Predicting stream bank erosion on the northern Gulf of Mexico coastal plain: Pitfalls and solutions.

Introduction

According to the EPA's 2000 National Water Quality Inventory (USEPA 2000), sediment pollution is the second leading cause of impairment to U.S. streams. In areas where sediment pollution and eroding stream banks coincide, professionals are apt to cite bank erosion as a suspected source of contamination. Bank erosion can lead to a number of problems, not only by contributing sediment, but by altering channel dimensions as bank area is lost. Thus, funds allotted to federal, state and county agencies for soil conservation and stream stabilization are often used to implement techniques aimed at curbing lateral erosion. Realistically, it is impossible to secure funding for complete restoration of all eroding channels. What is needed is a predictive field-based method for determining sites that will incur the most rapid erosion and approximately how much sediment will be contributed to the channel. With such a powerful tool for prioritizing restoration sites, more funding could be funneled to high risk sites, resulting in more comprehensive restoration projects.

In the last 10 years, several studies have been conducted correlating observed rates of bank erosion with field-measured erosion potential factors (Harmel et al. 1999; Rosgen 2001; Jennings and Harman 2001; Van Eps et al. 2004; Sass and Keane 2012). Such studies, when carried out in a single hydrophysiograhic region and on hydrologically and morphologically similar streams, can provide professionals a means for rapidly estimating the sediment contribution of eroding banks in that region. Our study is developing regional bank erosion curves for the Northeast Gulf Coastal Plain thereby providing local management experts a valuable tool for the speedy prioritization of enhancement and restoration projects and follow-up monitoring of restoration efforts. Our study applies an established method (Rosgen 2001; USEPA 2012) but seeks to improve on some of the weaknesses inherent to the method.

Rosgen Method Background

Stream assessment methodology is widely used to describe the morphological type and condition of streams (Rosgen 1996). When applied at a regional level, the Rosgen methodology can provide data sufficient for developing predictive curves for bank erosion and other applications. For bank erosion prediction, Rosgen (1996, 2001) correlated two independent factors, bank erosion potential (BEP) and near-bank stress (NBS), with measured bank erosion rates. The Bank Erodibility Hazard Index (BEHI) rating system was designed by

Rosgen to describe BEP as one of six risk categories, ranging from very low to extreme. The BEHI rating of a stream bank is determined by the individual scores for five risk factors known to affect bank stability. These five risk factors are:

1) Ratio of bank height to bankfull height,
2) Ratio of vegetation root depth to bank height,
3) Percent root density,
4) Bank slope, and
5) Percent bank surface protection.

Numerical values for each risk factor are converted to an index, the sum total of which is the final BEHI score. The BEHI score can be adjusted for the bank soil/sediment texture and stratification. The BEHI represents a bank erosion potential rating on a 5-50 scale.

Various methods exist to estimate NBS (USEPA, 2012) but all represent a measure for the hydraulic forces affecting a stream bank. Rosgen (2001) and USEPA (2012) provide a method to convert the numerical measures for NBS to one of six qualitative ratings ranging from very low to extreme stress.

In streams in Colorado and Wyoming, Rosgen (2001) found high (0.92 - 0.84) significant (□=5%) R^2 values describing the relationship between the independent variables (NBS and BEHI) and measured bank erosion rates when NBS scores were grouped within BEHI categories. Rosgen (2001) observed that the predictive curves for the Colorado and Wyoming streams were different and concluded that predictive curves have to be established on a regional basis. Harmel et al. (1999) applied Rosgen's methods to reaches in the Upper Illinois River in Northeast Oklahoma and found no significant relationship between observed erosion and NBS within BEHI categories. Rosgen (2001) argued that the lack of a significant relationship was due to Harmel et al. (1999) using cross-sectional area ratios rather than shear stress ratios to estimate NBS. The BEHI indices in the Harmel et al. study were shown to be significantly (□=5%) correlated with bank erosion though high variability was evident by low R^2 values. Development of predictive erosion curves in NE Kansas demonstrated that combinations of BEHI-NBS produced R^2 values of 0.77 for high-very high BEHI ratings (Sass and Keane 2012). However, trend lines intersected at lower NBS and BEHI ratings suggesting discrepancies in the model.

Rosgen Method Pitfalls and Solutions

Even though it is widely used by the stream restoration community, the Rosgen approach has several shortcomings, ranging from conceptual (Simon et al. 2007, Miller and Skidmore, 2001, Juracek and Fitzpatrick 2003) to practical. Practical issues include development of the method in grass prairies with sparse trees and its resulting limited applicability in forested areas (Sass and Kean 2012), an oversimplified treatment of bank material properties, reliance on indexations and statistics that are poorly explained at best in the peer-reviewed literature, and its dependence on visual estimates.

One of the most contentious visual estimates is that of root density (the proportion of the soil occupied by roots), which is estimated visually without excavation of the stream bank or any other direct observation of roots. A visual estimate of below ground root mass or volume is virtually impossible to make and unlikely to be accurate, even with field training, yet it accounts for 20% of the final BEHI. Our study developed two quantitative methods to determine proxies for root density in an objective and consistent manner.

The first method is based on the point-intercept method (PIM) that traditionally has been used to measure the density of forest understory vegetation (Jonasson, 1988) but to our knowledge has not yet been applied in a stream bank erosion study. Its potential applicability for our study was brought to our attention by Johnathon Phillips (2014, personal communication). In our approach, a thin metal rod is inserted horizontally into the stream bank on a regular grid until it either reaches a set depth or encounters a root. The number of root hits is counted and assumed to represent the amount of roots in the stream bank. There is some subjectivity in deciding how much resistance to the rod movement represents a root hit, as opposed to resistance from dense soil materials, but comparison of the root hits with excavated root mass shows a high correlation (see below). Even though the difference between a root hit and a hit of a rock can be felt, the method obviously works best in soils with few rocks or other hard objects such as the soils in the study area.

The second method generates a proxy for root density by determining the above ground biomass at the stream banks. Several studies have shown that a strong positive relationship exists between above ground biomass and stream bank erosion (Micheli and Kirchner, 2002). In our method, the diameter at breast height (DBH) of trees and shrubs of a certain size-class are measured in a series of concentric semi-circles centered on the study bank. This type of protocol is often employed in forest surveys and has been widely tested (Bechtold and Patterson, 2005; Law et al., 2008). Allometric equations for specific species-based categories of trees are then applied to determine the above ground biomass at the study bank (Jenkins et al., 2003).

Objectives

The overall goal of this project is to develop regional curves to predict stream bank erosion rates for the Northeast Coastal Plain of the Gulf of Mexico. The resulting model will identify statistical relationships between BEP, as represented by the BEHI, NBS, and observed bank erosion rates. The specific objective reported on here is to enhance the power of the Rosgen approach by assessing alternatives for the visual estimation of root density. Particularly, we will evaluate the feasibility of using a PIM method and an above ground biomass survey as an alternative for visual root density estimation.

Project Methods

Overall steam bank survey methods

Seventy-five study sites were selected in priority freshwater basins in the Florida Panhandle and adjacent areas of Alabama and Georgia. Study sites represent a wide range of stream bank instabilities, which ensures broad applicability of the resulting predictive models. At the study sites a specific bank profile was selected as the "study bank" and four types of data were collected: risk factor values to determine the BEHI, measurements to determine the NBS, actual bank erosion measurements, and ancillary data. For data collection for the BEHI and NBS we closely follow methods described in Rosgen (1996, 2001) and USEPA (2012).

Bank erosion is measured with two methods. In one method, a pin made out of rebar with a plastic cap is driven vertically into the river bed at the toe of the study bank. A surveying rod is held vertically on top of the toe pin and the distance from the rod to the bank face is measured every 10 vertical cm with a handheld laser range finder. In the other method, two or three erosion pins, also made out of rebar, are driven horizontally into the study bank. The erosion pins are spaced vertically from the toe of the bank, or as low as practicably possible given the water level, to the top of the bank. The pins are driven in until flush with the bank so as to avoid creating turbulence in the water flow near the bank.

Root density proxy methods: PIM and biomass survey

In the PIM approach, a thin (1 mm diameter), 50 cm long, metal rod is horizontally pushed into the stream bank by hand. The rod is inserted at the nodes of a 20 cm by 20 cm grid that is 2 m wide and is centered on the study bank (grid is 1 m to each side of the study bank). The bottom of the grid is as low as practicably possible given the water level in the stream and extends to the top of the bank. When a sudden increase in resistance is felt or the rod comes to a stop it is interpreted as a root hit. The rod is withdrawn and a 1 is recorded for the grid node. When the whole rod can be inserted without sudden increases in resistance or stopping a 0 is recorded. Other hard objects, such as rocks, can obviously also make the rod come to a stop. However, in the study area rocks are rare and field experience indicates that it is quite easy to feel the difference between a hard stop caused by a rock and a gentler stop caused by a root. Dense soil that is hard to push through presents a bigger problem. It is possible to push through small or soft roots in dense soil without feeling the difference in resistance, but such dense soils are also rare in the study area.

To assess this method we mechanically excavated two soil pits 1 m wide, approx. 3 m long and 1.5 m deep. One of the long faces of each pit was completely smoothened with a trowel and loose material and vegetation were removed from the top just enough to make the surface smooth and level and reach the mineral soil. On the side of the two cleaned pit faces a 20 cm by 20 cm grid was marked extending from the surface to 40 cm depth. At the surface, a line was drawn at 50 cm from the edge of the pit to mark the end of the rod when fully inserted in the pit face. This created cells of 20 cm by 20 cm by 50 cm. In 24 of these cells the metal rod was inserted horizontally on a 5 cm by 5 cm grid and root hits were recorded as in the field (see above). After the PIM was applied, the cells were excavated and sieved in the field through an 8mm sieve to separate large roots from the other soil materials. The excavated soil was weighed and a weighed subsample was taken to determine fine roots. In the lab, fine roots were separated manually from the rest of the subsample, washed, oven dried and weighed. The large roots that were separated in the field were also washed, oven dried and weighed in the lab. Moisture content of the subsample was determined gravimetrically. Root density was calculated as the ratio of total dry root mass, including fine roots back calculated for the whole sample, to total dry soil weight.

Above ground biomass was determined by measuring the diameter at breast height (DBH) of trees of a certain size-class in concentric semi-circles centered on the study bank. In semi-circles near the bank all trees were measured, in semi-circles further away from the study bank only larger trees were measured because small trees at larger distances from the bank are unlikely to affect bank erosion (Table 1). In the 1 m semi-circle the biomass of the herbaceous layer (DBH < 2.5 cm) was estimated by visually estimating percent ground cover with the aid of charts. Estimates were made by three observers independently and results were averaged to minimize operator bias. The average was related to the herbaceous above ground biomass according to methods described in Law et al. (2008). Initial observations indicate that the herbaceous layer biomass is negligible compared to the tree biomass at a site.

Table 1: Semi-circle radii and tree size-classes surveyed for above ground vegetation survey.

Semi-circle radius	Tree size-class
1 m	all
2.5 m	> 2.5 cm DBH
5 m	> 10 cm DBH
10 m	> 30 cm DBH

Summary of Results

The validation of the PIM approach in the two soil pits shows a high correlation between the number of root hits and the oven dry weight of roots (Table 2). The correlation is lowest, but still relatively high (r=0.63), for the lowest root size class. This is to be expected as fine roots are most likely to be missed by the inserted rod. Even when a fine root is hit, the operator may not notice it given the small force required to push the rod through a fine root. The significant ($p < 0.001$) and very high correlation coefficient (r=0.84) for all root sizes combined demonstrates the viability of this approach. Simple linear regression shows that the number of root hits are a significant ($p < 0.001$) predictor of root mass ($R^2 = 0.70$) and indicates that our approach is a suitable method to estimate root mass when destructive methods are not an option. As cautioned above, the method will yield best results in relatively soft soils with no rocks. In such a situation a root hit is most noticeable by the operator. This validation of the PIM approach indicates that it is a superior alternative for the visual root density estimation method that is standard practice in the Rosgen methodology.

Table 2: Pearson correlation coefficients for PIM root hits and oven dry root weight.

Root size class	Poke Hits
> 10mm	0.77
2-10 mm	0.80
< 2 mm	0.63
all roots	0.84

Comparison between results of the PIM approach and the visually estimated root density at 44 of the stream banks yielded a significant weak Pearson correlation (r=0.42, p<0.01).

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