and season impact stream bank erosion in the Central Claypan Region of NE Missouri. This study used a three-year data set based on the erosion pin method. The second study (Chapter 3) investigates the impacts of different types of vegetation and various watershed characteristics on stream bank erosion. Erosion data from Chapter 2 was used in conjunction with riparian area vegetation survey data and watershed data calculated with a Geographic Information System, in order to examine trends and relationships. Finally, the third study (Chapter 4) investigates the applicability of two procedures used by the Michigan Department of Environmental Quality for estimating bank instability for use in the Central Claypan Region of NE Missouri. Sediment from stream banks is a very harmful and wide-spread problem, and the development of quick and easy procedures of predicting bank instability to be used in conjunction with long-term measurement procedures is critical for the prioritization of effective bank stabilization projects.

Thesis organization

This thesis is arranged into five chapters. The first chapter is a general introduction to topics covered in later chapters. The second chapter is titled "Season, land use, and stream order effects on extent and magnitude of stream bank erosion in the Salt River watershed in Northeast Missouri". The third chapter is titled "Vegetation and watershed characteristics influence on stream bank erosion in a claypan watershed". The fourth chapter is titled "Applicability of a bank erosion hazard index to streams in the claypan region of Northeast Missouri". The final chapter is a general conclusion. This chapter sums up what was learned from the three projects described above based on their results.

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Chapter 2. Season, land use, and stream order effects on extent and magnitude of stream bank erosion in the Salt River watershed in Northeast Missouri

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Abstract

Sediment and nutrients are arguably the most pervasive and costly form of water pollution in North America. There is a growing body of literature that suggests that as in-field conservation practices become more widespread, the main source of eroded materials in streams is shifting from upland sources to erosion of gullies and stream channels. This study investigated the influence of land use, stream order, and season of stream bank erosion in the Central Claypan Region of Northeast Missouri. The erosion pin method was used to measure erosion on 36 treatment reaches stratified across stream order and land use categories. The mean percent eroding bank length was 53%, the mean sediment horizontal retreat rate was 5.6 cm/year, and the mean mass loss rate was 135.6 kg/m/year. Erosion rates fell into the range of other pin erosion studies from the Midwest. Season interactions were statistically significant with much greater soil loss occurring during the winter months than during the other seasons. Neither the land use or stream order effects were significant. Watershed scale estimates show that approximately 182,000 Mg of sediment and 68 Mg of phosphorus per year were contributed to steams during this study period. However, the study years had much higher than normal rainfall and so should not be considered normal rates.

Introduction

Suspended sediment severely impacts surface waters by degrading water quality for human purposes and interfering with the physiological and life history functions of aquatic life (Simon & Darby, 1999). Excess phosphorus, which is often carried by sediment, can create dissolved oxygen shortages, causing fish kills and encouraging blooms of cyanobacteria, which are toxic for livestock and humans (Daniel et al., 1998). Sediment and nutrients are arguably the most pervasive and costly form of water pollution in North America (Osterkamp, 1998).

In order to decrease the sediment and nutrient loads in streams, we must first identify its major sources. As in-field soil conservation practices have become more widespread and erosion from upland sources has largely decreased, some researchers suggest that the main source of eroded materials in streams is shifting from upland sources to the erosion of gullies and stream channels (Simon and Klimetz, 2008; Wilson et al., 2008a,b). In general, there is a growing consensus in the literature that stream bank erosion is almost always a significant source of stream sediment (Nagle et al., 2007; Rondeau et al., 2000; Simon, 2008; Thoma et al., 2005; Sekely et al., 2002) and in many instances, it is the dominant source (Amiri-Tokaldany et al., 2003; Laubel et al., 1999; Laubel et al., 2003; Mukundan et al., 2010; Schilling and Wolter, 2000; Schilling et al., 2011; Simon and Rinaldi, 2006; Wilson et al., 2008a). Zaimes et al. (2008a) and Zaimes et al. (2008b) suggest that stream bank erosion may be an important source of phosphorus in watersheds, and a two-year grazing study (Schwarte et al., 2011) showed that the major source of the sediment and phosphorus in a pasture stream in Iowa is eroding stream banks, specifically cutbanks, and not surface runoff or fecal deposition.

The Mark Twain Lake/Salt River watershed lies within the Central Claypan Region (USDA Natural Resource Conservation Service [NRCS], 2006), a Major Land Resource Area (113) that has a unique geology: loess overlies old glacial drift that has a high content of clay, resulting in a subsurface soil layer through which water does not easily pass (Bouma, 1980; Jamison and Peters, 1967). This has resulted in an unusual soil hydrography that causes the top soil layers to be quickly saturated from precipitation and stay saturated for a long time, making soils in this region more highly erodible than their counterparts in other regions (Jamison and Peters, 1967; Rinaldi and Casagli, 1999). Mark Twain Lake, the major source of public water in the region (Lerch et al., 2008), is a place where sedimentation and turbidity are the most severe water quality problems (Dames and Todd, 2009). Water that passes through the lake flows into the Mississippi River, whose high sediment and nutrient concentrations have been linked to the dead zone in the Gulf of Mexico (USEPA, 2007).

Objectives and *Hypotheses*

The objectives of this study were to: (1) investigate the effects and interactions of land use, stream order, and season on erosion rates from streams in two claypan watersheds using erosion pins, (2) estimate the total mass of sediment and P contributed to streams by stream bank erosion for the two watersheds for each sampling year. Our hypotheses are that: (1) streams flowing through pasture and crop land will have higher erosion rates and total bank soil loss than those flowing through riparian forests or broader forest land; (2) erosion rates and soil loss will be highest in the winter because of freeze-thaw cycling and other processes.

Materials and Methods

Study area

This research was conducted within the Salt River Basin in Northeast Missouri. The Salt River Basin was selected as a Benchmark Research Watershed for the Conservation Effects Assessment Project (CEAP) by the USDA's Agricultural Research Service (USDA ARS). Of the ten major watersheds of the Salt River Basin, two were selected for investigation in this study. The Crooked and Otter Creek watersheds were chosen because of their type and intensity of land use and their claypan soils are representative of watersheds within the Central Claypan Areas (Lerch et al., 2008). The Crooked Creek watershed is approximately 288 km^2 while the Otter Creek watershed is approximately 272 km^2.

Claypan soils have a soil layer ranging from about 0.1 m to 0.8 m below the surface that has a relatively high proportion of clay (>450 g/kg) (Blanco-Canqui et al., 2002; Jamison and Peters, 1967). Clay soils typically have low saturated hydraulic conductivity (Bouma, 1980; Jamison and Peters, 1967). Therefore, water is largely restricted to the soil layers above the claypan, resulting in quick saturation, lateral flows above the claypan, higher levels of surface run-off, and generally increased erodibility (Jamison and Peters, 1967).

Experimental design

Land use, Strahler (1957) stream order, and season were used as independent variables in a factorial experimental design to study their effects, and interactions between these effects, on stream bank erosion. Four categories of land use were tested: crop, pasture, riparian forest, and forest. For each land use, treatment reaches were stratified by stream order: 1st, 2nd, and 3rd+ (Table 1). The 3rd+ stream order category includes 3rd and 4th order streams because the total length of streams designated as 3rd order within these watersheds was relatively limited, and there were not enough 3rd order stream reaches available to meet the needs for treatment reach establishment for this experimental design.

Each land use and stream order pairing was replicated three times, with the exception of 3rd+ order crop treatment reach because only one such treatment reach could be found within the study area (Table 1). Therefore, 34 total treatment reaches (instead of 36 total treatment reaches for a balanced experiment) were initially investigated. Due to restrictions from landowners to accessing some treatment reaches and the difficulty of finding stream reaches that met our land use and stream order requirements, some seasonal measurements were missed for some treatment reaches. During the three-year sampling period, a 1st order Riparian Forest and a 2nd order Forest treatment reach were abandoned due to landowner restrictions. New treatment reaches with the corresponding land uses and stream orders were established to replace them and prevent further loss of data for the two land use and stream order combinations. Therefore, the data analysis includes a total of 36 treatment reaches, which includes 34 treatment reaches originally established in 2007 and 2008 plus two replacement treatment reaches that were established in 2010 (Table 1).

Treatment reaches that were suitable for our experiment were found by studying aerial photos of the Crooked and Otter Creek watersheds and by using the National Hydrography Dataset (Dewald and Roth, 1998). For a stream length to be designated as a treatment reach, it had to fit the descriptions of one of the land-use categories and that land use had to be present on both sides of the stream for the entire length of the treatment reach. Treatment reaches were determined to have a “Crop” land use if the land on both sides of the stream was in row-crop agriculture and had less than 10 meters of natural vegetation on either side. “Pasture” treatment reaches were continuously grazed (defined here simply as the grazing of one pasture for a long period) by cattle with no attempt to fence the cattle out of the stream. A treatment reach was labeled as “Riparian Forest” only if there were stands of trees on both sides of the stream that were 10 meters to 30 meters wide along the entire length of the treatment reach. Finally, treatment reaches with a stand of trees measuring more than 30 meters on each side were designated as “Forest” treatment reaches. Stream order was determined using the National Hydrography Dataset (Dewald and Roth, 1998) and the Strahler (1957) method. All treatment reaches were ground-truthed and, as all treatment reaches were on private lands, the use of each treatment reach was contingent on acquiring permission from the landowner to access his or her property.

Stream surveys

After a stream reach was determined to have the needed land use and stream order parameters, a survey was conducted to determine the extent and location of severely and very severely eroding bank lengths based on criteria established by the Natural Resources Conservation Service (USDA-NRCS) (1998a, 1998b). Waypoints were taken frequently along both right and left stream banks using Global Positioning System (GPS) units (Trimble Juno ST using TerraSync Software version 3.01 and Trimble GeoExplorer3 using GeoExplorer Software, version 1.20 or Dell X51 with GlobalSat BC-337 Compact Flash GPS Receiver and Trac-Mate software Farm Works Software, Version 12.16). Bank heights and the presence of other features were recorded (Table 2). Features recorded included gully entries, point bars, debris dams, and livestock access points. All stream lengths measured between 300 and 600 meters although the majority of treatment reaches were approximately 400 meters (31 out of 36 treatment reaches) (Table 2).

Stream banks were mapped using the data collected during stream surveys and ArcMap 9.2 as the geographic information system (GIS). Eroding banks were randomly selected in each treatment reach so that the sum of their lengths was equal to 20 percent of the total eroding length of both stream banks. To do this, the total stream length was divided into four sub-sections of equal length, and eroding lengths in each sub-section were summed. Severe and very severely eroding lengths in each sub-section were then randomly chosen until their sum lengths represented 20 percent of the total eroding length of that sub-section. The selected bank lengths were then located in the field using GPS units with Universal Transverse Mercator (UTM) coordinates. Pin plots (an arranged set of erosion pins across the bank length) were installed at these locations in order to measure erosion or deposition rates.

Pin plot installation

Pin plots consisted of evenly spaced erosion pins hammered horizontally into selected severe and very severely eroding bank lengths to measure horizontal bank retreat or deposition. Erosion pins are long, thin, cylindrical pieces of rolled steel that measure 76.2 cm in length with a 6.2 mm diameter.

Pins were arranged in columns spaced two meters apart and in rows whose number and spacing were dependent on bank height. Where bank height was one meter or less, one row of pins was installed at half bank height. Banks with heights between one and two meters tall received two rows of pins: a bottom row at 1/3 bank height and a top row at 2/3 bank height. Finally, plots with banks that measured over two meters in height were given three rows of pins: the bottom row at ¼ bank height, a middle row at half bank height, and a top row set at ¾ bank height. Pins were hammered horizontally into the face of the stream banks with 10.2 cm left exposed and painted a fluorescent color to help find them during the next seasonal measurement.

Pin measurements

After installation, the lengths of the exposed portion of each erosion pin were measured from the end of the pin to the bank surface with a ruler. Measurements occurred from 2008 to 2010 in mid-March, early August, and late November as these are dates at the end of three designated seasons: Season 1 (winter) measures erosion that takes place from December – March, Season 2 (spring/summer) measures erosion that takes place from April – July, and Season 3 (summer/fall) measures erosion that takes place from August – November.

Pin lengths recorded during seasonal measurements were subtracted from the lengths left exposed during the previous measurement date. The resultant number was the amount of retreat or deposition in centimeters for each respective pin that took place since the preceding measurement date. Negative values (the length of pin exposed was now shorter than it was last measurement) indicated that deposition had occurred, while positive values (the length of pin exposed was longer than it was last measurement) indicated erosion. After measurement, pins longer than 10.2 cm were hammered back into the bank until they once again measured 10.2 cm. Pins where deposition had occurred that measured less than four cm were replaced with a new pin to prevent the pin from being buried before the next measurement. New pins were hammered into the bank as close as possible to the original pin with 10.2 cm exposed. When a pin could not be found, the field crew would examine the bank and conclude whether the pin had been lost to erosion, which would result in a recorded value of 65 cm, or buried by deposition, which would result in a recorded value of zero. If the fate of the pin could not be confidently determined, the pin was labeled as “missing” and a value was not given to the pin. Replacement pins were hammered into the bank as close as possible to the location of the previous pin.

Erosion data was collected three times a year to investigate seasonal effects: in March, to investigate the winter effect, in August to investigate the spring/summer effect, and in November to investigate the summer/fall effect. Data from a total of twelve measurement dates were obtained beginning with a March, 2008 measurement and ending with a measurement in November, 2010 (Tables 3 and 4). The March, 2008 – March, 2009 data set (first and second order streams only) was analyzed by Berges (2009), and the March, 2008 – November, 2009 data set was analyzed by Willett (2010).

Soil sampling and bulk density analysis

Soil samples were collected from fifty percent of the pin plots in each treatment reach to determine averages for soil bulk density and total phosphorus. Samples were taken either between pin columns or just outside the first or last pin column so that erosion pin readings were not impacted. Soil profile descriptions were conducted and cores for bulk density were taken in each major bank layer (Odgaard, 1984). Additional bagged samples for phosphorus analysis were taken from each of the major stratified bank layers. Samples were collected as soon as possible after treatment reaches were established. Most of the samples were collected during the summer and fall of 2008. However, as mentioned earlier, two replacement treatment reaches were established later than the others. Those samples were not collected until October 2010.

Bulk density samples were collected using 7.5 cm diameter Uhland sample rings. Samples were oven-dried at 110ºC (230^{o}F) for a minimum of 72 hours, brought to room temperature in a desiccator, and weighed. The dry soil weight for each core was then divided by the volume of the Uhland sample ring to get a bulk density for each stratified bank layer (Blake and Hate, 1986). A weighted average (based on depth of the soil layer relative to total bank height) bulk density for each soil sampling location was calculated. Finally, a treatment reach average bulk density was calculated by averaging the soil sampling locations' bulk densities (Table 2).

Calculation of sediment horizontal retreat rate and sediment mass loss rate

Two calculations were produced to represent the rate of loss or gain of stream bank materials: a sediment horizontal retreat rate (cm) (Figure 1) (Table 3) and a sediment mass loss rate (kg/m) (Figure 2) (Table 4). Note that these calculations are averages for the total bank length (right bank plus left bank, usually 800 m) as opposed to the treatment reach length (usually 400 m). Also, note that the term "year" used in this study is from November of the previous year to November of that year. For instance, the year 2008 refers to November, 2007 to November, 2008.

The sediment horizontal retreat rate (Figure 1) is the average horizontal retreat or gain of bank materials. To calculate the horizontal retreat rate (cm), the average pin length change was calculated for each pin plot. Then, the pin plots were averaged and multiplied by the percent eroding bank length. Sediment horizontal retreat rates for each season (Table 3) were summed for each respective year to get a sediment horizontal retreat rate per year. Example: March 2008 rate + August 2008 rate + November 2008 rate = 2008 rate. Then, the 2008, 2009, and 2010 rates were averaged for an average yearly rate (Table 5).

The sediment mass loss rate (Figure 2) is the average mass of soil lost or gained per meter of total bank length. To calculate the sediment mass loss rate for each treatment reach, first, an average pin length change was calculated for a given seasonal dataset. This was done for each pin plot and multiplied by each pin plot's respective average bank height (m). The product of this number (m^2) and the bulk density (kg/m^3) produced a within-plot sediment mass loss rate (kg/m). Finally, the within-plot sediment mass loss rate was multiplied by the percent eroding bank length of the treatment reach to get a sediment mass loss rate for that treatment reach for that season (Table 4). Yearly rates were calculated the same way as described in the previous paragraph (Table 5).

Data analysis

Statistical analyses on the 2008, 2009, and 2010 data were performed using SAS version 9.2 (SAS Institute, 2008). Analysis of variance (ANOVA) models were used to analyze the sediment mass loss rates, the sediment horizontal retreat rates, and their interactions with the main factors of land use, stream order, and season. The MIXED procedure was used to fit the respective ANOVA models. The default covariance structure for SAS – variance components – was used, and since repeated measurements were made at each treatment reach, the RANDOM statement was used with treatment reach as the random variable. This statement, which has the same effect as the REPEATED statement, was used to account for the decreased variability you will have when you take repeated measurements on the same treatment reach as opposed to measurements made on different treatment reaches.

Because our data were unbalanced, least squares means of sediment mass loss rates and sediment horizontal retreat rates were used in many cases instead of arithmetic means, because least squares means correct for the imbalances in the variables so that the means are not biased toward the variables with the most observations. Therefore, least squares means were used instead of arithmetic means for testing for significance and making comparisons among effects. However, arithmetic means best represent the Crooked and Otter Creek watershed conditions. For instance, there is only one 3^{rd}+ order crop site because there are not many 3^{rd}+ order crop sites in the watersheds. Therefore, arithmetic means were used for making comparisons with other similar studies, and for computing watershed scale estimates.

For the sediment mass loss rates, after the ANOVA model was fit, the residuals were examined and were determined to not have met the normal distribution or equal variance assumptions. A second analysis was run using the transformation Y=log(mass loss rate+90). This transformation moved the numbers closer to the equal variance assumption, but the distribution could still not be described as normal. However, the new set of residuals was symmetric with heavy tails, and this transformation was deemed to be acceptable because data exhibiting heavy tails tend to be conservative when it comes to determining whether interactions are significant (Ramsay and Schafer, 2002). The transformation resulted in one outlier.

Interactions between sediment horizontal retreat rate with season, land use, and stream order variables were analyzed in the same way as described above. After the first ANOVA model was fit, the residuals did not meet the assumption of normality or equal variance. Therefore, a second analysis was run using the transformation Y=log(retreat rate+4). This transformation also resulted in a symmetric distribution with heavy tails and was accepted for the same reasons as above. This transformation resulted in one outlier.

Watershed scale estimates - sediment

The total amount of sediment delivered to streams from stream banks in the Crooked and Otter Creek watersheds was estimated by multiplying the arithmetic mean sediment mass loss rates for each stream order by the total length of streams in that stream order within the two watersheds. Total length of streams for each stream order was taken from Willet (2010) who used the National Hydrography Dataset (Dewald and Roth, 1998).

Watershed scale estimates – phosphorus

Soil phosphorus concentrations were analyzed from bagged soil samples taken from each stratified bank layer using an alkaline oxidation method developed by Dick and Tabatabai (1977). Bagged samples were air dried, sieved through a 2 mm screen, weighed, digested with a sodium hypobromite solution, and the extracted phosphorus was quantified colorimetrically by a modified molybdenum blue reaction (Murphy and Riley 1962). Finally, the mass of phosphorus extracted was divided by the mass of the soil sample.

Treatment reach average phosphorus concentrations were calculated in basically the same way as treatment reach average bulk densities. Phosphorus concentrations for each stratified bank layer were weighted based on the depth of each layer in proportion to total bank height. The depth-weighted phosphorus concentrations were then averaged together in order to calculate an average phosphorus concentration for each soil sampling location. Finally, a treatment reach average phosphorus concentration was calculated by averaging the pin plot soil sampling locations' average phosphorus concentrations. The total delivery of phosphorus per year was estimated by multiplying the average phosphorus concentrations for each stream order by the estimated total amount of delivered stream bank sediment calculated for each stream order category (Table 8).

Results and Discussion

A total of 3,364 pins were installed in 243 pin plots across 36 treatment reaches. An average of 93 (SE = 7) pins were installed within each treatment reach. Over 28,000 individual pin measurements were taken over the course of this study's 9 seasonal measurements. The mean number of pin plots per treatment reach was 6.8 (SE = 0.3). The mean treatment reach bank height was 1.51 m (SE = 0.07), and the average bulk density across treatment reaches was 1.41g/cm^3 (SE = 0.01).

The mean percent eroding bank length per treatment reach was 53% (SE = 4). The treatment reach with the lowest percent eroding length was 15%, while the highest percent eroding length was 100%. Zaimes et al. (2008a) reported that their percent eroding bank lengths per treatment reach fell between 10% and 54%. Schilling et al., (2011) reported that 9.1% and 30.4% of stream banks of two respective streams in southern Iowa were eroding, while Lyons et al., (2000) reported that the percent eroding length at their sites were 1-66%. Bank erosion ranged from 11% - 70% at rotational and conventional grazing sites in Iowa, Minnesota, and Wisconsin (Raymond and Vondracek, 2011). Simonson et al., (1994) suggest that a stream in "excellent" condition should have no more than 10% of its bank eroding, a stream in "good" condition would have between 10% and 25% bare soil, a "fair" bank would have between 25% and 50%, and a "poor" stream will have 50% or more of its bank length eroding.

The average sediment horizontal retreat rate across all treatment reaches was 5.59 cm/year (SE = 0.64). The average for 2008 was 5.36 cm/year (SE = 0.71), the average for 2009 was 5.30 cm/year (SE = 0.71), and the average for 2010 was 5.99 cm/year (SE = 0.73). Zaimes et al. (2008a) reported a loss of 10 cm/year within plot erosion rate, and an average eroding bank length of 30%. This equals a sediment horizontal retreat rate of approximately 3 cm/year, which is slightly over half of the mean rate reported in this study. Using the USDA-NRCS (1998) eroding streambank categories and corresponding erosion rates, Schilling et al. (2011) estimated an average erosion rate of 8.5 cm/year.

The average mass of bank sediment loss across all treatment reaches was 135.6 kg/m/year (SE = 19.6) based on the total length of banks in a treatment reach (~800 m). The average for 2008 was 134.1 kg/m/year (SE = 22.83), the average for 2009 was 129.6 kg/m/year (SE = 21.0), and the average for 2010 was 142.8 kg/m/year (SE =21.5).

Data analysis

Four interactions between the sediment horizontal retreat rates and the main effects were found to be significant using P<0.05 (Table 6): Season (<.0001), Season and Order (0.0093), Land use and Order (0.0135), and Land use, Order, and Season (0.0009). The same four effects were found to be significant among the sediment mass loss rates and the main effects (Table 7): Season (<0.0001), Season and Order (0.0002), Land use and Order (0.0098), and Land use, Order, and Season (0.0003).

Land use

The arithmetic mean sediment horizontal retreat rate per year for the different land use classifications (Figure 3) were as follows: crop treatment reaches retreated 5.36 cm/year (SE = 0.77), pasture treatment reaches retreated 5.79 cm/year (SE = 0.87), riparian forest treatment reaches retreated 5.51 cm/year (SE = 0.67), and forest treatment reaches retreated 5.47 cm/year (SE = 0.97). The mean sediment mass loss rate for the different land use classifications (Figure 4) were as follows: crop treatment reaches lost 113.03 kg/m/year (SE = 21.86), pasture treatment reaches lost 157.49 kg/m/year (SE = 25.99), riparian forest treatment reaches lost 127.74 kg/m/year (SE = 21.11), and forest treatment reaches lost 138.08 kg/m/year (SE = 28.97).

The land use erosion rates did not show the expected trends as there were no significant differences between the land uses for sediment horizontal retreat or sediment mass loss rates. Our hypothesis that the streams flowing through cropland and pastures would erode more than the forested treatment reaches is not supported by our results. However, there does not seem to be a consensus in the literature on whether or not land use impact of stream bank erosion is a determining factor.

Zaimes et al. (2006) reported that riparian forest buffers had significantly lower soil loss per unit stream bank than streams within crop and pasture fields. However, it should be noted that the riparian forest buffers in that study were designed and planted for conservation purposes whereas the riparian forest and forest land uses in our study were remnant strips of mature forest vegetation along streams or extensive mature forests. The riparian forest buffers in Zaimes et al. (2006) were four to eight years old. Therefore, the difference in forest structures between the 2006 study and our research makes comparisons difficult. It is unclear whether the forests in our study would have a comparable impact on stream bank erosion as the designed riparian forest buffers in the Zaimes et al. (2006) study. In Zaimes et al. (2008a), stream banks in crop, rotational pasture, and continuous pasture had higher soil losses per unit of bank length than grass filter, forest buffer, and fenced pastures (pasture where cows were fenced out of the stream). However, that study was testing the soil conservation management practices of grass filter strips and riparian forest buffers, so direct comparisons to our study are not appropriate as it is unknown whether remnant strips and large areas of mature forest will impact stream bank erosion in the same ways.

Many studies have shown the negative impacts that riparian grazing can have on many measures of stream health, including decreasing vegetation cover, increasing surface soil compaction, and decreasing bank stability at cattle access points, encouraging bank soil loss (Besky et al., 1999; Evans et al., 2006; Kauffman et al., 1983; Magner et al., 2008; Trimble, 1994). Evidence shows that riparian fencing reduces stream suspended sediment loads by between 40 and 80% (Owens et al., 1996; Williamson et al., 1996; Line et al., 2000). In this study, there were no significant differences between the pasture treatment reaches and the erosion rates of other land uses. However, it is worth noting that factors such as stocking rates, stocking density, size of pasture, and length of rotations were not tracked or held constant or accounted for in this study. And since the pin plots were placed randomly along banks of the treatment reaches, it is possible that areas where dense congregations of cattle access stream water were, in fact, highly eroding, but were not pinned because those areas were not randomly selected.

The question of how forests influence stream bank erosion receives a mix of answers from the research community. Some studies indicate that forested banks tend to erode less than banks with grass vegetation or in other land uses (Harmel et al., 1999; Geyer et al., 2000), and riparian forest buffers are advocated as riparian management tools whose purpose is to, in part, reduce stream bank erosion (Shields et al., 1995). Trimble (1997) proposed that wider forested channels were more unstable than narrower nonforested channels, and it has been found that the weight of large trees can have a destabilizing effect on moist soils (Simon and Collison,

2002) and cause local scouring around large woody debris, debris dams, and around tree roots (McBride et al., 2007; Zimmerman et al., 1967).

Other studies have results that discredit the supposed influence of land use on stream bank erosion. Lyons et al. (2000) found that sediment losses from stream banks in rotationally grazed pastures were similar to streams within riparian buffer strips, a management tool thought to decrease stream bank erosion (Zaimes et al., 2008a). Also, Schwarte et al. (2010) found no significant differences between sediment horizontal bank retreat between pasture treatments with different grazing regimes, including continuous stocking with restricted stream access, continuous stocking with unrestricted access, and rotational stocking. Schilling et al. (2010) monitored two watersheds over a ten year period in Central Iowa as one watershed decreased the amount of its watershed in crop and the other increased the amount of its watershed in crop. Both watersheds had similar row crop percentages in 1990 (about 70%) but by 2005, the amount of row crop land increased by 9% in Squaw Creek (due to losses of CRP land) and decreased 15% in Walnut Creek (due to prairie reconstruction). Analysis of the suspended sediment within the watersheds showed that, although the authors hypothesized that suspended sediment load would decrease in the less agricultural watershed and increase in the more agricultural watershed, the suspended sediment load actually showed no significant changes over time and no significant differences between the two watersheds. Stream mapping in 2004 indicated that Walnut Creek had three times more eroding stream banks than Squaw Creek. This suggests that bank erosion dominated sources in Walnut Creek and sheet and rill sources dominated sediment sources in Squaw Creek. These studies show that in some streams, there are disconnects between recent land use changes and bank erosion, leaving other factors to control bank erosion.

Stream order

Arithmetic mean sediment horizontal retreat rates per year for 1^{st}, 2^{nd}, and 3^{rd} + order streams (Figure 5) were 5.85 cm/year (SE = 0.62), 5.44 cm/year (SE = 0.82), and 5.33 cm/year (SE = 0.67), respectively. Mean sediment mass loss rates per year for 1st, 2nd, and 3rd + streams (Figure 6) were 122.45 kg/m/year (SE = 17.66), 127.71 kg/m/year (SE = 23.13), and 159.37 kg/m/year (SE = 23.62), respectively.

There were no significant differences between the stream orders for sediment horizontal retreat rates or sediment mass loss rates. However, the sediment mass loss rates show that 3rd+ order streams lost about 100 kg/m more than the other two stream orders on average for the sampling years. Since the sediment horizontal retreat rates were very similar among the stream orders (a calculation that only takes into account average pin length change and percent eroding length), we can conclude that the difference is caused by 3rd+ order streams having a higher average bank height than 1st or 2nd order streams in this study (Table 2).

Season

The seasonal arithmetic mean sediment horizontal retreat rate (Figure 7) for Winter (March) was 3.56 cm (SE = 0.25), 1.58 cm (SE = 0.22) for Spring/Summer (August), and 0.40 cm (SE = 0.08) for Summer/Fall (November). The seasonal sediment mass loss rate mean (Figure 8) for Winter was 85.73 kg/m (SE = 7.6), 41.15 kg/m (SE = 5.90) for Spring/Summer, and 9.17 kg/m (SE = 1.77) for Summer/Fall. Note that season rates are measuring the bank retreat and soil loss for approximately four-month periods as opposed to the per year rates presented in the previous section.

The results from the measurement date analysis showed the expected trends with March having far greater erosion than the other two measurements. Many studies of stream bank erosion show that most erosion occurs during the winter and spring period (Simon et al., 2000; Tufekcioglu et al., 2010; Zaimes et al., 2008a) due to weakened, saturated soils. Zaimes, et al. (2006) noted that the highest magnitudes of bank erosion occurred in spring and early summer. He sampled monthly and noted that magnitudes of stream bank erosion greater than 20 mm were measured primarily in spring and early summer.

Wynn et al. (2008) found that banks tend to destabilize after freeze-thaw cycling, which happens during periods when day-time temperatures are high enough to allow soil-water to melt and night temperatures are cold enough to re-freeze the soil-water, causing expansion and retraction of soil pores, weakening soil stability. Wolman (1959) concluded that high winter erosion rates were largely caused by high flow events occurring during times when bank soils were already saturated. High flow events occurring in summer did not produce high erosion rates compared to those that occurred during the winter (Wolman, 1959). Hooke (1979) also found that most erosion occurs during high stream flow levels when bank soils were already saturated from previous precipitation or snow melt events, conditions occurring more commonly in winter due to decreased evapotranspiration. Lawler et al. (1999) described the aforementioned factors along with decreased vegetative cover as factors destabilizing stream banks during the winter.

Other factors influencing stream bank erosion

Post-settlement changes in land cover throughout the Midwest have destabilized the hydrologic and geomorphic conditions of these landscapes, and although upland conservation practices have improved over time, watersheds in this region have not re-equilibrated following this massive land disturbance (Trimble, 1999). In a Wisconsin watershed, it is estimated that during peak agricultural activity in the 1930's, sediment loads were 2.5 times greater than under modern land cover and may have been five times greater than under pre-settlement forest cover (Fitzpatrick et al., 1999). Today, as much of the 1930's eroded sediment remains in Midwest stream networks, there remains a disconnect between current land uses and bank erosion as these watersheds have not re-equilibrated following this massive land disturbance.

Riparian vegetation and watershed characteristics influences on stream bank erosion are discussed in the next chapter, but another factor that may also warrant further investigation is stage of channel evolution (Simon and Hupp, 1986). Some of the stream reaches in this study are still incising and therefore will have lower erosion rates than stream reaches that are in the widening stage, regardless of land use or stream order.

Also, based on observations in the field, unique characteristics of some of our treatment reaches may be exacerbating erosion rates. For instance, the treatment reach with the highest horizontal retreat and mass soil loss rates was a 2^{nd} order Forest reach. This reach lies just upstream from joining with another stream that has been channelized. Instability of this treatment reach may be at least partially attributable to the increased slope that the downstream channelized reach encourages.

Watershed scale estimates - sediment

The total length of first order streams in the Crooked and Otter Creek watersheds is 704 km (Table 8). Second order streams measure 323 km, and 3^{rd}+ order streams measure 338 km (Table 8). The total amount of sediment estimated to be contributed to streams from stream banks within the watersheds are 182,000 Mg/year (SE = 4800) (Table 8). The total amount of sediment delivered from 1st order streams is estimated to be 86,800 Mg/year, the total amount of sediment contributed from 2nd order streams is 41,900 Mg/year, and the contribution from 3rd+ order streams is 53,300 Mg/year (Table 8). An estimated 182,000 Mg were lost from stream banks in 2008, 172,000 Mg were lost in 2009, and 189,000 Mg were lost in 2010. Schilling et al. (2011) reported annual average stream bank erosion of 7,600 Mg and 7,300 Mg for two respective watersheds in southern Iowa which both have watersheds of approximately 5,000 ha. These stream bank erosion losses are comparable to the approximately 180,000 Mg of loss in our watersheds when the differences in watershed size are accounted for.

Willet et al. (2011) estimated that 190,000 Mg/year was contributed from stream banks in this study area and that 28,000 Mg/year was contributed to streams from overland sediment sources. This led to 79-96% of the total in-stream sediment in the Crooked and Otter Creek watersheds being attributed to stream bank erosion (Willett et al., 2011). Using stream bank sediment loss rates calculated in this study and estimates of overland erosion from Willet et al. (2011), we similarly estimate that 79-95 % of the total in-stream sediment within the Crooked and Otter Creek watersheds comes from stream banks.

Watershed scale estimates - phosphorus

The mean phosphorus concentration for all treatment reaches was 375.4 mg/kg (SE = 15.2) (Table 2). The mean phosphorus concentration for 1st order streams was 355.9 mg/kg (SE = 28.0), the mean for 2nd order steams was 368.7 mg/kg (SE = 26.8), and the mean for 3rd+ order streams was 410.0 mg/kg (SE = 31.4) (Table 8). These are similar to the phosphorus concentrations found by Zaimes (2008b) who found concentrations between 360 and 555 mg/kg in bank soils in the southeast part of Iowa. However, in a southern Iowa study, concentrations averaged 574 mg/kg among all sites and varied within a relatively narrow range with a few exceptions (Schilling et al., 2009). Tufekcioglu (2010) reported phosphorus concentrations ranging from 246 to 349 mg/kg in southern Iowa.

The total amount of phosphorus contributed to streams from stream banks within the two watersheds is 68.21 Mg/year (SE = 1.8) (Table 8). The estimated phosphorus contribution from 1st order streams was 30.90

Mg/year (Table 8). Second order streams are estimated to contribute 15.45 Mg/year, and 3rd+ order streams are estimated to contribute 21.87 Mg/year (Table 8). An estimated 68.3 Mg were lost from stream banks in 2008, 64.5 Mg were lost in 2009, and 71.0 Mg were lost in 2010. Tufekcioglu (2010) reported total-P losses from stream banks ranging from 20 to 21 kg/km/year in Conservation Reserve Program sites and 33 to 183 kg/km/year in grazed sites. Our stream order means of 44, 48, and 65 kg/km/year for 1st, 2nd, and 3rd+ order streams, respectively, fall into the range that Tufekcioglu (2010) presented (Table 8).

Discharge during study years

Although the erosion rates do not vary widely across years, Zaimes et.al (2006) points out that "a dataset of many years is needed to get a good estimate of bank erosion contributions to stream sediment load." Discharge data from the US Geological Survey (USGS) for Crooked Creek shows that 2008-2010 were much wetter than average (USGS, 2011). In fact, since 1980, calendar years 2008, 2009, and 2010 were three of the 6 years with the highest average daily discharge from Crooked Creek. The average daily discharge from 1980 to 2010 was 1.9 cubic meter per second (cms). The average daily discharge during this study was 4.8 cms for 2008, 3.1 for 2009, and 3.0 for 2010. Since stream bank erosion is highly related to precipitation (Zaimes et al., 2006), it should not be assumed that the erosion rates presented here are representative of long-term trends. On the other hand, given the strong seasonality of bank erosion, the annual erosion rates reported here may not be substantially higher than erosion rates that occur during years with average precipitation as most precipitation during these above average precipitation study years took place during the summer, a time when bank erosion is less susceptible to high flows because banks are relatively drier than during the winter and spring periods (Hooke, 1979).

Conclusions

Land-use changes from natural vegetative communities into agricultural uses can result in adjustments to the hydrology and geomorphology of an area (Magilligan and Stamp 1997), which will alter a stream's sediment transporting power (Simon and Rinaldi, 2006), and it may take a very long time for streams to adjust to these changes made in the upland areas. There were no significant differences found between land uses, a conclusion echoed by several other studies. In the Midwest, there remains a disconnect between current land use and bank erosion as these watersheds have not re-equilibrated following the massive post-settlement hydrologic disturbance.

Season 1 erosion rates were significantly greater than Seasons 2 or 3, which indicated that most bank erosion occurred during the November to March time period than any other time during the year. This is thought to be because of the weakening of bank soils during the winter months from freeze-thaw action and saturated soils. Erosion rates by stream order were not significantly different, indicating that the hierarchical basis for categorizing stream orders has little or no relationship to stream bank erosion processes.

Watershed scale estimates show that approximately 182,000 Mg of sediment and 68 Mg of phosphorus were contributed to streams in the Crooked and Otter Creek watersheds on average for each year during this study. We estimate that 79-95% of the total in-stream sediment within the Crooked and Otter Creek watersheds comes from stream banks. Although discharge during our study years was higher than average, because of the seasonality of bank erosion, rates presented here are probably similar to rates that occur during years of average discharge rates.

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Figures and Tables

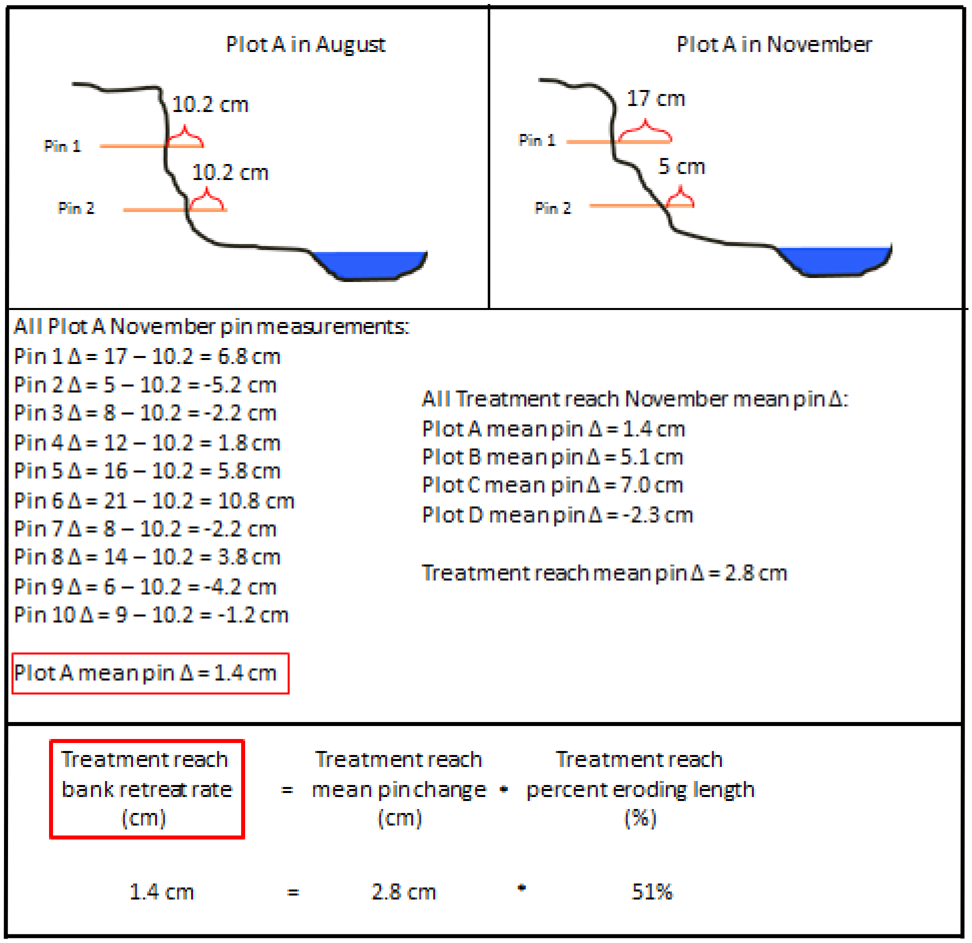

Figure 1. Example showing how to calculate treatment reach horizontal bank retreat rate. Pins are installed in banks with 10.2 cm exposed in August. In November, Pin 1 is measured at 17 cm, and Pin 2 is measured at 5 cm. A total of 10 pins are measured at Plot A with the mean pin change coming to 1.4 cm. All plot mean pin changes are averaged to get a treatment reach mean pin change. For this treatment reach, the November mean pin change is 2.8 cm. Finally, the mean pin change is multiplied by the treatment reach percent eroding length to get a treatment reach bank retreat rate, which for this example equals 1.4 cm of retreat from August to November.

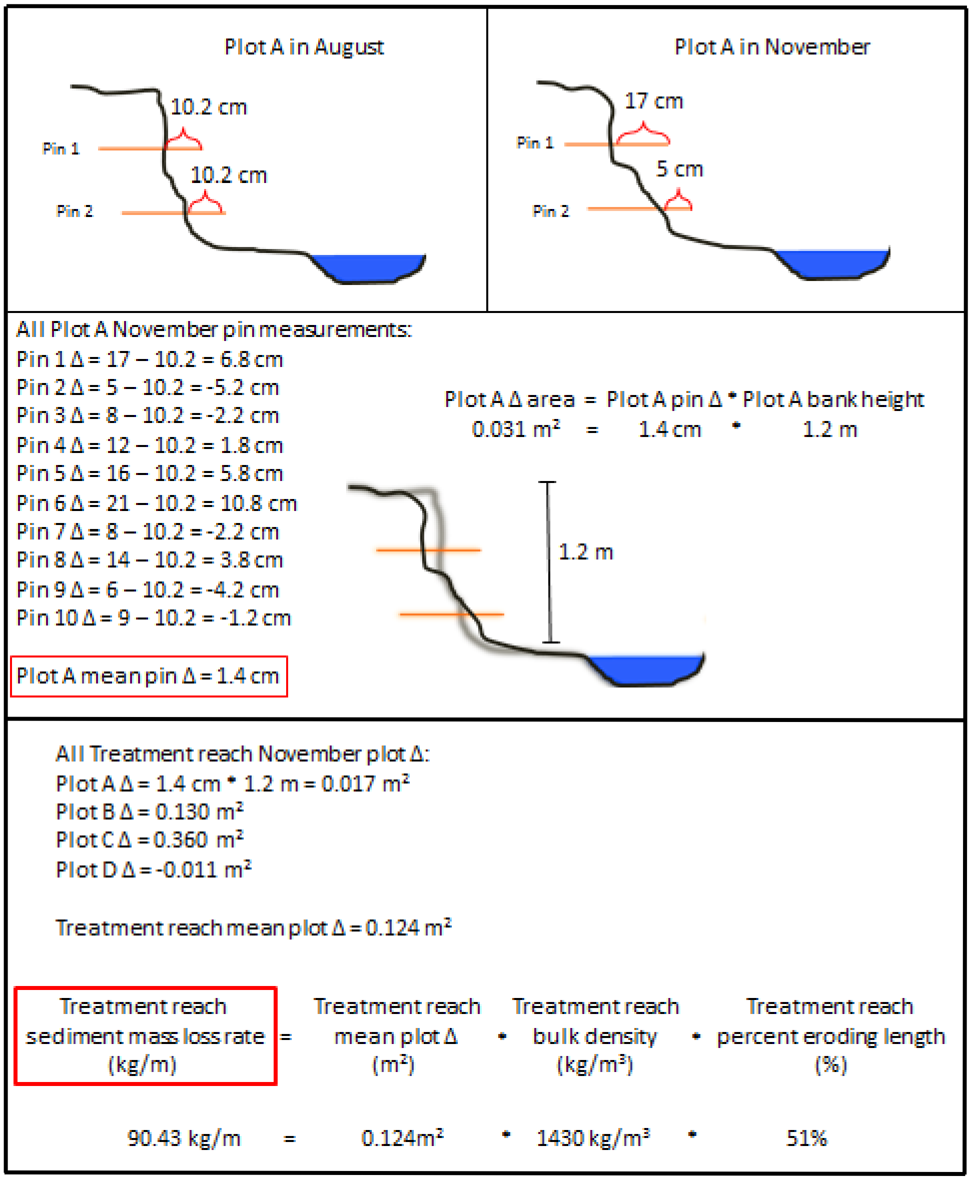

Figure 2. Example showing how to calculate treatment reach sediment mass loss rate. Pins are installed in banks with 10.2 cm exposed in August. In November, Pin 1 is measured at 17 cm, and Pin 2 is measured at 5 cm. A total of 10 pins are measured at Plot A with the mean pin change coming to 1.4 cm. To calculate the Plot A change in area from August to November, Plot A mean pin change is multiplied by Plot A bank height. This process is repeated at all plots within the treatment reach, and all plot changes are averaged to get a treatment reach mean plot change. Finally, we calculate treatment reach sediment mass loss rate by multiplying treatment reach mean plot change, treatment reach bulk density, and treatment reach percent eroding length. In this example, the treatment reach lost 90.43 kg of bank soil per meter of stream bank from August to November.

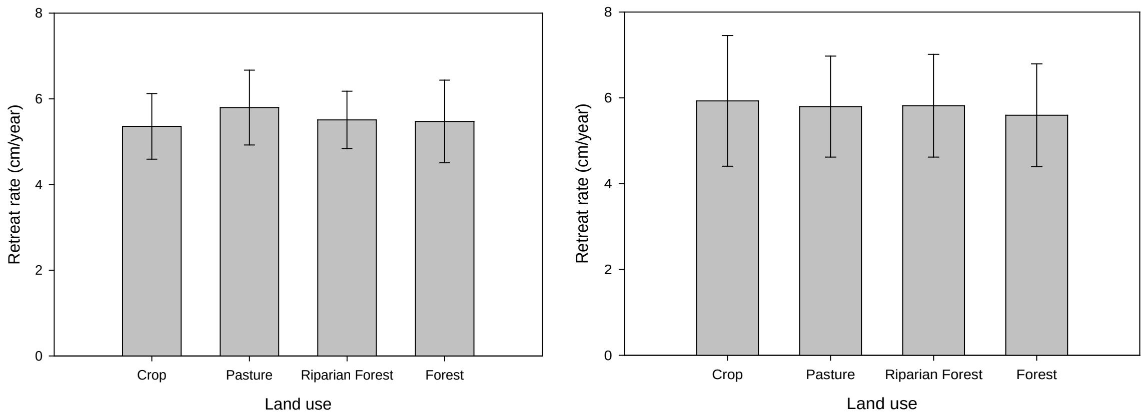

Figure 3. Arithmetic mean land use retreat per year (left), and least squares mean land use retreat per year (right). Error bars represent standard error of the mean. Rates represent the average of retreat over the total bank length including both eroding and non-eroding sections.

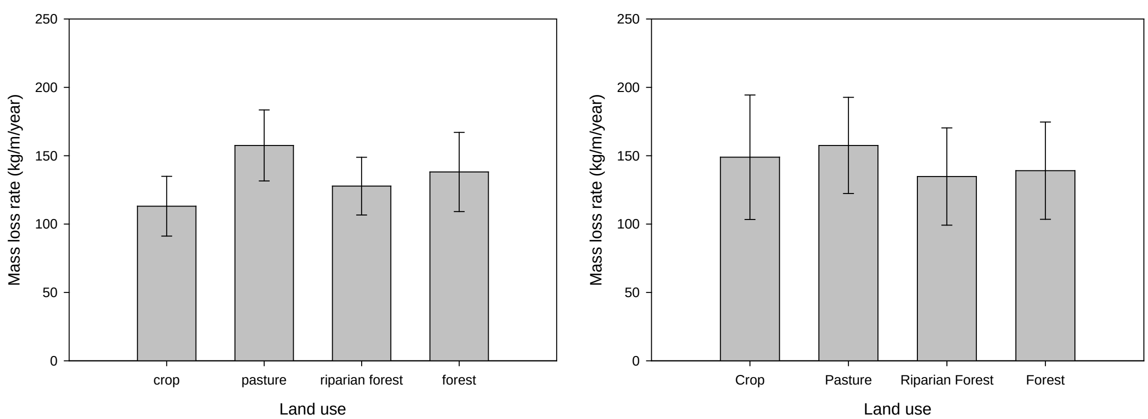

Figure 4. Arithmetic mean land use mass loss rate per year (left), and least squares mean land use mass loss rate per year (right). Error bars represent standard error of the mean. Rates represent the average of mass lost over the total bank length including both eroding and non-eroding sections.

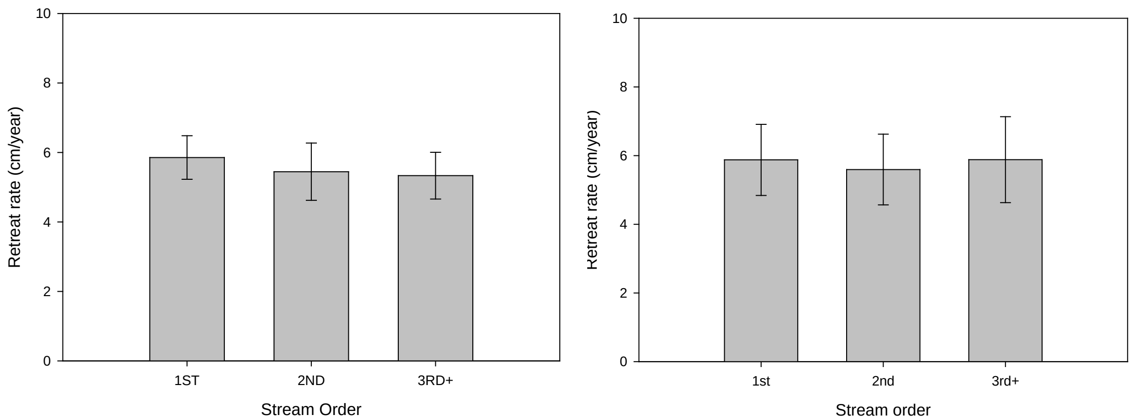

Figure 5. Arithmetic mean stream order retreat per year (left) and least squares mean stream order retreat per year (right). Error bars represent standard error of the mean. Rates represent the average of retreat over the total bank length including both eroding and non-eroding sections.

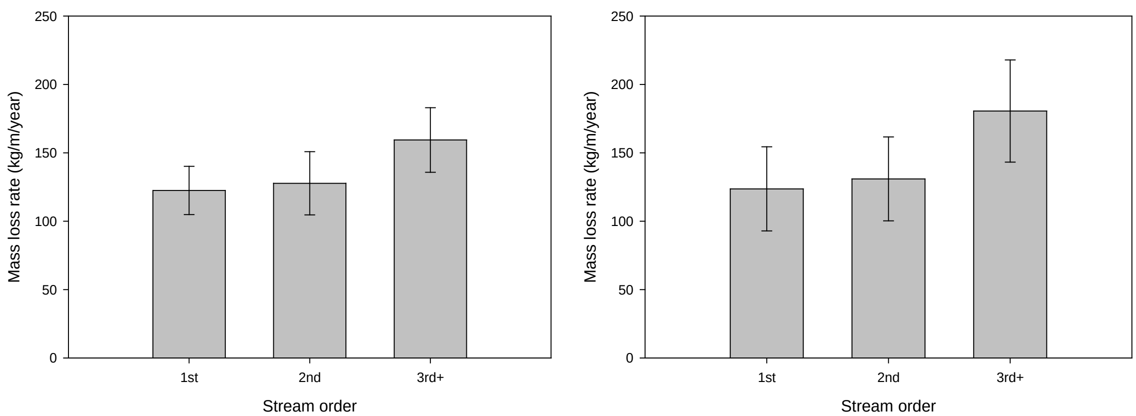

Figure 6. Arithmetic mean stream order mass loss rate per year (left) and least squares mean stream order mass loss rate (right). Error bars represent standard error of the mean. Rates represent the average of mass lost over the total bank length including both eroding and non-eroding sections.

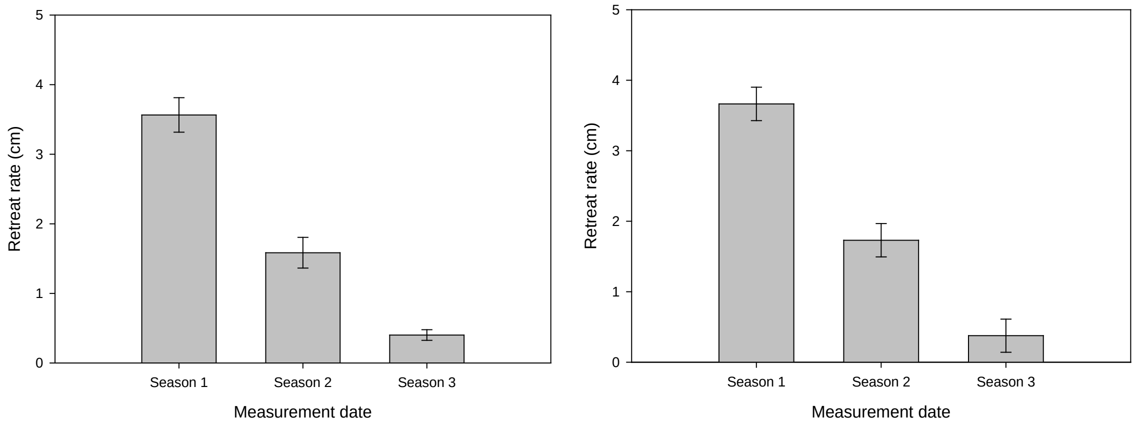

Figure 7. Arithmetic mean season retreat rate (left) and least squares mean retreat rate (right). Error bars represent standard error of the mean. Rates represent the average of retreat over the total bank length including both eroding and non-eroding sections. (Season 1 – December – March; Season 2 – April – July; Season 3 – August – November)

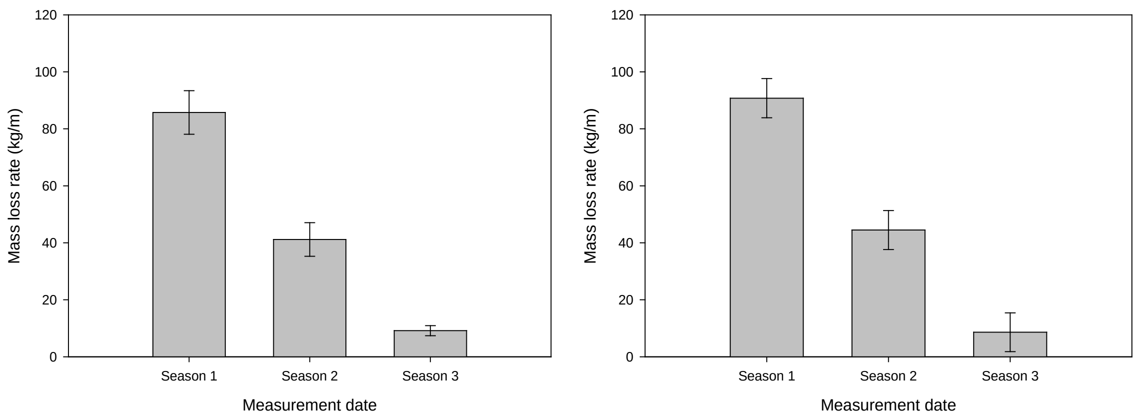

Figure 8. Arithmetic mean season mass loss rate (left) and least squares mean measurement date mass loss rate (right). Error bars represent standard error of the mean. Rates represent the average of mass lost over the total bank length including both eroding and non-eroding sections. (Season 1 – December – March; Season 2 – April – July; Season 3 – August – November)

Table 1. Treatment reach stream order, land use, measurement dates, and watershed.

Treatment reach	**Stream Order**	**Land use**	**Measurement dates**	**Watershed**
A	1st	Crop	March, 2008 - November, 2010	Otter Creek
B	1st	Crop	March, 2009 - November, 2010	Crooked Creek
C	1st	Crop	March, 2008 - November, 2010	Otter Creek
D	1st	Forest	March, 2008 - November, 2010	Otter Creek
E	1st	Forest	March, 2008 - November, 2010	Otter Creek
F	1st	Forest	November, 2008 - November, 2010	Crooked Creek
G	1st	Pasture	March, 2008 - November, 2010	Crooked Creek
H	1st	Pasture	March, 2008 - November, 2010	Crooked Creek
I	1st	Pasture	March, 2008 - November, 2010	Otter Creek

Table 1, continued.				
J	1st	Riparian Forest	March, 2008 - November, 2010	Crooked Creek
K	1st	Riparian Forest	March, 2008 - November, 2010	Crooked Creek
L	1st	Riparian Forest	March, 2008 - August, 2009	Crooked Creek
M	1st	Riparian Forest	November, 2010	Crooked Creek
N	2nd	Crop	March, 2008 - November, 2010	Otter Creek
O	2nd	Crop	March, 2008 - November, 2010	Otter Creek
P	2nd	Crop	March, 2008 - November, 2010	Otter Creek
Q	2nd	Forest	March, 2008 - November, 2010	Otter Creek
R	2nd	Forest	August, 2008 - November, 2010	Crooked Creek
S	2nd	Forest	March, 2008 - November, 2008	Otter Creek
T	2nd	Forest	August, 2010 - November, 2010	Crooked Creek
U	2nd	Pasture	March, 2008 - November, 2010	Otter Creek
V	2nd	Pasture	March, 2008 - November, 2010	Crooked Creek
W	2nd	Pasture	March, 2008 - November, 2010	Otter Creek
X	2nd	Riparian Forest	March, 2008 - November, 2010	Otter Creek
Y	2nd	Riparian Forest	March, 2008 - November, 2010	Otter Creek
Z	2nd	Riparian Forest	March, 2008 - November, 2010	Crooked Creek
AA	3rd+	Crop	March, 2008 - November, 2010	Crooked Creek
AB	3rd+	Forest	March, 2008 - November, 2010	Otter Creek
AC	3rd+	Forest	March, 2008 - November, 2010	Otter Creek
AD	3rd+	Forest	March, 2008 - November, 2010	Otter Creek
AE	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
AF	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
AG	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
AH	3rd+	Riparian Forest	March, 2008 - November, 2010	Otter Creek
AI	3rd+	Riparian Forest	March, 2008 - November, 2010	Crooked Creek
AJ	3rd+	Riparian Forest	March, 2009 - November, 2010	Crooked Creek

Table 2. Treatment reach height, soil, length, and eroding length information.

Treatment reach	**Average height (m)**	**Bulk density (g/cm3)**	**P concentrations (mg/kg)**	**Treatment reach length (m)**	**Total bank length (right bank + left bank) (m)**	**Percent eroding length (%)**
A	0.84	1.36	615	400	800	41
B	0.88	1.37	352	400	800	23
C	0.85	1.38	432	400	800	46
D	0.75	1.4	382	340	680	47
E	1.43	1.52	197	300	600	37
F	1.44	1.49	261	400	800	61
G	1.65	1.4	286	400	800	71
H	1.24	1.36	360	400	800	23
I	1.9	1.48	311	400	800	73
J	1.67	1.43	316	400	800	72
K	1.18	1.3	357	400	800	86
L	1.43	1.48	327	400	800	83
M	1.37	1.31	431	400	800	33
N	1.46	1.26	503	400	800	100
O	1.87	1.4	377	400	800	57
P	1.56	1.3	386	400	800	69
Q	1.71	1.63	208	400	800	58

Table 2, continued.

R	1.53	1.47	249	400	800	40
S	1.78	1.48	263	600	1200	23
T	1.71	1.27	442	400	800	65
U	1.76	1.45	382	400	800	97
V	1.75	1.36	534	475	950	15
W	1.21	1.34	412	400	800	37
X	1.08	1.49	314	400	800	23
Y	1.3	1.48	406	400	800	22
Z	1	1.36	315	400	800	45
AA	2.24	1.48	373	400	800	53
AB	1.22	1.38	401	400	800	30
AC	1.58	1.41	452	350	700	49
AD	2.37	1.48	307	400	800	17
AE	1.79	1.42	391	400	800	88
AF	1.48	1.42	476	400	800	86
AG	2.36	1.49	278	400	800	58
AH	1.67	1.35	411	400	800	70
AI	2.02	1.52	373	400	800	34
AJ	1.34	1.36	637	400	800	70

Table 3. Treatment reach sediment horizontal retreat rates (cm) for each seasonal measurement period. S1 = Season 1, S2 = Season 2, S3 = Season 3

Treatment reach	**S1, 2008**	**S2, 2008**	**S3, 2008**	**S1, 2009**	**S2, 2009**	**S3, 2009**	**S1, 2010**	**S2, 2010**	**S3, 2010**
A	4.72	-0.12	-0.14	2.69	0.61	-0.30	1.51	3.72	2.92
B				1.25	0.16	-0.21	1.35	0.52	0.13
C	6.38	-0.74	0.27	2.24	0.37	0.42	5.42	1.05	0.34
D	0.35	-0.50	0.23	0.89	1.03	0.19	0.48	-0.19	0.36
E	3.70	2.14	0.49	3.38	2.06	0.14	1.56	4.34	0.79
F			-0.04	3.99	-0.14	-0.56	0.95	3.61	0.45
G	1.56	3.67	0.37	3.02	4.81	1.45	2.68	10.08	0.67
H	1.50	-0.17	-0.07	2.11	0.21	-0.03	1.29	1.50	0.11
I	5.89	4.94	0.99	6.31	4.18	0.36	3.49	3.31	1.46
J	2.96	5.38	0.81	7.57	1.50	2.65	3.48	4.14	1.12
K	3.06	2.80	0.32	4.00	2.13	1.44	1.44	3.19	0.35
L	5.11	3.50	0.46	5.74	5.43				
M									0.57
N	7.14	-1.80	0.82	7.77	2.82	-0.84	6.88	4.23	1.59
O	5.60	0.51	0.42	3.71	0.80	0.10	3.03	1.23	0.77
P	1.36	-1.01	0.25	0.89	-0.51	-0.55	1.67	-0.32	0.57
Q	6.43	8.38	1.47	8.80	4.20	0.27	3.42	8.29	2.77
R		0.77	0.56	8.26	2.33	0.67	7.46	3.39	0.84
S	1.97	1.86	0.02						
T								3.48	0.40
U	9.66	-0.69	0.19	5.74	3.31	1.76	6.22	2.33	0.46
V	1.58	0.09	0.04	0.88	0.43	0.09	1.14	0.26	-0.11
W	1.48	0.29	0.44	1.68	0.19	0.67	3.43	-0.27	0.25
X	0.86	0.33	-0.08	0.21	0.22	-0.11	0.18	-0.22	0.03

Table 3, continued.									
Y	1.40	0.45	-0.02	2.04	0.31	0.24	1.82	0.47	0.17
Z	4.17	0.15	0.55	3.87	0.22	0.47	1.85	0.53	0.10
AA	5.69	2.21	-0.24	4.01	3.55	0.70	5.58	3.09	0.86
AB	0.89	0.57	0.66	1.57	0.57	0.72	1.65	0.75	0.42
AC	1.49	0.61	0.69	1.84	1.09	0.46	3.17	0.67	0.55
AD	1.67	0.50	0.11	1.12	1.01	0.24	2.06	0.37	0.06
AE	5.16	-3.46	0.24	4.76	0.74	-1.39	7.60	3.30	0.06
AF	3.27	1.81	-1.06	1.13	-1.28	-2.19	1.41	-0.49	-1.64
AG	8.86	1.05	1.04	6.13	1.65	0.45	6.98	3.37	0.77
AH	4.13	-1.14	0.88	3.90	1.65	0.67	4.65	0.54	0.78
AI	9.43	1.43	0.08	5.98	2.77	0.37	3.68	3.46	0.13
AJ				4.81	0.84	-0.03	3.70	1.84	0.28
Mean	3.92	1.09	0.34	3.71	1.49	0.26	3.16	2.29	0.57

Table 4. Treatment reach sediment mass loss rates (kg/m) for each measurement period. S1 = Season 1, S2 = Season 2, S3 = Season 3

Treatment reach	**S1, 2008**	**S2, 2008**	**S3, 2008**	**S1, 2009**	**S2, 2009**	**S3, 2009**	**S1, 2010**	**S2, 2010**	**S3, 2010**
A	52.9	-1.4	-1.2	30.1	7.2	-3.5	17.2	42.2	34.0
B				15.2	3.4	-2.6	14.2	7.8	1.4
C	76.3	-7.5	4.0	27.1	4.7	5.3	66.5	13.4	4.0
D	3.8	-5.1	2.8	9.5	10.7	2.1	5.4	-1.7	3.7
E	83.9	50.3	11.1	75.8	48.4	4.2	33.9	100.8	18.4
F			-0.6	80.6	-2.7	-10.6	19.2	72.5	9.2
G	37.4	77.7	8.6	69.1	113.2	32.3	62.9	227.9	18.5
H	24.1	-1	-0.8	32.8	4.0	0.3	20.8	28.3	2.3
I	180.5	145.6	5.3	188.7	118.6	10.8	98.8	106.5	39.5
J	71.9	132.5	21.8	187.9	36.2	62.9	87.3	104.2	27.4
K	46.1	43.9	5.1	60.8	35.0	21.1	21.1	49.5	5.4
L	117.8	82.0	8.9	120.5	131.1				
M									10.1
N	133.3	-34.4	13.3	140.6	53.1	-18.4	117.2	75.2	32.3
O	145.2	14.8	11.6	95.9	21.1	2.8	76.7	32.8	21.8
P	26.7	-20.9	5.1	17.9	-10.3	-11.1	34.2	-6.5	11.5
Q	179.3	259.4	37.0	264.2	157.4	5.5	113.9	238.6	87.3
R		17.2	13.1	185.7	53.0	15.2	168.4	77.5	20.6
S	51.1	46.2	0.6						
T								72.5	10.7
U	250.7	-18.0	4.5	143.5	88.4	45.8	153.6	37.3	11.7
V	42.6	3.3	1.6	23.9	11.5	2.1	29.6	6.8	-2.8
W	23.8	4.8	6.5	26.8	2.7	10.5	54.4	-4.2	3.9
X	15.1	7.4	-1.1	3.9	4.4	-1.7	3.1	-4.1	0.5
Y	25.6	8.5	-0.1	37.3	5.3	4.4	33.4	8.6	3.2
Z	53.6	3.7	7.5	46.9	3.3	5.3	23.3	6.6	1.8
AA	190.9	75.9	-7.4	136.7	121.7	24.1	191.3	105.8	29.1
AB	18.3	13.2	13.9	32.9	12.6	15.8	33.6	17.4	8.9
AC	26.1	12.0	11.9	37.0	20.2	8.4	60.3	11.4	10.4
AD	54.7	17.0	3.4	36.0	31.3	6.5	62.9	11.1	1.5
AE	144.6	-92.0	13.6	127.3	28.2	-37.5	207.8	89.5	1.2
AF	71.5	38.9	-21.5	31.3	-24.8	-43.4	34.8	-9.1	-30.8

Table 4, continued.									
AG	319.4	39.6	36.2	222.6	61.6	15.8	252.5	122.6	28.7
AH	93.5	-22.8	20.2	91.6	43.2	15.2	111.7	14.2	17.2
AI	319.2	48.7	2.6	202.3	93.8	12.3	124.9	110.1	4.3
AJ				92.2	15.8	0.6	70.4	37.0	7.0
Mean	96.00	30.31	7.42	87.72	39.49	6.27	75.17	54.62	13.35

Table 5. Treatment reach mean sediment mass loss rate per year and sediment horizontal retreat rate per year with standard errors of the mean. Averages are for 2008, 2009, and 2010.

Treatment reach	**Sediment horizontal retreat rate (cm/year)**	**SE**	**Sediment mass loss rate per year (kg/m/year)**	**SE**
A	5.20	1.53	59.2	17.7
B	1.60	0.40	19.6	3.7
C	5.25	1.14	64.6	14.1
D	0.95	0.60	10.4	6.2
E	6.18	0.32	142.3	7.3
F	4.15	0.86	84.2	16.8
G	9.43	2.26	215.9	53.6
H	2.15	0.48	36.9	8.4
I	10.31	1.06	298.1	26.9
J	9.87	0.93	244.0	21.6
K	6.24	0.75	96.0	11.8
L	9.07	no data	208.7	no data
M	no data	no data	no data	no data
N	9.54	1.89	170.7	32.6
O	5.39	0.58	140.9	15.7
P	0.78	0.61	15.5	12.6
Q	14.68	0.87	447.5	14.5
R	11.48	0.22	260.2	6.3
S	3.85	no data	97.9	no data
T	no data	no data	no data	no data
U	9.66	0.58	239.2	21.7
V	1.47	0.13	39.6	4.1
W	2.72	0.36	43.1	5.7
X	0.47	0.33	9.2	6.4
Y	2.29	0.23	42.1	4.1
Z	3.97	0.75	50.7	9.9
AA	8.48	0.55	289.4	19.6
AB	2.56	0.24	55.5	5.1
AC	3.50	0.47	65.9	9.3
AD	2.37	0.06	74.8	0.5
AE	5.67	2.72	159.5	71.3
AF	0.32	1.91	15.6	37.8
AG	10.43	0.60	366.3	33.2
AH	5.28	0.70	128	18.7
AI	9.11	1.06	306.1	37.9
AJ	5.72	0.10	111.5	2.9

Table 6. Significance of main factors and interactions among main factors on sediment horizontal retreat rates.	
Effect	**P value**
Riparian land use	0.9195
Stream order	0.8087
Riparian land use and Stream order	0.0135
Season	<.0001
Land use and Season	0.2086
Stream order and Season	0.0093
Land use and Stream order and Season	0.0009

Table 7. Significance of main factors and interactions among main factors on sediment mass loss rates.	
Effect	**P value**
Riparian land use	0.9937
Stream order	0.6694
Riparian land use and Stream order	0.0098
Season	<.0001
Land use and Season	0.1776
Stream order and Season	0.0002
Land use and Stream order and Season	0.0003

Table 8. Crooked and Otter Creek watersheds estimated total soil and phosphorus loss per year was calculated using total bank length for each stream order, average yearly sediment mass loss rates, soil loss per year, phosphorus concentrations, phosphorus mass loss rates, and phosphorus loss per year. Ranges represent standard errors.

Stream order	**Bank length (km)**	**Sediment mass loss rate (kg/m/year)**	**Soil loss mass (Mg/year)**	**P concentration (mg/kg)**	**P loss rate (kg/km/yr)**	**P loss mass (Mg/yr)**
1st	704	123	86,800	355	44	30.90
2nd	323	130	41,900	369	48	15.45
3rd+	338	158	53,300	410	65	21.86
Totals			**182,000**±4800			**68.21**±1.8

Chapter 3: Vegetation and watershed characteristics influence on stream bank erosion

Rachel Peacher, Cathy Mabry McMullen, Robert N. Lerch, Richard C. Schultz, and Thomas M. Isenhart

Abstract

Riparian vegetation has been shown to have various effects on stream bank erosion, some of which are stabilizing, and some of which are destabilizing. Characteristics of a watershed will determine the ability of stream discharge to scour and potentially destabilize stream banks. Vegetation data was taken on the top of banks and on the bank face in the riparian area of study treatment reaches, and watershed characteristics were calculated using a geographic information system. Variables were modeled using regression analysis with the best fit model accounting for 50% of the variability of the stream bank erosion. Land-use changes in the Midwest US from natural vegetative communities into agricultural uses have resulted in adjustments to stream hydrology and geomorphology that have not yet re-equilibrated. These influences may be overshadowing the influences of vegetation and watershed variables.

Introduction

Suspended sediment severely impacts surface waters by degrading water quality for human purposes and interfering with the physiological and life history functions of aquatic life (Simon & Darby, 1999). Sediment and nutrients are arguably the most pervasive and costly form of water pollution in North America (Osterkamp, 1998).

In order to decrease the sediment and nutrient loads in streams, we must first identify its major sources. As in-field soil conservation practices have become more widespread and erosion from upland sources has largely decreased, some researchers suggest that the main source of eroded materials in streams is shifting from upland sources to the erosion of gullies and stream channels (Simon and Klimetz, 2008; Wilson et al., 2008a,b). In general, there is a growing consensus in the literature that stream bank erosion is almost always a significant source of stream sediment (Nagle et al., 2007; Rondeau et al., 2000; Simon, 2008; Thoma et al., 2005; Sekely et al., 2002) and in many instances, it is the dominant source (Amiri-Tokaldany et al., 2003; Laubel et al., 1999; Laubel et al., 2003; Mukundan et al., 2010; Schilling and Wolter, 2000; Schilling et al., 2011; Simon and Rinaldi, 2006; Wilson et al., 2008a). Zaimes et al. (2008a) and Zaimes et al. (2008b) suggest that stream bank erosion may be an important source of phosphorus in watersheds, and a two-year grazing study (Schwarte et al., 2011) showed that the major source of the sediment and phosphorus in a pasture stream in Iowa is eroding stream banks, specifically cutbanks, and not surface runoff or fecal deposition.

The Mark Twain Lake/Salt River watershed lies within the Central Claypan Region (USDA Natural Resource Conservation Service [NRCS], 2006), a Major Land Resource Area (113) that has a unique geology: loess overlies old glacial drift that has a high content of clay, resulting in a subsurface soil layer through which water does not easily pass (Bouma, 1980; Jamison and Peters, 1967). This has resulted in an unusual soil hydrography that causes the top soil layers to be quickly saturated from precipitation and stay saturated for a long time, making soils in this region more highly erodible than their counterparts in other regions (Jamison and Peters, 1967; Rinaldi and Casagli, 1999). Mark Twain Lake, the major source of public water in the region (Lerch et al., 2008), is a place where sedimentation and turbidity are the most severe water quality problems (Dames and Todd, 2009). Water that makes it past the lake flows into the Mississippi River, whose high sediment and nutrient concentrations have been linked to the dead zone in the Gulf of Mexico (US Environmental Protection Agency, 2007).

Riparian vegetation has both mechanical and hydrologic effects on stream bank stability, some of which improve bank stability and some of which are destabilizing (Simon and Collison, 2002). The mechanical effects are for the most part beneficial. Roots anchor themselves into the soil to support the above ground component of the plant and in doing so produce a reinforced soil matrix, such as steel rods might reinforce concrete. The disadvantageous mechanical impacts of vegetation on soil stability are associated with the weight of the vegetation, which can produce a surcharge on the stream bank and reduce its stability (Simon and Collison, 2002). The beneficial hydrological effects of vegetation on bank stability also include processes that occur above and below ground. Vegetation removes water from the root zone for use in the processes occurring in the above ground biomass. Pore water pressures in the soil hence remain lower, and the likelihood of mass failure is reduced. The hydrologic disadvantages of vegetation on bank stability are related to the way in which soil infiltration characteristics are altered both at the soil surface and deeper within the soil profile. At the surface, canopy interception and stem flow tend to concentrate rainfall locally around the stems of plants, creating higher local pore water pressures (Simon and Collison, 2002). The presence of stems and roots at the soil surface can also act to disturb the soil, increasing infiltration capacity. An increase in infiltration capacity creates higher pore water pressures inside the stream bank, reducing its stability.

Wynn et al. (2004) showed that stream banks with herbaceous vegetation were dominated by very fine roots (diameter < 0.5 mm). In contrast, forested stream banks had a significantly greater volume and length of larger roots (diameters of 2 to 20 mm) below depths of 15 cm. Additionally, the woody roots were better distributed over the bank face: 75 % of all roots less than 20 mm in diameter were concentrated in the upper 30 cm of the stream bank at the herbaceous sites, as compared to 55 % at the forested sites. These findings suggest that riparian forests may provide better protection against stream bank erosion than herbaceous buffers due to a greater distribution and quantity of larger diameter roots.

However, in another study (Wynn and Mostaghimi, 2006), the cumulative impact of riparian vegetation type and density on stream bank soil moisture and temperature regimes was analyzed. Forested stream banks in the study experienced winter diurnal temperature ranges two to three times greater than stream banks under dense herbaceous cover, and they underwent as many as eight times the number of freeze/thaw cycles. During the winter, the stream banks under deciduous forests were exposed to solar heating and nighttime cooling, which increased the diurnal soil temperature range and the occurrence of freeze/thaw cycling. Considering that soil freezing reduces erosion resistance for soils, a dense ground cover may provide added protection against soil weakening due to freeze/thaw cycling than just deciduous woody vegetation.

The same study (Wynn and Mostaghimi, 2006) showed that the daily average summer soil water tension was 13% to 57% higher under herbaceous riparian vegetation than woody vegetation, which was likely due to evapotranspiration from the shallow herbaceous root system on the bank. The deeper root systems of the woody vegetation allowed these species to obtain water from a larger soil volume, thus reducing the impact of evapotranspiration on surface soil moisture. Therefore, critical shear stress may be reduced under herbaceous vegetation, compared to woody vegetation, due to decreases in soil moisture.

Vegetation also has an impact on water turbulence. In a flume experiment modeling overland flow (McBride et al., 2007), although velocities of overland flow were generally greater in the non-forested runs in the near-bank region, the magnitude of total kinetic energy in forested runs was consistently more than twice that of the non-forested runs, regardless of bank angle at the bed. Results suggested that compared to non-forested runs, the hydraulic characteristics of forested runs appear to create an environment with higher erosion potential. This study demonstrated a possible driving mechanism for channel widening of stream reaches with mature forests, as these reaches have been found to be wider than reaches with grassy vegetation in many different studies.

However, Piercy and Wynn (2008) suggest that soil erodibility decreased rapidly with increases in tree basal stem area on gently sloping stream banks. Similarly, Van De Wiel and Darby (2007) modeled the influence of vegetation positioning on bank stability and showed that vegetation has a greater effect on net bank stability when it is growing on low, shallow, banks comprised of weakly cohesive sediments. The model shows that extensive, strong root networks tend to improve bank stability, while excessive vegetation weight is destabilizing.

Stream bank erosion is directly related to a river’s ability to erode and transport materials (Ritter et al. 2002). As surface runoff increases in impaired land uses, precipitation runoff is diverted to streams more quickly and in larger volumes than under natural vegetation (Whitney, 1994; Burkart et al. 1994). Stream gradient and sinuosity can also have a large influence on the potential energy of discharge in a watershed.

The objectives of this study were to investigate the impacts that different types of vegetation and vegetation cover and various watershed characteristics might have on horizontal bank retreat.

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Materials and Methods

Study area

This research was conducted within the Salt River Basin in Northeast Missouri. The Salt River Basin was selected as a Benchmark Research Watershed for the Conservation Effects Assessment Project (CEAP) by the USDA’s Agricultural Research Service (USDA ARS). Of the ten major watersheds of the Salt River Basin, two were selected for investigation in this study. The Crooked and Otter Creek watersheds were chosen because their type and intensity of land use and their claypan soils are representative of watersheds within the Central Claypan Areas (Major Land Resource Area 113) (USDA-NRCS, 2006; Lerch et al., 2008).

Claypan soils have a soil layer ranging from about 0.1 m to 0.8 m below the surface that has a relatively high proportion of clay particles (>450 g/kg) (Blanco-Canqui et al., 2002; Jamison and Peters, 1967). Clay soils typically have low saturated hydraulic conductivity (Bouma, 1980; Jamison and Peters, 1967). Therefore, water is largely restricted to the soil layers above the claypan, resulting in quick saturation, lateral flows above the claypan, higher levels of surface run-off, and generally increased erodibility (Jamison and Peters, 1967).

Experimental design

Eighteen treatment reaches were stratified across three riparian land uses (crop, pasture, and forest) and three Strahler (1957) stream orders (1st, 2nd, and 3rd +) in a factorial experimental design (Table 1). The 3rd+ stream order category includes 3rd and 4th order streams because the total length of streams designated as 3rd order within these watersheds was relatively small, and there were not enough 3rd order stream reaches available to meet the needs for treatment reach establishment for this experimental design. Two sites for each land use/stream order combination were used in this study, with the exception of 3rd + order crop sites, because only one treatment reach could be found for this combination that fit our requirements. A 2nd order stream was used in its place.

Treatment reaches that were suitable for our experiment were found by studying aerial photos of the Crooked and Otter Creek watersheds and by using the National Hydrography Dataset (Dewald and Roth, 1998). For a stream length to be designated as a treatment reach, it had to fit the descriptions of one of the land-use categories, and that land use had to be present on both sides of the stream for the entire length of the treatment reach. Treatment reaches were determined to have a “Crop” land use if the land on both sides of the stream was in row-crop agriculture and had less than 10 meters of natural vegetation on either side. “Pasture” treatment reaches were continuously grazed (defined here simply as the grazing of one pasture for a long period) by cattle with no attempt to fence the cattle out of the stream. A treatment reach could be labeled as “Forest” only if there was a tree stand on both sides of the stream that was greater than 10 meters wide along the entire length of the treatment reach.

Calculation of sediment horizontal retreat rate

Stream bank erosion data was collected using the erosion pin method as described in-depth in Chapter 2. Pin plots were installed in 20% of the total eroding length in each 400 m long treatment reach. Pins were measured three times per year during 2008, 2009, and 2010.

A sediment horizontal retreat rate (cm) (Figure 1) was produced to represent the rate of loss or gain of stream bank materials. Note that this calculation is an average for the total bank length (right bank plus left bank, usually 800 m) as opposed to the treatment reach length (usually 400 m). The sediment horizontal retreat rate (Figure 1) is the average horizontal retreat or gain of bank materials along the total bank length. To calculate the horizontal retreat rate (cm), the average pin length change was calculated for each pin plot. Then, the pin plots were averaged and multiplied by the percent eroding bank length. Sediment horizontal retreat rates for each season were summed for each respective year to get a sediment horizontal retreat rate per year. For example, the sum of the March 2008 rate, the August 2008 rate, and the November 2008 rate would equal the sediment horizontal retreat rate for 2008. Then, the 2008, 2009, and 2010 rates were averaged for an average yearly sediment horizontal retreat rate.

Riparian vegetation survey

Vegetation surveys were conducted at each of the 18 treatment reaches during the summer of 2010. Data was collected on either the right or the left bank, which was randomly chosen. Eight plots were spaced 50 meters apart on a line transect 1.5 meters from the top of the bank (Figure 2). At each plot location, a ground/canopy cover survey, a shrub survey, and a tree survey were conducted (Figure 3). A bank face survey was conducted for every 2nd, 4th, 6th, and 8th meter square plot location.

Ground/canopy plots

A one square meter frame was constructed from PVC pipe, which was placed straddling the line-transect at each sampling location. Ground cover and canopy cover for each of the categories were recorded based on the percent class it represented within the meter square. Ground cover categories were tree (TBTG), shrub, grass (TBGG), forb, litter, and bare ground (TBBG). Canopy cover categories were tree (TBTC), shrub (TBSC), grass, and forb. Each ground or canopy cover category was assigned a percent range at each of the sampling locations. Percent ranges were designated as follows: 1-2 individuals, <5%, 5-10%, 11-15%, 16-20%, 21-30%, 31-50%, 51-75%, 76-100%. Percent classes for each cover category for each site were averaged by taking the middle number of the percent class. For instance, the range 76-100% was translated into a value of 88.

Shrub plot survey

A five meter by five meter shrub plot was positioned to include the one m^2 plot and share the bank-side plot borders while staying as parallel as possible to the bank edge (Figure 3). Any shrubs with a main trunk that was larger than five centimeters diameter at breast height (dbh) were not included in the shrub survey. Species and approximate number of stems for each species were recorded in order to calculate stem density per square meter. Mean stem density (stems/m^2) (TBSSD) for each treatment reach was calculated.

Tree plot survey

A five meter by ten meter tree plot was delineated with the shrub plot and one m^2 plot nested inside of it. The plot was positioned so that the tree plot shared a bank-side border with the meter square and shrub plots (Figure 3). Only trees with a dbh of more than five cm were included. Species and dbh were recorded for each tree. The basal area (m^2/hectare) (TBBA) was calculated and averaged across survey plots for each treatment reach.

Bank face vegetation survey

For every 2nd, 4th, 6th, and 8th plot, a bank face survey was conducted. Two lines that corresponded with the meter square plot were used to delineate a meter wide plot from the top of the bank to the bank toe (Figure 4). Percent ground cover and canopy cover were recorded using the same methods as in the meter square plots. Ground cover classes were tree (BFTG), shrub (BFSG), grass (BFGG), forb, litter, roots (BFRG), and bare ground (BFBG). Canopy cover classes were tree, shrub, grass (BRGC), and forb. Averages were calculated the same way as for the meter square plots.

Watershed characteristics

Although top of bank and bank face vegetation data was only collected on 18 treatment reaches, stream bank erosion data was collected on a total of 36 treatment reaches (as described in Chapter 2), which were observed for horizontal retreat in the same way as described above. Watershed variables were investigated on a total of 34 of those treatment reaches (two treatment reaches did not have a full year of horizontal retreat data with which to compare the watershed data to).

Watershed size

Watersheds were delineated using ArcSWAT and a 10-m Digital Elevation Model (DEM) file from the MSDIS website. ArcSWAT uses the DEM to create a flow direction file and a stream layer file to determine the watershed boundaries. The point that each watershed was delineated from was the most downstream point of each site. Some of the downstream points had to be altered to line up with the depression in the DEM as the survey files and the DEM did not always line up perfectly. ArcSWAT automatically calculates the area of the shapefile in the file's Attribute Table. Each treatment reach watershed size (WSIZ) was converted to km^2.

Watershed slope

The watershed slope (WSLO) was computed by subtracting the elevation of the lowest point of the longest flow path from the elevation of the highest point of the longest flow path and then dividing by the length of the longest flow path. The longest flow path for each watershed was delineated using ArcHydro Tools in

ArcMap 10. The elevations were taken from using the Identify Tool in the DEM layer, and the length of the longest flow path was calculated using the longest flow path's attribute table.

Watershed sinuosity

Most treatment reach watersheds were drained by multiple stream segments. To calculate the total sinuosity of each treatment reach's watershed, the sinuosity of each segment of the stream layer shapefile within each respective treatment reach watershed was calculated using Hawth's Tools in ArcMap 9.2 by dividing the end-to-end total length of each respective segment by its end-to-end straight line distance. The sinuosity of each segment was weighted based on its length and averaged to get a watershed sinuosity (WSIN) for each respective treatment reach.

Impervious surface

Percent cover of 14 different land uses were calculated for each watershed using 2006 land cover data from the USGS National Land Cover Database. Percent land cover in each watershed was determined by using the ArcSWAT-created shapefiles and the Clip Tool in ArcMap 10. This created USGS 2006 land cover files for each respective treatment reach watershed. The new land cover files were polygon shapefiles made up of individual polygons representing the land cover for each treatment reach watershed. The area for each polygon in the attribute table had to be recalculated using the attribute table menu based on the new shapes of the land cover polygons. Attribute tables for each treatment reach watershed were then copied to Excel files for additional calculations. Impervious surface percent cover (WISUR) was calculated by summing the areas of Low intensity development, Medium intensity development, High intensity development, Barren land (rock/sand/clay), Pasture/hay, and Cultivated crops and dividing that total by the watershed area. A second impervious surface percent cover that excludes the Pasture/hay land cover (ISURNP) was calculated as pastures and hay fields probably have intermediate compaction and may not be impervious.

Data analysis

Correlation matrix

A correlation matrix was created in SAS that included all independent variables (Table 2) in order to prevent the multicollinearity problem, which occurs in regression when independent variables are highly correlated with one another and can have an impact on the quality and stability of the fitted regression model. The objective of this step was to omit explanatory variables from further analysis that were explained by another variable. This was only used for pairs of variables that were correlated greater than 0.80 and were thought to be redundant or where one variable explained the other. Only one variable was eliminated using this method: Bank face tree canopy cover (BFTC) was eliminated after it was found to have a correlation of 0.81 with Bank face bare ground cover (BFBG).

Initial Regression Models

Initially, three regression models were built using variables chosen based on which variables were thought to have the most impact on horizontal retreat rate. In the first regression model, top of bank factors (Table 2) were examined using the variables of (1) TBBA, (2) TBSSD, (3) TBGG, and (4) TBBG. In the second regression model, five bank face variables (Table 2) – (1) BFTG, (2) BFGG, (3) BFSG, (4) BFRG, and (5) BFBG – were examined. In the third regression model, all watershed variables (Table 2) were examined, including: (1) WSIZ, (2) WSLO, (3) WSIN, (4) WISUR, and (5) WISURNP. As described earlier, note that for the watershed variables, horizontal retreat rate data was available for 34 treatment reaches (as opposed to 18 treatment reaches for the vegetation data) and all 34 treatment reaches were used in this watershed-only regression model.

Three respective regression models were initially run using the variables described above. In order to increase the fit of each model, the variable with the highest p-value of t was eliminated from the model after each regression was run. Then, the regression models were run again with the remaining variables. This was repeated until only two variables remained in each model.

Best subset

After viewing the results of the first three models, the author decided to use an investigatory approach in order to identify the combination of top of bank, bank face, and watershed variables that best explain the variation in horizontal retreat rate. A best subset regression was performed using SAS to construct the best multiple linear regression models for predicting horizontal bank retreat. Best subset regressions construct all possible regression equations using all possible combinations of independent variables up to limits, which can be set by the user. Eighteen variables (Table 2) were chosen to run in the subset based on correlation coefficients and which factors the author thought would impact horizontal bank retreat. The function was specified to show the ten models with the highest r square values for all one-variable, two-variable, three-variable, and four-variable models. Note that 18 treatment reaches (not 34) were used in this best subset regression as both vegetation and watershed variables were used to construct models.

Running regressions on best models

The top four one-variable, two-variable, three-variable and four-variable models based on their r square value were chosen to run through a multiple regression in SAS. Assumptions for normality and equal variance were visually checked for each model using graphical methods.

Results

Horizontal retreat rate

The average sediment horizontal retreat rate across all 34 treatment reaches was 5.59 cm/year (SE = 0.64) (Table 3). The average for 2008 was 5.36 cm/year (SE = 0.71), the average for 2009 was 5.30 cm/year (SE = 0.71), and the average for 2010 was 5.99 cm/year (SE = 0.73). Zaimes et al. (2008a) reported a loss of 10 cm/year within plot erosion rate, and an average eroding bank length of 30%. This equals a sediment horizontal retreat rate of approximately 3 cm/year, which is less than the 5.59 cm/year average rate reported in this study. Using the USDA-NRCS (1998) eroding streambank categories and corresponding erosion rates, Schilling et al. (2011) estimated an average erosion rate for the entire bank length of 8.5 cm/year using visual estimation techniques to estimate soil lost from eroding banks (USDA-NRCS, 1998b).

Means and standard errors are shown in Table 4 for top of bank vegetation variables, bank face vegetation variables, and watershed variables.

Initial regression models

Top of bank factors were examined using the variables of (1) TBBA, (2) TBSSD, (3) TBGG, and (4) TBBG (Table 5). TBBG and TBGG were eliminated in the first and second runs, respectively. This left TBBA and TBSSD in the two-variable model. Both of these variables had positive parameter estimates in this model. This model had an r square value of 0.20 and a p-value of F of 0.18 (Table 5).

Five bank face variables – (1) BFTG, (2) BFGG, (3) BFSG, (4) BFRG, and (5) BFBG – were examined (Table 6). BFSG, BFBG, and BFGG were eliminated in the first, second, and third runs, respectively. This left BFTG and BFRG in the two-variable model. The parameter estimate for BFTG was -0.22, and 0.17 for BFRG. This two-variable model had an r square of 0.26 and a p-value of F of 0.10 (Table 6).

All watershed variables were examined, including: (1) WSIZ, (2) WSLO, (3) WSIN, (4) ISUR, and (5) ISURNP (Table 7). WISURNP, WSIZ, and WISUR were eliminated in the first, second, and third runs, respectively. This left WSLO and WSIN in the two-variable model. The parameter estimates for these two variables were 1.82 and -17.52, respectively. The final two-variable model had an r square of 0.05 and a p value of F of 0.49 (Table 7).

Best subset

A best subset regression was run using eighteen variables in order to identify the combination of top of bank, bank face, and watershed variables that best explain the variation in horizontal retreat rate. The four one-variable models (Table 8) with the highest r square values were: (1) WISUR, (2) TBTC, (3) TBSSD, and (4) TBBA. All of these variables had positive parameter estimates in their models except for WISUR, which had a negative parameter estimate. The four two-variable models (Table 9) with the highest r square values were: (1) BFTG and WISUR, (2) TBTC and BFTG, (3) TBTC and WISUR, and (4) BFRG and WISUR. The top four three-variable models (Table 10) based on r square values were: (1) TBTG, BFTG, and BFRG, (2) BFTG, BFRG, and WISUR, (3) BFTG, BFRG, and WSLO, and (4) TBTC, BFTG, and WISUR. Finally, the four four-variable models (Table 11) with the highest r square were: (1) TBTC, BFTG, BFRG, and WISUR, (2) TBTG, TBTC, BFTG, and BFRG, (3) TBTG, BFTG, BFRG, WSLO, and (4) TBTG, BFTG, BFRG, WSIZ.

Discussion

Based on the regression results, bank vegetation and upstream watershed characteristics could only explain about 50% of the observed variation in bank erosion. Therefore, other factors must be having more of an influence on bank erosion rates. Post-settlement changes in land cover throughout the Midwest have destabilized the hydrologic and geomorphic conditions of these landscapes, and although upland conservation practices have improved over time, watersheds in this region have not re-equilibrated following this massive land disturbance (Trimble, 1999). In a Wisconsin watershed, it is estimated that during peak agricultural activity in the 1930's, sediment loads were 2.5 times greater than under modern land cover and may have been five times greater than under pre-settlement forest cover (Fitzpatrick et al., 1999). Today, as much of the 1930's eroded sediment remains in Midwest stream networks, there remains a disconnect between current land uses and bank erosion as these watersheds have not re-equilibrated following this massive land disturbance.

Based on observations in the field, stage of channel evolution (Simon and Hupp, 1986) may be controlling much of the variability that we are seeing in stream bank erosion among our treatment reaches. Some of the stream reaches in this study are still incising and therefore will have lower erosion rates than stream reaches that are in the widening stage, regardless of riparian vegetation or watershed characteristics.

Also, unique characteristics of some of our treatment reaches may be exacerbating erosion rates. For instance, the treatment reach with the highest horizontal retreat and mass soil loss rates was a 2^{nd} order Forest reach. This reach lies just upstream from joining with another stream that has been channelized. Instability of this treatment reach may be at least partially attributable to the increased slope that the downstream channelized reach encourages.

Conclusion

Land-use changes from natural vegetative communities into agricultural uses can result in adjustments to the hydrology and geomorphology of an area, which will alter a stream's sediment transporting power, and it may take a very long time for streams to adjust to these changes made in the upland areas. Regression models built from riparian vegetation and watershed variables proved to be poorly fit, showing that vegetation and watershed factors have limited influence on the variability of stream bank erosion in our study area. In the Midwest, there remains a disconnect between current land use and bank erosion as these watersheds have not re-equilibrated following the massive post-settlement hydrologic disturbance.

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Figures and Tables

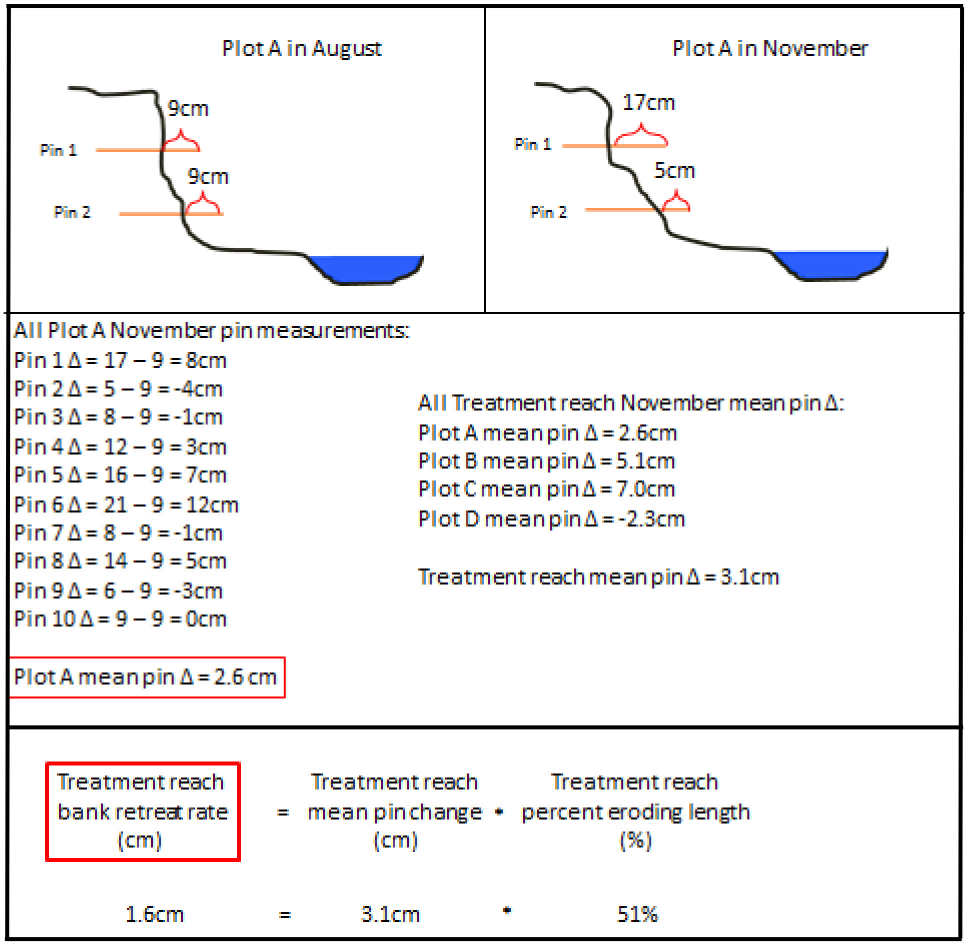

Figure 1. Example showing how to calculate treatment reach bank retreat rate. Pins are installed in banks with 9 cm exposed in August. In November, Pin 1 is measured at 17 cm, and Pin 2 is measured at 5 cm. A total of 10 pins are measured at Plot A with the mean pin change coming to 2.6 cm. All plot mean pin changes are averaged to get a treatment reach mean pin change. For this treatment reach, the November mean pin change is 3.1cm. Finally, the mean pin change is multiplied by the treatment reach percent eroding length to get a treatment reach bank retreat rate, which for this example equals 1.6cm of retreat from August to November.

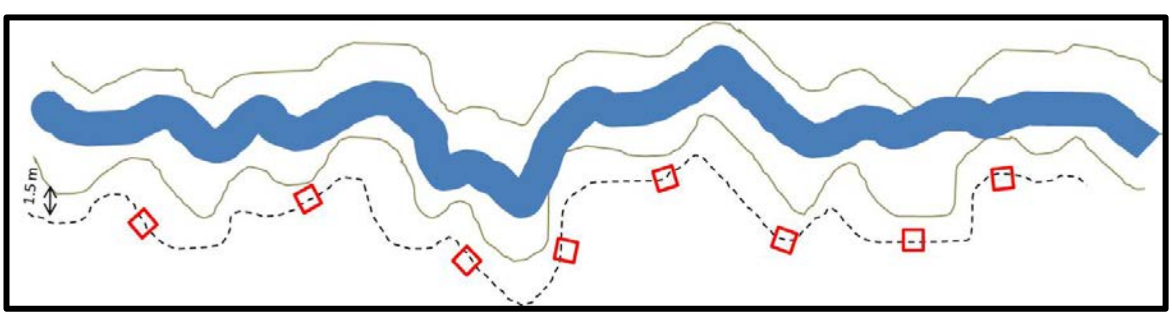

Figure 2. Meter square plots were spaced 50 meters apart on a line transect that ran parallel to and 1.5 meters from the top of the stream bank.

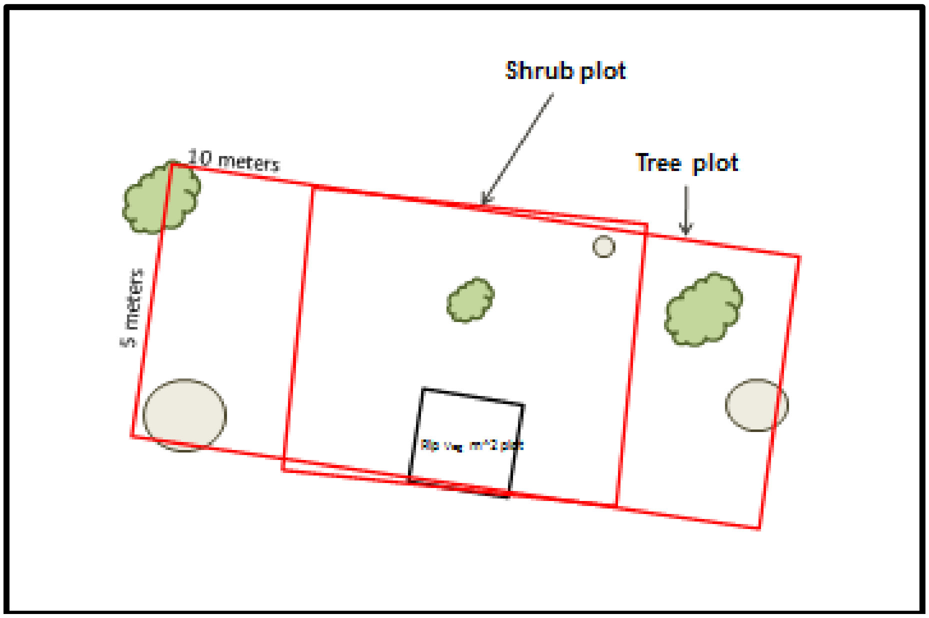

Figure 3. Meter square plot, shrub plot, and tree plot are positioned so that they are nested and share a stream-side border.

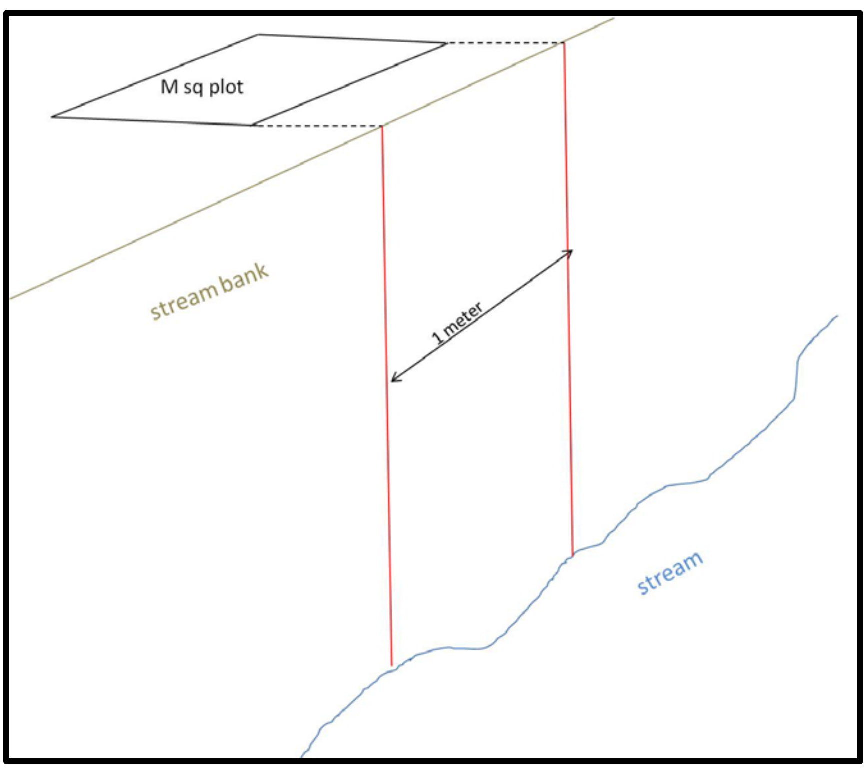

Figure 4. Bank face vegetation plots were one meter wide and extended from the top of the bank edge to the bank's toe slope.

Table 1. Treatment reach stream order, land use, measurement dates, and watershed.				
Treatment reach	**Stream Order**	**Land use**	**Measurement dates**	**Watershed**
A	1st	Crop	March, 2008 - November, 2010	Otter Creek
B	1st	Crop	March, 2009 - November, 2010	Crooked Creek
E	1st	Forest	March, 2008 - November, 2010	Otter Creek
F	1st	Forest	November, 2008 - November, 2010	Crooked Creek
H	1st	Pasture	March, 2008 - November, 2010	Crooked Creek
I	1st	Pasture	March, 2008 - November, 2010	Otter Creek
N	2nd	Crop	March, 2008 - November, 2010	Otter Creek
O	2nd	Crop	March, 2008 - November, 2010	Otter Creek
P	2nd	Crop	March, 2008 - November, 2010	Otter Creek
Q	2nd	Forest	March, 2008 - November, 2010	Otter Creek
R	2nd	Forest	August, 2008 - November, 2010	Crooked Creek
U	2nd	Pasture	March, 2008 - November, 2010	Otter Creek
W	2nd	Pasture	March, 2008 - November, 2010	Otter Creek
Z	2nd	Forest	March, 2008 - November, 2010	Crooked Creek
AF	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
AG	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
AH	3rd+	Forest	March, 2008 - November, 2010	Otter Creek
AI	3rd+	Forest	March, 2008 - November, 2010	Crooked Creek

Table 2. Vegetation and watershed characteristics with their corresponding codes and descriptions.		
Variable	**Code**	**Description**
Top of bank tree ground cover (%)	TBTG	Mean ground cover of trees within meter square plots
Top of bank grass ground cover (%)	TBGG	Mean ground cover of grass within meter square plots
Top of bank bare ground cover (%)	TBBG	Mean bare ground cover within meter square plots
Top of bank tree canopy cover (%)	TBTC	Mean canopy cover of trees above meter square plots
Top of bank shrub canopy cover (%)	TBSC	Mean canopy cover of shrubs above meter square plots
Top of bank shrub stem density (stems/m^2)	TBSSD	Mean stem density of shrubs within 5m x 5m shrub plot
Top of bank basal area (m^2/hectare)	TBBA	Mean basal area of trees within 5m x 10m tree plot
Bank face tree ground cover (%)	BFTG	Mean ground cover of trees within bank face plot
Bank face shrub ground cover (%)	BFSG	Mean ground cover of shrubs within bank face plot
Bank face grass ground cover (%)	BFGG	Mean ground cover of grass within bank face plot
Bank face root ground cover (%)	BFRG	Mean ground cover of roots within bank face plot
Bank face bare ground cover (%)	BFBG	Mean bare ground cover within bank face plot
Bank face grass canopy cover (%)	BFGC	Mean canopy cover of grass within bank face plot
Watershed size (km^2)	WSIZ	Size of watershed from most downstream point of treatment reach
Watershed slope (%)	WSLO	Slope of watershed's longest flow path
Watershed sinuosity	WSIN	Average sinuosity of all stream lengths within the watershed
Watershed impervious surface (%)	WISUR	Sum of percent cover of land uses with impervious surfaces
Watershed impervious surface excluding pasture/hay (%)	WISUR NP	Sum of percent cover of land uses with impervious surfaces excluding pasture/hay land use.

Table 3. Treatment reach mean sediment horizontal retreat rate per year with standard error of the mean. Averages are for 2008, 2009, and 2010. * denotes treatment reaches that were sampled for vegetation data.		
Treatment reach	**Sediment horizontal retreat rate (cm/year)**	**SE**
A*	5.2	1.53
B*	1.6	0.4
C	5.25	1.14
D	0.95	0.6
E*	6.18	0.32
F*	4.15	0.86
G	9.43	2.26
H*	2.15	0.48
I*	10.31	1.06
J	9.87	0.93
K	6.24	0.75
L	9.07	no data
M	no data	no data
N*	9.54	1.89
O*	5.39	0.58
P*	0.78	0.61
Q*	14.68	0.87
R*	11.48	0.22
S	3.85	no data
T	no data	no data
U*	9.66	0.58
V	1.47	0.13
W*	2.72	0.36
X	0.47	0.33
Y	2.29	0.23
Z*	3.97	0.75
AA	8.48	0.55
AB	2.56	0.24
AC	3.5	0.47
AD	2.37	0.06
AE	5.67	2.72
AF*	0.32	1.91
AG*	10.43	0.6
AH*	5.28	0.7
AI*	9.11	1.06
AJ	5.72	0.1

Table 4. Means and standard deviations of vegetation and watershed variables used in analysis

Variable	**Mean**	**SE**
TBTG (%)	3.0	1.3
TBGG (%)	21.3	5.7
TBBG (%)	26.5	4.3
TBTC (%)	53.6	5.8
TBSC (%)	7.2	2.5
TBSSD (stems/m^{2})	1.0	0.2
TBBA (m^{2}/hectare)	28.6	6.9
BFTG (%)	5.6	1.7
BFSG (%)	1.3	0.4
BFGG (%)	14.9	5.4
BFRG (%)	13.7	2.5
BFBG (%)	53.4	5.8
BFGC (%)	16.3	5.2
WSIZ (km$^{2)}$	26,269	7,805
WSLO (%)	0.446	0.057
WSIN	1.13	0.01
WISUR (%)	90.9	0.8
WISURNP (%)	75.0	2.2

Table 5. Multiple regression model using only top of bank vegetation variables. Variables were chosen based on *a priori* assumptions of which variables most influence bank erosion. The variable with the highest p value of t was taken out of the analysis after each run.

	Variables	**Parameter estimate**	**p-value of t**	**R square**	**P value for F**
1st run	TBBA	0.03	0.40	0.22	0.49
	TBSSD	0.77	0.60		
	TBGG	-0.03	0.63		
	~~TBBG~~	-0.03	0.69 ← highest		
2nd run	TBBA	0.03	0.36	0.21	0.34
	TBSSD	1.10	0.35		
	~~TBGG~~	-0.01	0.77 ← highest		
3rd run	TBBA	0.04	0.30	0.20	0.18
	TBSSD	1.22	0.26		

Table 6. Multiple regression model using only bank face vegetation variables. Variables were chosen based on *a priori* assumptions of which variables most influence bank erosion. The variable with the highest p value of t was taken out of the analysis after each run.

	Variables	Parameter estimate	p-value of t	R square	P value for F
1st run	BFTG	-0.25	0.12	0.30	0.45
	BFGG	-0.05	0.55		
	~~BFSG~~	0.16	0.80 ← highest		
	BFRG	0.16	0.15		
	BFBG	-0.03	0.74		
2nd run	BFTG	-0.25	0.11	0.29	0.31
	BFGG	-0.05	0.55		
	BFRG	0.15	0.14		
	~~BFBG~~	-0.02	0.75 ← highest		
3rd run	BFTG	-0.23	0.10	0.29	0.18
	~~BFGG~~	-0.03	0.51 ← highest		
	BFRG	0.15	0.14		
4th run	BFTG	-0.22	0.10	0.26	0.10
	BFRG	0.17	0.07		

Table 7. Multiple regression model using only watershed variables. Variables were chosen based on *a priori* assumptions of which variables most influence bank erosion. The variable with the highest p value of t was taken out of the analysis after each run.

	Variables	Parameter estimate	p-value of t	R square	P value for F
1st run	WSIZ	0.00	0.42	0.08	0.77
	WSLO	5.04	0.18		
	WSIN	-24.30	0.31		
	WISUR	0.21	0.36		
	~~WISURNP~~	-0.02	0.80 ← highest		
2nd run	~~WSIZ~~	0.00	0.38 ← highest	0.08	0.64
	WSLO	5.04	0.17		
	WSIN	-23.18	0.32		
	WISUR	0.19	0.37		
3rd run	WSLO	2.83	0.29	0.06	0.62
	WSIN	-15.06	0.48		
	~~WISUR~~	0.11	0.56 ← highest		
4th run	WSLO	1.82	0.36	0.05	0.49
	WSIN	-17.52	0.39		

Table 8. The top four one-variable multiple regression models from best subset regression based on r squared values.					
Rank	**Variables**	**Parameter estimate**	**p-value of t**	**R square**	**P value for F**
1	WISUR	-0.55	0.04	0.23	0.04
2	TBTC	0.07	0.07	0.19	0.07
3	TBSSD	1.60	0.12	0.14	0.12
4	TBBA	0.05	0.14	0.13	0.14

Table 9. Multiple regression two-variable models from best subset regression					
Rank	**Variables**	**Parameter estimate**	**p-value of t**	**R square**	**P value for F**
1	BFTG	-0.14	0.25	0.30	0.07
	WISUR	-0.54	0.05		
2	TBTC	0.07	0.05	0.29	0.08
	BFTG	-0.17	0.17		
3	TBTC	0.04	0.29	0.29	0.08
	WISUR	-0.40	0.18		
4	BFRG	0.08	0.36	0.27	0.09
	WISUR	-0.48	0.09		

Table 10. Multiple regression three-variable models from best subset regression					
Rank	**Variables**	**Parameter estimate**	**p-value of t**	**R square**	**P value for F**
1	TBTG	-0.38	0.06	0.43	0.04
	BFTG	-0.29	0.03		
	BFRG	0.30	0.01		
2	BFTG	-0.20	0.12	0.39	0.07
	BFRG	0.12	0.17		
	WISUR	-0.43	0.11		
3	BFTG	-0.22	0.09	0.38	0.08
	BFRG	0.19	0.04		
	WSLO	4.24	0.14		
4	TBTC	0.05	0.23	0.37	0.08
	BFTG	-0.16	0.19		
	WISUR	-0.37	0.21		

Table 11. Multiple regression four-variable models from best subset regression					
Rank	**Variables**	**Parameter estimate**	**p-value of t**	**R square**	**P value for F**
1	TBTC	-0.33	0.10	0.51	0.04
	BFTG	-0.26	0.05		
	BFRG	0.24	0.04		
	WISUR	-0.34	0.18		
2	TBTG	-0.36	0.07	0.49	0.05
	TBTC	0.05	0.25		
	BFTG	-0.27	0.04		
	BFRG	0.23	0.06		
3	TBTG	-0.31	0.15	0.47	0.06
	BFTG	-0.27	0.04		
	BFRG	0.29	0.01		
	WSLO	2.72	0.34		
4	TBTG	-0.53	0.05	0.47	0.07
	BFTG	-0.31	0.02		
	BFRG	0.30	0.01		
	WSIZ	0.00	0.35		

Chapter 4. Applicability of a Bank Erosion Hazard Index to streams in the claypan region of Northeast Missouri

Rachel Peacher, Thomas M. Isenhart, Richard C. Schultz, Robert N. Lerch

Abstract

There is a growing consensus in the literature that stream bank erosion is almost always a significant source of stream sediment and in many instances, it is the dominant source. Therefore, there is a need to be able to identify banks that are unstable and contributing large amounts of sediment to streams so that they can be targeted for conservation practices. The goal of this project was to determine whether two modified Rosgen's Bank Erosion Hazard Index (BEHI) Procedures used by the Michigan Department of Environmental Quality (MDEQ) would be applicable to streams in the claypan region of NE Missouri. We tested the Procedures using erosion data collected over three years in two sub-watersheds of the Salt River Basin. Treatment reaches fell into Moderate and High and the High, Very High and Extreme categories for the two respective procedures. We found that the methodologies currently used by MDEQ, when applied to study sites in the claypan region of NE Missouri, did not reflect the wide range of actual erosion rates across treatment reaches that have been recorded in this region.

Introduction

Sediment pollution has caused great harm to stream ecosystems (Simon & Darby, 1999) and is very costly for state and federal government agencies to manage (Osterkamp, 1998). Sediment is arguably the most pervasive and costly form of water pollution in North America (Osterkamp, 1998). Upland erosion is often thought of as the primary culprit for sediment pollution in streams. However, there is reason to believe that stream bank erosion may also be a significant non-point source (Simon and Rinaldi, 2000). As in-field soil conservation practices have become more widespread and erosion from upland sources has largely decreased, some researchers suggest that the main source of eroded materials in streams is shifting from upland sources to the erosion of gullies and stream channels (Simon and Klimetz, 2008; Wilson et al., 2008a,b). In general, there is a growing consensus in the literature that stream bank erosion is almost always a significant source of stream sediment (Nagle et al., 2007; Rondeau et al., 2000; Sekely et al., 2002; Simon, 2008; Thoma et al., 2005) and in many instances, it is the dominant source (Amiri-Tokaldany et al., 2003; Laubel et al., 1999; Laubel et al., 2003; Mukundan et al., 2010; Schilling and Wolter, 2000; Schilling et al., 2011; Simon and Rinaldi, 2006; Wilson et al., 2008a).

Therefore, there is a need to be able to identify banks that are unstable and contributing large amounts of sediment to streams so that they can be targeted for conservation practices. The Michigan Department of Environmental Quality (MDEQ) has developed two Standard Operating Procedures (SOPs) (Rathbun, 2008; Rathbun, 2011) over the past three years for assessing bank erosion potential using methods based on Rosgen's (2001) Bank Erosion Hazard Index (BEHI). MDEQ uses the SOPs to train watershed groups and conservation districts to do surveys of stream banks in order to prioritize bank stabilization projects.

The goal of this project was to determine whether the modified BEHI would be applicable to streams in the clay-pan region of NE Missouri. We tested the SOPs using erosion data collected over three years in the claypan region of NE Missouri.

Materials and Methods

Study area

Stream bank erosion research was conducted in the Salt River Basin in Northeast Missouri. The Salt River Basin was selected as a Benchmark Research Watershed for the Conservation Effects Assessment Project (CEAP) by the USDA's Agricultural Research Service (USDA ARS). Of the ten major watersheds of the Salt River Basin, two were selected for investigation in this study. The Crooked and Otter Creek watersheds were chosen because of their type and intensity of land use and their claypan soils which are representative of watersheds within the Central Claypan Areas (Major Land Resource Area 113) (Lerch et al., 2008; USDA-NRCS, 2006).

Claypan soils have a soil layer ranging from about 0.1 m to 0.8 m below the surface that has a relatively high proportion of clay particles (>450 g/kg) (Blanco-Canqui et al., 2002; Jamison and Peters, 1967). Clay soils typically have low saturated hydraulic conductivity (Bouma, 1980; Jamison and Peters, 1967).

Therefore, water is largely restricted to the soil layers above the claypan, resulting in quick saturation, lateral flows above the claypan, higher levels of surface run-off, and generally increased surface soil erodibility (Jamison and Peters, 1967).

Eighteen treatment reaches were stratified across three riparian land uses (crop, pasture, and forest) and three Strahler (1957) stream orders (1st, 2nd, and 3rd +) in a factorial experimental design (Table 1). The 3rd+ stream order category includes 3rd and 4th order streams because the total length of streams designated as 3rd order within these watersheds was relatively small, and there were not enough 3rd order stream reaches available to meet the needs for treatment reach establishment for this experimental design. Two sites for each land use/stream order combination were used in this study, with the exception of 3rd + order crop sites, because only one treatment reach could be found for this combination that fit our requirements. A 2nd order stream was used in its place.

Treatment reaches that were suitable for our experiment were found by studying aerial photos of the Crooked and Otter Creek watersheds and by using the National Hydrography Dataset (Dewald and Roth, 1998). For a stream length to be designated as a treatment reach, it had to fit the descriptions of one of the land-use categories, and that land use had to be present on both sides of the stream for the entire length of the treatment reach. Treatment reaches were determined to have a “Crop” land use if the land on both sides of the stream was in row-crop agriculture and had less than 10 meters of natural vegetation on either side. “Pasture” treatment reaches were continuously grazed (defined here simply as the grazing of one pasture for a long period) by cattle with no attempt to fence the cattle out of the stream. A treatment reach could be labeled as “Forest” only if there was a tree stand on both sides of the stream that was greater than 10 meters wide along the entire length of the treatment reach.

Calculation of sediment horizontal retreat rate and sediment mass loss rate

Stream bank erosion data was collected using the erosion pin method as described in-depth in Chapter 2. Pin plots were installed in 20% of the total eroding length in each 400 m long treatment reach. Pins were measured three times per year during 2008, 2009, and 2010 (Table 1).

Two calculations were produced to represent the rate of loss or gain of stream bank materials: a sediment horizontal retreat rate (cm) (Figure 1) and a sediment mass loss rate (kg/m) (Figure 2). Note that these calculations are averages for the total bank length (right bank plus left bank, usually 800 m) as opposed to the treatment reach length (usually 400 m). Also, note that the term "year" used in this study is from November of the previous year to November of that year. For instance, the year 2008 refers to November, 2007 to November, 2008.

The sediment horizontal retreat rate (Figure 1) is the average horizontal retreat or gain of bank materials along the total bank length. To calculate the horizontal retreat rate (cm), the average pin length change was calculated for each pin plot. Then, the pin plots were averaged and multiplied by the percent eroding bank length. Sediment horizontal retreat rates for each season were summed for each respective year to get a sediment horizontal retreat rate per year. For example, the sum of the March 2008 rate, the August 2008 rate, and the November 2008 rate would equal the sediment horizontal retreat rate for 2008. Then, the 2008, 2009, and 2010 rates were averaged for an average yearly sediment horizontal retreat rate.

The sediment mass loss rate (Figure 2) is the average mass of soil lost or gained per meter of total bank length. To calculate the sediment mass loss rate for each treatment reach, first, an average pin length change was calculated for a given seasonal dataset. This was done for each pin plot and multiplied by each pin plot's respective average bank height (m). The product of this number (m^2) and the bulk density (kg/m^3) produced a within-plot sediment mass loss rate (kg/m). Finally, the within-plot sediment mass loss rate was multiplied by the percent eroding bank length of the treatment reach to get a sediment mass loss rate for that treatment reach for that season. Yearly rates were calculated the same way as for the sediment horizontal retreat rates as described in the previous paragraph.

MDEQ Standard Operating Procedures

Two SOPs were created and used by the Michigan Department of Environmental Quality for the use of training volunteers to do surveys of banks in order to prioritize bank stabilization projects. The first SOP was created in 2008, and an updated version has been used since September, 2011. The SOPs describe stream surveys for assessing bank erosion potential using slightly different methods: the 2008 SOP requires a ratio of bank height to bankfull height (Table 2), which the 2011 SOP leaves out, and the 2011 SOP includes adjustment factors for bank material and soil layer stratification (Table 3). Both SOPs are based on the Bank Erosion Hazard Index (BEHI) created by Dave Rosgen of Wildland Hydrology, Inc. (Rosgen, 2001).

BEHI category data collection

Bank Erosion Hazard Index (BEHI) data was collected at each of the 18 treatment reaches during the summer of 2010. Data was collected on either the right or the left bank, which was randomly chosen. Bank height, bankfull height, root depth, root density, surface protection and bank angle were measured at four plots spaced 100 meters apart at each treatment reach.

Means for each category were translated into BEHI category scores using both the 2008 (Table 2) and 2011 (Table 3) MDEQ SOPs, respectively (Table 4). Category scores were then summed for each treatment reach to get BEHI total scores. The BEHI total scores were plotted with sediment horizontal retreat rate (cm/year) and sediment mass loss rate (kg/m/year). Pearson correlation coefficients were calculated using a Microsoft Office Excel spreadsheet.

Results and Discussion

Erosion rates

Sediment horizontal retreat rates ranged from 0.32 cm/year to 14.68 cm/year with a mean of 6.10 and a standard error of 0.94 for the eighteen treatment reaches (Table 5). The erosion rates in this study, like many stream bank erosion studies, yield wide ranges in results across treatment reaches. The USDA-NRCS (1998) classifies stream banks into categories based on visual criteria. They assume that slightly eroding stream banks erode at 0.9 cm/year, moderately eroding stream banks erode at 4.0 cm/year, severely eroding stream banks erode at 12.2 cm/year, and very severely eroding stream banks erode at 15.2 cm/year. These rates are not directly comparable to the sediment horizontal retreat rates calculated in this study because the rates used by the USDA-NRCS represent individual eroding sections of stream bank. The calculation for sediment horizontal retreat rate used in this study represents the average erosion of many eroding stream bank sections multiplied by the treatment reach's percent eroding length. However, what we can extrapolate from this is that some of the treatment reaches on the high end may be experiencing erosion rates (within eroding sections) that are higher than the USDA-NRCS rates that correspond to very severely eroding. Our lowest rates are comparable to the slightly eroding rates in USDA-NRCS (1998). Therefore, based on this comparison, it seems as though our rates will fall across a broad range of bank erosion potential categories if either index is working properly.

Sediment mass loss rates for the 18 treatment reaches ranged from 15.5 kg/m/year to 447.5 kg/m/year with a mean of 158.5 and a standard error of 31.8 (Table 4). Zaimes et al. (2008) reported erosion rates of 5 to 304 kg/m/year in Iowa streams with various riparian land uses. However, those rates are not averaged across the length of the total bank length of the treatment reach as done in this study. The Zaimes et al. (2008) study percent eroding length range was between 10-54%. If we take the mid-range of 32% and multiple by the erosion rates, the range drops to 2 to 97 kg/m/year. This range is quite a bit lower than the sediment mass loss rates reported for this study. Tufekcioglu (2010) found sediment mass loss rates of 58 to 85 kg/m/year in streams with riparian areas in Conservation Reserve Program and 111 to 664 kg/m/year in grazed pastures. Again, similar to the sediment horizontal retreat rates, the sediment mass loss rates show a wide range of rates that one would expect to be ranked across several bank erosion potential categories.

Index scores

Using the 2008 SOP, total scores ranged from 24.75 to 33.35 (Table 6). Three treatment reaches fell into the Moderate category (scores 14.76 - 24.75), and fifteen treatment reaches fell into the High category (scores 24.760 – 34.75). No treatment reaches had scores that matched the Very low, Low, Very high, or Extreme categories. The three treatment reaches in the Moderate category were (1) a 2nd order Pasture, (2) a 3rd+ order Pasture, and (3) a 3rd+ order Forest. The correlation coefficient for sediment horizontal retreat rate and 2008 BEHI score is -0.16 (p-value = 0.54) (Figure 3). The correlation coefficient for sediment mass loss rate and 2008 BEHI score is -0.25 (p-value = 0.33) (Figure 4).

Using the 2011 SOP, total scores ranged from 28.0 to 38.5, and all treatment reaches fell into the High (scores 20.1 – 28), Very high (scores 28.1 – 34), and Extreme (scores > 34) categories (Table 7). No treatment reaches fell into the Very low, Low, or Moderate categories. There were two treatment reaches in the High category: a 2nd order Pasture and a 3rd+ order Pasture. Seven treatment reaches fell into the Very high category: a 1st order Forest, a 2nd order Forest, a 3rd+ order Forest, a 1st order Pasture, a 2nd order Pasture, a 3rd+ order

Pasture, and a 2nd order Crop. Nine treatment reaches fell into the Extreme category: two 1st order Crops, two 2nd order Crops, a 1st order Forest, a 2nd order Forest, a 3rd+ order Forest, a 1st order Pasture, and a 3rd+ order Pasture. The correlation coefficient for sediment horizontal retreat rate and 2011 BEHI score is -0.35 (p-value = 0.16) (Figure 5). The correlation coefficient for sediment mass loss rate and 2011 BEHI score is -0.40 (p-value = 0.10) (Figure 6).

The erosion rates for the eighteen treatment reaches were weakly negatively correlated with 2008 and 2011 SOP BEHI total scores, respectively. Both 2008 and 2011 total scores covered a fairly narrow range, which suggests that one or more of the variables were scored very similarly across the treatment reaches. In fact, for the 2008 SOP, all treatment reaches received the same score for bank angle (Table 6). For the 2011 SOP, all treatment reaches received the same scores for bank angle, the bank materials adjustment, and the soil stratification adjustment (Table 7). This may indicate that these variables are not appropriate to include in the development of a BEHI for our study area in Northeast Missouri.

Since the Rosgen's (2001) BEHI was originally designed for mountainous areas, it was thought that the BEHI total score results for the two respective SOPs may underestimate the erosion hazard for sites in the clay-pan region of NE Missouri. However, it seems as though the methods and calculations used here may not be sensitive enough to quantify relative stream bank erosion potential. Another caveat to consider is that Rosgen's method incorporates near-bank velocity gradients and shear stress distributions, which are not incorporated into the survey methods of either MDEQ SOP examined here.

Conclusions

Measuring the extent and magnitude of stream bank erosion can take many forms, such as erosion pin studies, LiDar experiments, and assigning erosion potential based on visual criteria. Most of the methods necessitate repeated measurements, extensive training or other time- and/or labor-consuming methodologies. There is a need for the development of survey methodologies that can be done by non-scientist volunteers in short periods of time and that can accurately predict erosion potential.

We found that the methodologies currently used by MDEQ, when applied to study sites in the claypan region of NE Missouri, did not reflect the wide range of actual erosion rates across treatment reaches that have been recorded in this region. Since Rosgen originally designed the BEHI to be used in mountainous areas, and calibrated it to that region, its use in other landscapes may not be appropriate for assessing bank erosion potential or helpful for identifying stream reaches in greatest need of management. However, the complete Rosgen methodology was not investigated in this study, and therefore, no conclusions about the effectiveness of his method could be made.

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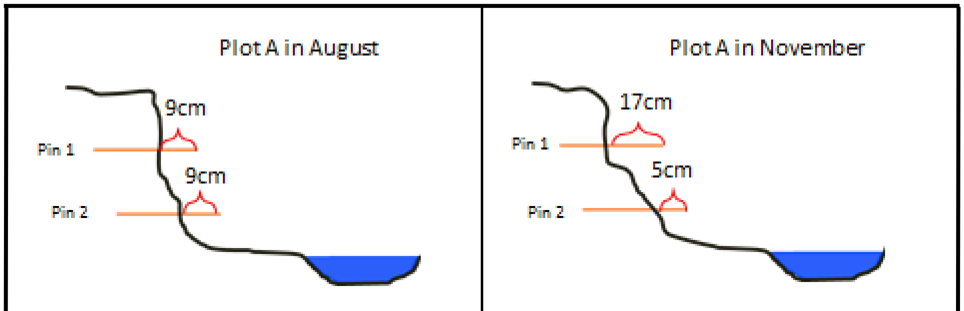
Figures and Tables



All Plot A November pin measurements:
Pin 1 Δ = 17 – 9 = 8cm
Pin 2 Δ = 5 – 9 = -4cm
Pin 3 Δ = 8 – 9 = -1cm
Pin 4 Δ = 12 – 9 = 3cm
Pin 5 Δ = 16 – 9 = 7cm
Pin 6 Δ = 21 – 9 = 12cm
Pin 7 Δ = 8 – 9 = -1cm
Pin 8 Δ = 14 – 9 = 5cm
Pin 9 Δ = 6 – 9 = -3cm
Pin 10 Δ = 9 – 9 = 0cm

Plot A mean pin Δ = 2.6 cm

All Treatment reach November mean pin Δ:
Plot A mean pin Δ = 2.6cm
Plot B mean pin Δ = 5.1cm
Plot C mean pin Δ = 7.0cm
Plot D mean pin Δ = -2.3cm

Treatment reach mean pin Δ = 3.1cm

Treatment reach bank retreat rate (cm)		Treatment reach mean pin change (cm)		Treatment reach percent eroding length (%)
1.6cm	=	3.1cm	•	51%

Figure 1. Example showing how to calculate treatment reach bank retreat rate. Plot mean pin change is calculated the same as in Figure 1. All plot mean pin changes are averaged to get a treatment reach mean pin change. For this treatment reach, the November mean pin change is 3.1cm. Finally, the mean pin change is multiplied by the treatment reach percent eroding length to get a treatment reach bank retreat rate, which for this example equals 1.6cm of retreat from August to November.

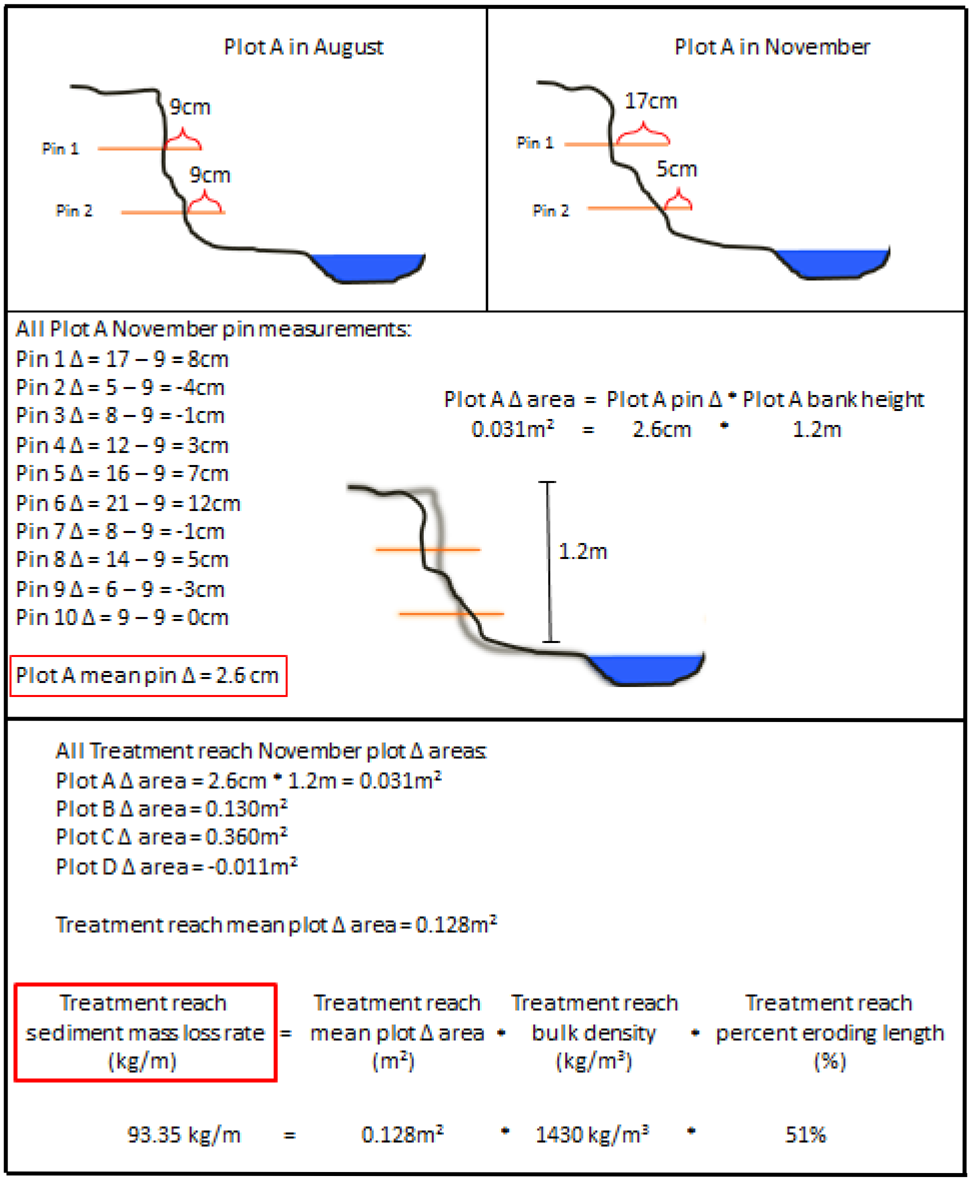


Figure 2. Example showing how to calculate treatment reach sediment mass loss rate. Pins are installed in banks with 9 cm exposed in August. In November, Pin 1 is measured at 17 cm, and Pin 2 is measured at 5 cm. A total of 10 pins are measured at Plot A with the mean pin change coming to 2.6 cm. To calculate the Plot A change in area from August to November, Plot A mean pin change is multiplied by Plot A bank height. This process is repeated at all plots within the treatment reach, and all plot change in areas are averaged to get a treatment reach mean plot area change. Finally, we calculate treatment reach sediment mass loss rate by multiplying treatment reach mean plot change area, treatment reach bulk density, and treatment reach percent eroding length. In this example, the treatment reach lost 93.35 kg of bank soil per meter of stream bank from August to November.

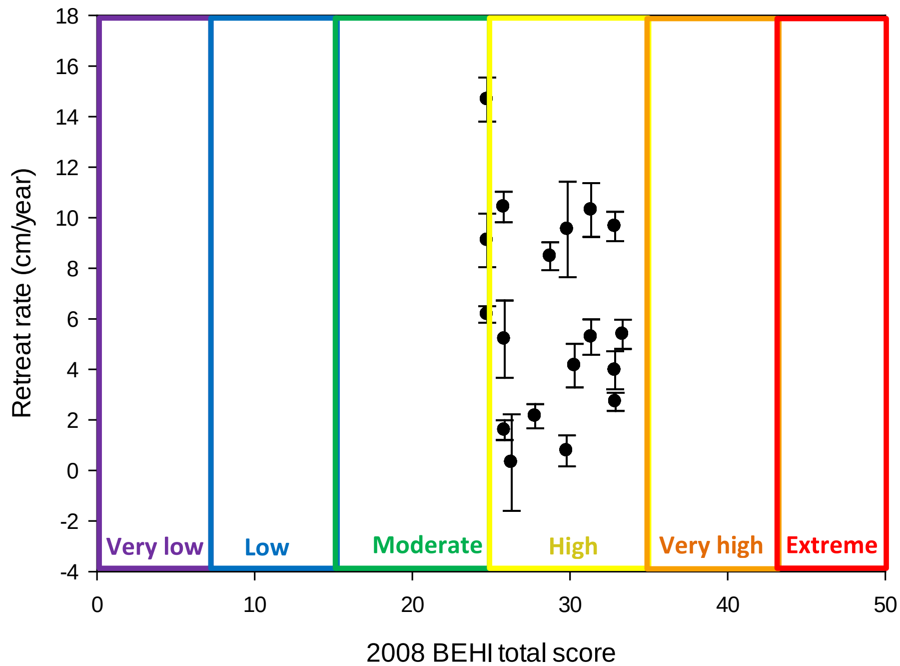


Figure 3. Sediment horizontal retreat rate and 2008 BEHI total scores. Correlation coefficient = -0.27 . Error bars represent sediment horizontal retreat rate standard error of the mean.

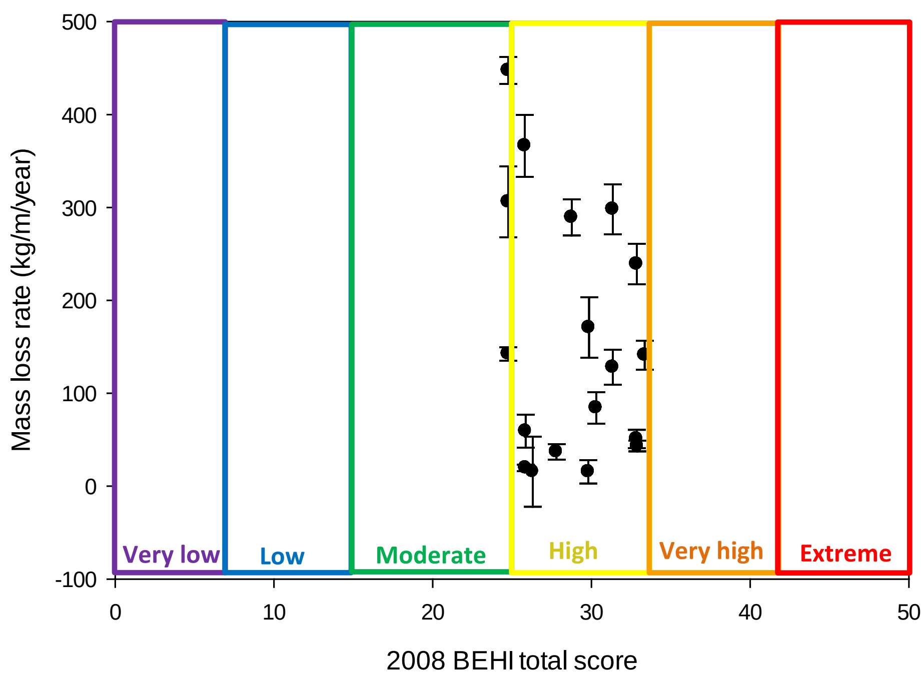


Figure 4. Sediment mass loss rate and 2008 BEHI total scores. Correlation coefficient = -0.40 . Error bars represent sediment mass loss rate standard error of the mean.

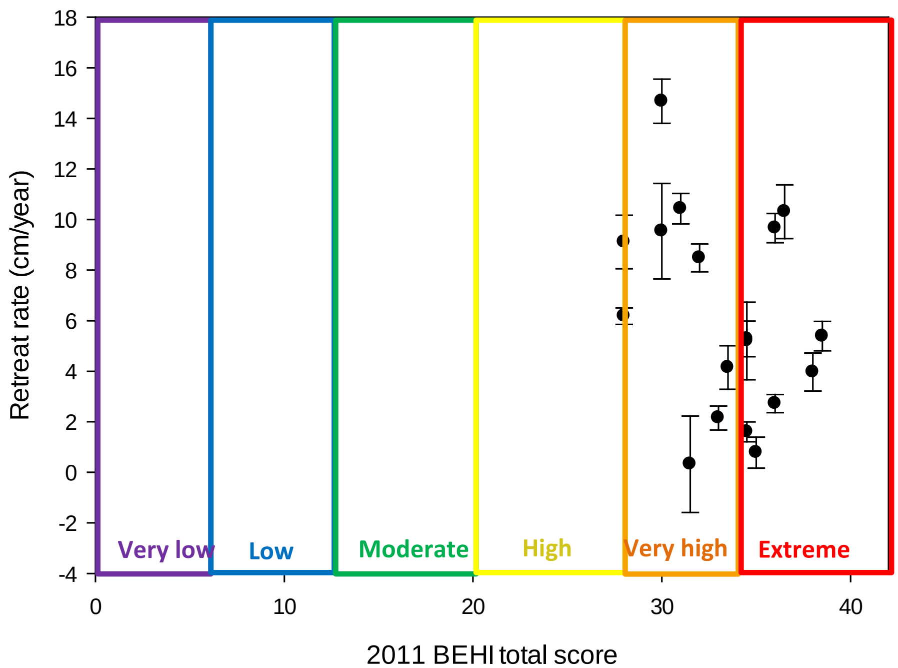


Figure 5. Sediment horizontal retreat rate and 2011 BEHI total scores. Correlation coefficient = -0.35 . Error bars represent sediment horizontal retreat rate standard error of the mean.

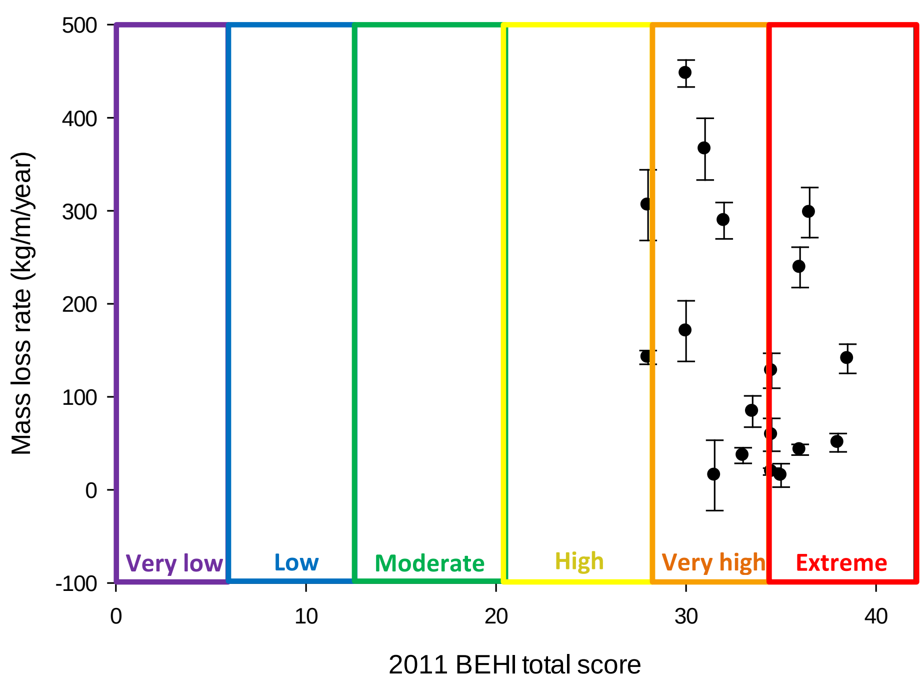


Figure 6. Sediment mass loss rate and 2011 BEHI total scores. Correlation coefficient = -0.40 . Error bars represent sediment mass loss rate standard error of the mean.

Table 1. Treatment reach stream order, land use, measurement dates, and watershed.				
Treatment reach	**Stream Order**	**Land use**	**Measurement dates**	**Watershed**
A	1st	Crop	March, 2008 - November, 2010	Otter Creek
B	1st	Crop	March, 2009 - November, 2010	Crooked Creek
C	1st	Forest	March, 2008 - November, 2010	Otter Creek
D	1st	Forest	November, 2008 - November, 2010	Crooked Creek
E	1st	Pasture	March, 2008 - November, 2010	Crooked Creek
F	1st	Pasture	March, 2008 - November, 2010	Otter Creek
G	2nd	Crop	March, 2008 - November, 2010	Otter Creek
H	2nd	Crop	March, 2008 - November, 2010	Otter Creek
I	2nd	Crop	March, 2008 - November, 2010	Otter Creek
J	2nd	Forest	March, 2008 - November, 2010	Otter Creek
K	2nd	Forest	August, 2008 - November, 2010	Crooked Creek
L	2nd	Pasture	March, 2008 - November, 2010	Otter Creek
M	2nd	Pasture	March, 2008 - November, 2010	Otter Creek
N	2nd	Forest	March, 2008 - November, 2010	Crooked Creek
O	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
P	3rd+	Pasture	March, 2008 - November, 2010	Otter Creek
Q	3rd+	Forest	March, 2008 - November, 2010	Otter Creek
R	3rd+	Forest	March, 2008 - November, 2010	Crooked Creek

Table 2. Scores for the 2008 BEHI. Credit: Joe Rathbun.

BEHI Category	Bank Height/ Bankfull Height	BH/BFH Score	Root Depth (% of BFH)	Root Depth Score	Root Density (%)	Root Density Score	Surface Protection (Avg. %)	Surface Protection Score	Bank Angle (degrees)	Bank Angle Score	Total Score, by Category
Very low	1.0-1.1	**1.45**	90-100	**1.45**	80-100	**1.45**	80-100	**1.45**	0-20	**1.45**	**≤ 7.25**
Low	1.11-1.19	**2.95**	50-89	**2.95**	55-79	**2.95**	55-79	**2.95**	21-60	**2.95**	**7.26 – 14.75**
Moderate	1.2-1.5	**4.95**	30-49	**4.95**	30-54	**4.95**	30-54	**4.95**	61-80	**4.95**	**14.76 – 24.75**
High	1.6-2.0	**6.95**	15-29	**6.95**	15-29	**6.95**	15-29	**6.95**	81-90	**6.95**	**24.76 – 34.75**
Very high	2.1-2.8	**8.5**	5-14	**8.5**	5-14	**8.5**	10-14	**8.5**	91-119	**8.5**	**34.76 – 42.50**
Extreme	>2.8	**10**	< 5	**10**	< 5	**10**	< 10	**10**	> 119	**10**	**42.51 - 50**

Table 3. Scores for the 2011 BEHI and bank material and stratigraphy adjustment factors (below). Credit: Joe Rathbun

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**	1.5	**80-100**	1.5	**80-100**	1.5	**0-20**	1.5	≤ 6
Low	**50-89**	3	**55-79**	3	**55-79**	3	**21-60**	3	6.1 – 12
Moderate	**30-49**	5	**30-54**	5	**30-54**	5	**61-80**	5	12.1 – 20
High	**15-29**	7	**15-29**	7	**15-29**	7	**81-90**	7	20.1 – 28
Very high	**5-14**	8.5	**5-14**	8.5	**10-14**	8.5	**91-119**	8.5	28.1 – 34
Extreme	**< 5**	10	**< 5**	10	**< 10**	10	**> 119**	10	> 34

Bank Materials	**Score Adjustment**
If banks = bedrock	Always classify as "Very Low"
If banks = boulders	Always classify as "Low"
If banks = cobble	Subtract 10 points from the BEHI score
If banks = gravel or a gravel/sand mix that is mostly gravel	Add 5 points
If banks = a gravel/sand mix that is mostly sand	Add 10 points
If banks = sand	Add 10 points
If banks = silt or clay	No adjustment
Stratification	**Score Adjustment**
No layers	No adjustment
Single layer of erodible material (usually sand)	Add 5 points
Multiple layers of erodible materials	Add 10 points

Table 4. BEHI category raw data means and standard errors.

Treatment reach	BH/BFH	BH/BFH S.E.	Root depth (% of BH)	Root depth S.E.	Root density (% cover)	Root density SE	Surface protection (% cover)	Surface protection S.E.	Bank angle (degrees)	Bank angle S.E.
A	1.00	0.00	0.00	0.00	0.00	0.00	103.40	3.01	42.43	1.45
B	1.10	0.04	0.00	0.00	1.94	1.86	118.71	17.07	50.20	7.44
C	1.44	0.14	0.00	0.00	7.50	0.00	22.50	6.36	38.28	4.39
D	3.29	1.54	10.83	0.79	28.38	20.76	99.96	36.69	58.50	12.61
E	1.59	0.06	0.00	0.00	27.65	20.45	49.85	18.83	28.78	1.04
F	1.96	0.38	20.34	0.76	18.95	8.74	39.84	10.55	36.05	3.36
G	1.29	0.07	33.47	1.14	3.83	3.11	51.71	19.05	32.10	3.55
H	1.38	0.15	0.00	0.00	8.88	1.38	44.70	12.08	38.30	4.18
I	1.77	0.24	0.00	0.00	3.03	1.59	62.80	20.72	38.98	6.22
J	2.17	0.44	0.00	0.00	4.98	2.68	59.25	19.10	31.13	4.52
K	1.45	0.16	7.81	0.78	15.75	15.75	71.79	16.46	20.85	3.73
L	1.43	0.22	2.98	0.30	31.69	19.47	72.95	17.06	33.00	3.51
M	1.69	0.45	61.67	2.17	22.70	13.82	53.56	29.95	46.50	3.67
N	1.78	0.30	47.26	2.74	9.63	6.11	24.65	5.96	45.08	5.34
O	1.38	0.15	40.79	0.91	16.50	5.20	48.35	9.46	33.55	1.44
P	1.52	0.12	0.00	0.00	2.00	1.83	30.23	2.72	21.20	5.81
Q	1.61	0.28	33.33	2.36	30.33	19.50	51.61	17.04	32.63	3.04
R	1.72	0.20	0.00	0.00	11.45	3.93	69.28	13.96	37.45	4.55

Table 5. Treatment reach mean sediment mass loss rate per year and sediment horizontal retreat rate per year with standard errors of the mean. Averages are for 2008, 2009, and 2010.

Treatment reach	**Sediment horizontal retreat rate (cm/year)**	**S.E.**	**Sediment mass loss rate (kg/m/year)**	**S.E.**
A	5.2	1.53	59.2	17.7
B	1.6	0.40	19.6	3.7
C	5.39	0.58	140.9	15.7
D	9.54	1.89	170.7	32.6
E	0.78	0.61	15.5	12.6
F	8.48	0.55	289.4	19.6
G	2.15	0.48	36.9	8.4
H	10.31	1.06	298.1	26.9
I	9.66	0.58	239.2	21.7
J	2.72	0.36	43.1	5.7
K	0.32	1.91	15.6	37.8
L	10.43	0.60	366.3	33.2
M	6.18	0.32	142.3	7.3
N	4.15	0.86	84.2	16.8
O	14.68	0.87	447.5	14.5
P	3.97	0.75	50.7	9.9
Q	9.11	1.06	306.1	37.9
R	5.28	0.70	128	18.7

Table 6. 2008 BEHI category scores, total scores and erosion rates.

Treatment reach	**Land use**	**BH/BFH score**	**Root depth score**	**Root density score**	**Surface protection score**	**Bank angle score**	**Total score**	**BEHI Category**
A	Crop	1.45	10	10	1.45	2.95	25.85	High
B	Crop	1.45	10	10	1.45	2.95	25.85	High
C	Forest	4.95	10	8.5	6.95	2.95	33.35	High
D	Forest	10	8.5	6.95	1.45	2.95	29.85	High
E	Pasture	4.95	10	6.95	4.95	2.95	29.8	High
F	Pasture	6.95	6.95	6.95	4.95	2.95	28.75	High
G	Crop	4.95	4.95	10	4.95	2.95	27.8	High
H	Crop	4.95	10	8.5	4.95	2.95	31.35	High
I	Crop	6.95	10	10	2.95	2.95	32.85	High
J	Forest	8.5	10	10	2.95	2.95	32.9	High
K	Forest	4.95	8.5	6.95	2.95	2.95	26.3	High
L	Pasture	4.95	10	4.95	2.95	2.95	25.8	High
M	Pasture	6.95	2.95	6.95	4.95	2.95	24.75	Moderate
N	Forest	6.95	4.95	8.5	6.95	2.95	30.3	High
O	Pasture	4.95	4.95	6.95	4.95	2.95	24.75	Moderate
P	Pasture	4.95	10	10	4.95	2.95	32.85	High
Q	Forest	6.95	4.95	4.95	4.95	2.95	24.75	Moderate
R	Forest	6.95	10	8.5	2.95	2.95	31.35	High

Table 7. 2011 BEHI category and adjustment factors scores, total scores, and erosion rates.

Treatment reach	**Land use**	**Root depth score**	**Root density score**	**Surface protection score**	**Bank angle score**	**Bank materials adjustment**	**Stratification adjustment**	**Total score**	**BEHI Category**
A	Crop	10	10	1.5	3	0	10	34.5	Extreme
B	Crop	10	10	1.5	3	0	10	34.5	Extreme
C	Forest	10	8.5	7	3	0	10	38.5	Extreme
D	Forest	8.5	7	1.5	3	0	10	30	Very high
E	Pasture	10	7	5	3	0	10	35	Extreme
F	Pasture	7	7	5	3	0	10	32	Very high
G	Crop	5	10	5	3	0	10	33	Very high
H	Crop	10	8.5	5	3	0	10	36.5	Extreme
I	Crop	10	10	3	3	0	10	36	Extreme
J	Forest	10	10	3	3	0	10	36	Extreme
K	Forest	8.5	7	3	3	0	10	31.5	Very high
L	Pasture	10	5	3	3	0	10	31	Very high
M	Pasture	3	7	5	3	0	10	28	High
N	Forest	5	8.5	7	3	0	10	33.5	Very high
O	Pasture	5	7	5	3	0	10	30	Very high
P	Pasture	10	10	5	3	0	10	38	Extreme
Q	Forest	5	5	5	3	0	10	28	High
R	Forest	10	8.5	3	3	0	10	34.5	Extreme

Chapter 5. General conclusions

Stream bank erosion is a natural phenomenon that is impacted by many things. The results of this thesis suggest that, although different studies in the literature have found some variables investigated here to be determining factors in the magnitude and extent of sediment lost from banks in their study areas, the relationships between these variables and bank stability are not clear and no individual variable other than season was shown to be a determining factor in the amount of soil leaving banks in our treatment reaches.

Land-use changes from natural vegetative communities into agricultural uses can result in adjustments to the hydrology and geomorphology of an area, which will alter a stream's sediment transporting power, and it may take a very long time for streams to adjust to these changes made in the upland areas. In the Midwest, there remains a disconnect between current land use and bank erosion as these watersheds have not re-equilibrated following the massive post-settlement hydrologic disturbance.

Measuring the extent and magnitude of stream bank erosion can take many forms, such as erosion pin studies, LiDar experiments, and assigning erosion potential based on visual criteria. Most of the methods necessitate repeated measurements, extensive training or other time- and/or labor-consuming methodologies. There is a need for the development of survey methodologies that can be done by non-scientist volunteers in short periods of time and that can accurately predict erosion potential.

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