# A WEST VIRGINIA CASE STUDY: DOES EROSION DIFFER BETWEEN STREAMBANKS CLUSTERED BY THE BANK ASSESSMENT OF NONPOINT SOURCE CONSEQUENCES OF SEDIMENT (BANCS) MODEL PARAMETERS?

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**Abstract.**—The integration of factors and processes responsible for streambank erosion is complex. To explore the influence of physical variables on streambank erosion, parameters for the bank assessment of nonpoint source consequences of sediment (BANCS) model were collected on a 1-km reach of Horseshoe Run in Tucker County, West Virginia. Cluster analysis was used to establish groups of streambanks, and observed erosion between the groups was compared. The cluster analysis revealed that groups of streambanks with uniform bank composition, high surface protection, low bank angles, and intermediate rooting depth and rooting density values tended to have less erosion. Our results suggest that the BANCS model input parameters may provide valuable insight into the susceptibility of a streambank to erosion.

## INTRODUCTION

### Streambank Erosion

Erosion and deposition are natural weathering processes that have been shaping the environment for millennia. Historically, sediment was thought to originate largely from surface runoff. Over the past several decades, sediment originating from streambanks has been thought to be a potentially greater source of sediment. Streambank erosion has been found to account for the majority of sediment input to streams in California (Trimble 1997), Montana (Rosgen 1973, 1976), Minnesota (Sekely et al. 2002), across the Southeast (Simon and Rinaldi 2006), and in Australia (Prosser et al. 2000), England (Lawler et al. 1999), and Ireland (Evans et al. 2006).

Streambanks erode through a combination of streambank weakening, failure of bank materials due to gravity, and detachment of bank materials due to flow (Lawler et al. 1999). The influence of each mechanism on total streambank erosion differs by stream and may vary both spatially and temporally within a single reach. Common variables that have been used to successfully predict erosion include freeze thaw cycling, soil bulk density, near bank velocities, cross-sectional dimensions, flow conditions (e.g., duration, peak), silt-clay content, and various vegetation indices (Chen et al. 2005, Julian and Torres 2006, Magner and Brooks 2008, Pizzuto 2009). Prediction models incorporating various combinations of these variables have been successfully tested at individual sites; however, there is a need to generate a model with an established set of variables that can be transferred across sites.

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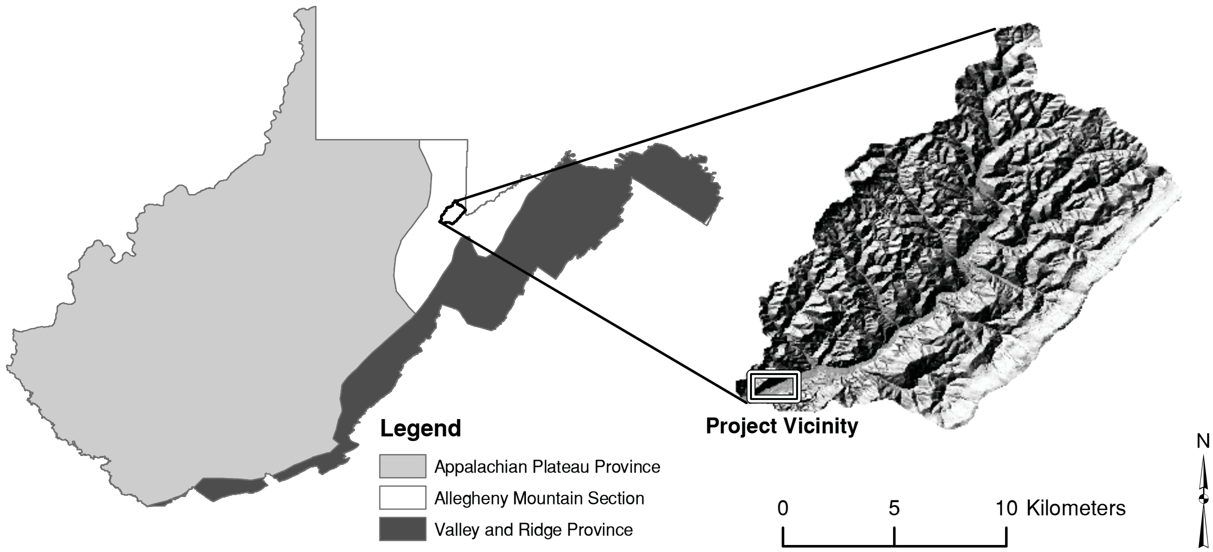


Figure 1.—The study area near the outlet of the Horsehoe Run watershed, which lies within the Allegheny Mountain Section of the Appalachian Plateau physiographic province, Tucker County, West Virginia.

## Model Description

The bank assessment of nonpoint source consequences of sediment (BANCS) model was developed based on the need of practitioners and watershed managers to have a comparable, transferable streambank erosion prediction model that could be easily and rapidly applied at the watershed scale (Rosgen 2006). This model relies on observations and statistical relationships to predict bank failure and erosion. Combining two submodels, the bank erosion hazard index (BEHI) and near bank stress (NBS), with a set of regional erosion curves, the model incorporates the susceptibility of a bank to mass or gravitational failure, fluvial entrainment, and surface erosion. The BANCS model groups streambanks into 36 categories based on the BEHI and NBS parameter scores. We did not have an adequate number of streambanks in unique categories to determine if erosion differed between these categories. In lieu of this comparison, we used cluster analysis to establish groups of streambanks based on the BANCS parameters and then compared the observed erosion between these groups.

## STUDY AREA

## Watershed

The Horseshoe Run watershed is located in the Allegheny Mountain Section of the Appalachian Plateau physiographic province in Tucker County, West Virginia, and is approximately 137 km$^2$ in size at the project site (Fig. 1). The project site is 300 m upstream of the Horseshoe Run confluence with the Cheat River, which drains into the Monongahela River and then the Ohio River. The Allegheny Mountain section of the province is highly dissected with steep, high-energy streams flowing into narrow and more moderate floodplains. Watershed elevations range from 1,115 m along Backbone Mountain, the eastern ridge of the watershed, to 473 m near the outlet with an average slope of 46°. The region is characterized by a humid continental climate with average annual rainfall of 1,318 mm and an average annual temperature of 9.7 °C.

The hillslopes and upper portions of the watershed are in various stages of forest stand development due to the historic and current logging in the watershed (Fansler 1962). Land uses in the narrow floodplain range from intensively grazed to rural residential to forested. Due to the steepness of the hillslopes and the narrowness of the valley, most anthropogenic impacts span the floodplain and in some cases border or intersect the stream (Homer et al. 2007).

A series of aerial photographs revealed that Horseshoe Run has been actively migrating and eroding at significant rates over the past several decades (Canaan Valley Institute 2006 [CVI], U.S. Geological Survey 1997, West Virginia Statewide Addressing and Mapping Board 2003). This migration can be attributed to a combination of natural and anthropogenic disturbances. An inherently high bedload and a history of large flooding events combined with the periodic clearing of large swaths of the hillslope and riparian zone for logging, agriculture, and rural development contribute to the erosive nature of the stream.

## Reach Characterization

Streambanks through the reach are characterized by a thin layer of cohesive silt loam in the upper bank overlaying layers of soil mixed with gravel and cobble. Floodplain soils through the reach are classified as Gilpin channery silt loams, Philo silt loams, or a mixture of alluvial material of the Fluvaquents-Udifluvents complex (Losche and Beverage 1967). Stream cross-sectional area averaged 85 $m^2$ with an average width of 83 m and depth of 1 m. The average bed slope was 0.0059 m/m and the substrate ranges from fine gravel to large cobble with a D50 (defined as the grain diameter at which 50 percent of the sediment sample is finer than that size) of very coarse gravel measuring 52 mm. Vegetation ranges from dense stands of American sycamore (*Platanus occidentalis* L.) to mowed grasses. River birch (*Betula nigra* L.), yellow buckeye (*Aesculus flava* Aiton), multiflora rose (*Rosa multiflora* Thunb.), autumn olive (*Elaeagnus umbellate* Thunb.), and wingstem (*Verbesina alterniflora* [L.] Britton ex Kearney) were other common species found growing adjacent to the stream.

# METHODS

## Data Collection

Fifteen streambank sites were selected along Horseshoe Run to represent a range of streambank conditions. Two permanent benchmarks, 45-cm lengths of 1.3-cm-diameter reinforcing bar, were pounded vertically into the ground along a transect perpendicular to the stream at each site beyond the top of the bank, from which bank profiles were aligned and measured. One horizontal benchmark, or bank pin, was installed in each bank profile where cohesive soils were present (Coffman 2009, Thorne 1981, U.S. Environmental Protection Agency 1999). Bank profiles were measured by using a laser distance finder. The laser distance finder was mounted to a stadia rod which was leveled and secured with a tripod to collect bank data.

Baseline bank profiles were measured in November 2009. The bank profiles were remeasured in October 2010 to generate annual erosion amounts for each streambank site (Henderson 2006, Pollen-Bankhead and Simon 2008, Prosser et al. 2000). The x and y bank profile coordinates were imported into ArcMap (ESRI, Redlands, CA), a polygon outlining the eroded area was created, and the area of the polygon was calculated. Cross-section data were collected at each site, from which mean and near bank maximum depths were derived (Harrelson et al. 1994).

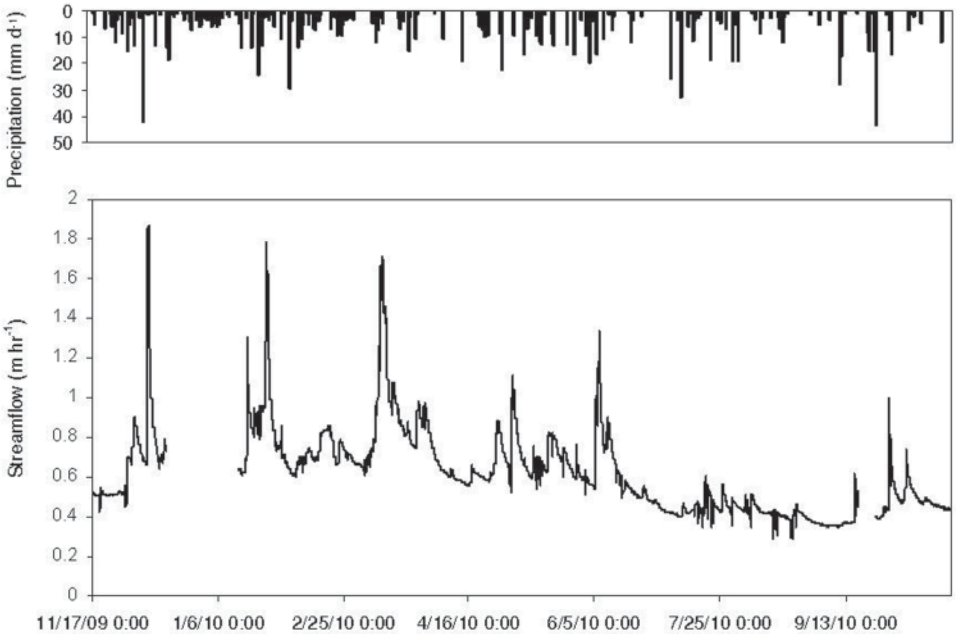


Figure 2.—Average precipitation from the Davis 3SE and Parsons 1NE National Climatic Data Center weather stations and streamflow stage from the Canaan Valley Institute stream gauge. Gaps in streamflow represent missing data.

A stream gauge installed by CVI approximately 5 km upstream of the project site on Horseshoe Run collected stage height in 15-minute intervals from November 2009 through October 2010. Lacking a weather station in the watershed, we used precipitation data from two National Climatic Data Center [NCDC] weather stations: Davis 3SE (Coop_ID 462211), located approximately 10 km east of the watershed at an elevation of 1,162 m, and Parsons 1NE (NCDC Coop_ID 466867), located approximately 6.5 km south of the watershed at an elevation of 557 m. Averaging values from the upper portion of the watershed represented by the Davis station and the mouth of the watershed represented by the Parsons station provided approximate values for the study reach (Fig. 2). Total precipitation averaged between the two stations was 1,240 mm for the study period with greater than 5 m of total snowfall.

The highest streamflow events occurred in the winter months between December and April from a combination of rainfall, snowmelt, and rain-on-snow events. Long-term data were unavailable for the CVI gauge; however, the nearby USGS Cheat River gauging station near Parsons, West Virginia (03069500) had a historic record and indicated that the January high-flow event had a recurrence interval of approximately 1.7 years, and the March flow event had a recurrence interval of approximately 1.5 years. The December high flow on Horseshoe Run was a localized event and did not have corresponding elevated discharge on the Cheat River (Fig. 2).

## Model Parameters

Bank height was calculated by measuring the vertical distance from the bank toe to the top of the bank. Bankfull height was derived by fitting a trend line to the top of bank points along the longitudinal profile and calculating a height from the fitted data. Root depth was measured from the top of the bank to the terminus of the majority of roots. Root density was visually estimated from that portion of the bank considered in the root depth measurement. When bare roots were exposed in three dimensions, the percentage of volume occupied by the roots in three dimensions was estimated. When roots were exposed only on the bank face, the percentage of area occupied by the roots in two dimensions was estimated. When roots were not exposed, percentages were estimated based on the aboveground density of vegetation present.

Bank angle was measured in ArcMap by using the measure angle tool. The angle most likely influencing the gravitational failure of the bank was measured. Surface protection represents the proportion of the bank face that is protected by vegetation, large rocks, or other materials that resist hydraulic erosion. We calculated a percentage of surface protection by measuring the height or length of the bank face that was protected, typically by vegetation, and dividing this value by the total height or length of the bank. A bank material adjustment factor was determined by adding 5 to 10 points to those sites where gravel or a gravel and sand composite matrix was present. Factors were determined by the percentage of sand and gravel in the banks by using the following classification, where the rating is followed by the percentage of sand and gravel in parentheses: 5 (0-30), 6 (30-45), 7 (45-55), 8 (55-70), 9 (70-85), and 10 (85-100). Percentages were determined based on a textural classification of soils in the laboratory (American Society for Testing and Materials 1988). A stratification adjustment factor was assigned for those banks in the upper reach that were stratified. Adjustment ratings were assigned as follows: 5 for banks with stratification but without preferential erosion; 8 for banks exhibiting any stratified preferential erosion; and 10 for banks with preferential erosion in the lower stratified layers, preferential erosion below the root zone, or both. The minimum, mean, and maximum values for the collected model parameters are listed in Table 1.

**Table 1.—BANCS model input parameters with associated measurement units**

| Parameter | Unit | Measured | Estimated/ derived | Summary data | | |
|---|---|---|---|---|---|---|
| | | | | Min | Mn | Max |
| Bank erosion hazard index (BEHI) | | | | | | |
| †Study bank height ratio | | | | 0.52 | 1.11 | 1.75 |
| Bankfull height | m | | X | 0.83 | 1.48 | 2.03 |
| Bank height | m | X | | 1.03 | 1.38 | 1.60 |
| †Root depth ratio | | | | 0.02 | 0.27 | 0.72 |
| Root depth | m | X | | 0.03 | 0.39 | 1.22 |
| Bank height | m | X | | 0.83 | 1.48 | 2.03 |
| †Weighted root density | | | | 0.17 | 4.95 | 14.44 |
| Root density | % | | X | 5.00 | 15.20 | 30 .00 |
| Root depth ratio | | X | | 0.02 | 0.27 | 0.72 |
| †Bank angle | degrees | X | | 30.00 | 66.43 | 136.00 |
| †Surface protection | % | X | | 0.00 | 19.20 | 72 .00 |
| †Bank material adjustment | | | X | 5.00 | 7.60 | 9.00 |
| †Stratification adjustment | | | X | 0.00 | 6.00 | 10.00 |
| Near bank stress index (NBS) | | | | | | |
| †Depth ratio | | | | 0.98 | 1.47 | 2.08 |
| Near bank max depth | m | X | | 0.98 | 1.76 | 2.42 |
| Mean depth | m | X | | 0.77 | 1.24 | 1.88 |

† indicates parameters used in the cluster analysis.

x's indicate whether the parameter was measured based on data collected in the field or estimated/derived by using best professional judgment. Minimum, mean, and maximum values for each parameter are included.

## Cluster Analysis

Cluster analysis using the Ward agglomeration method was run on all of the sites with the following parameters: study bank height ratio, root depth ratio, weighted root density, bank angle, surface protection, bank material adjustment, stratification adjustment, and near bank maximum depth ratio. The BEHI and NBS data were log transformed to meet normality assumptions where appropriate, scaled, and centered. Then a Euclidean distance matrix was generated from these data to be used as input to the cluster analysis. Analysis of variance was used to determine if erosion differed between the cluster groups. All statistical analyses were performed in the R language and environment, version 2.12.1 (R Development Core Team 2010).

## RESULTS

The erosion at all the streambank sites ranged from 0.09 $m^2$ to 5.33 $m^2$ (mean 1.05 $m^2$ and median 0.41 $m^2$) (Fig. 3). Because data were collected along a cross-sectional transect, only two-dimensional erosion data were calculated. A third dimension measured along the length of the bank would have been required to generate the volume of erosion.

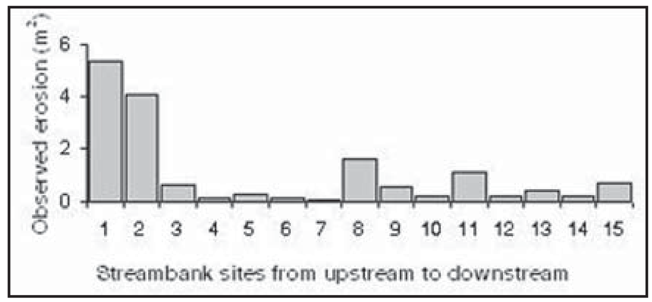


Figure 3.—Barplot of observed erosion ($m^2$) at the streambank sites in order from upstream to downstream.

The cluster analysis divided the streambanks into three groups: a highly stratified, densely vegetated group (Group 1), a sparsely vegetated group (Group 2), and a group with intermediate vegetation values and low bank angles (Group 3). Analysis of variance revealed that erosion differed between the cluster groups at the 0.1 significance level ($p = 0.08$). Boxplots of transformed erosion by cluster groups indicated that Group 3 had lower erosion amounts than the remaining sites (Fig. 4). This group of streambanks had uniform bank composition, high surface protection, low bank angles, and intermediate rooting depth and rooting density values compared to the other groups.

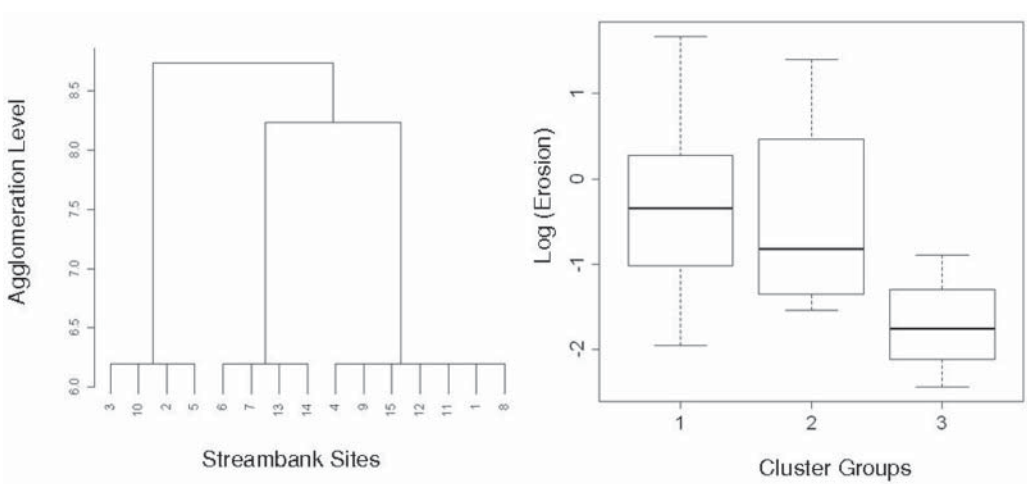


Figure 4.—Cluster analysis using the Ward agglomeration method and boxplots of log(erosion) values by cluster group.

## DISCUSSION

Banks with uniform composition, high surface protection, and low bank angles were typically believed to have a lower susceptibility to erosion; however, the banks with intermediate vegetation coverage behaved in a surprising way. Vegetation has been shown to have both positive and negative influences on bank stability (Simon and Collison 2002, Wallick et al. 2006); a negative influence was evident at one site in the project reach. The site with the highest erosion (5.33 $m^2$) had a large tree about 1 m beyond the top of the bank. Erosion caused the bank to retreat to the tree and removed the entire root network and underlying streambank when it failed. A streambank without any vegetation may be equally vulnerable because there is no protection from surface erosion and no added cohesion from roots (Abernathy and Rutherford 1998, Wynn and Mostaghimi 2006). Studies have found that a mix of vegetation with varying sizes of root classes or grass and shrub species with high densities but low surcharge may provide the best protection, and the intermediate classes of vegetation identified in this study may support these findings (Simon and Collison 2002, Wynn and Mostaghimi 2006).

## CONCLUSIONS

We used cluster analysis to establish groups of streambanks and then compared the observed erosion between these groups. When the streambank parameters were used to group sites independently of erosion, a group of streambanks with moderate rooting depths and densities and low bank angles emerged. This group had the least erosion. A variety of vegetation types with a wide distribution of root sizes and depths may provide more stability than larger vegetation with deeper, denser root networks. This relationship might be particularly true for incised streams with high hydraulic erosion at the bank toe, where the surcharge of large trees may outweigh the stabilizing effects of vegetation.

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