University of Nevada, Reno

Prediction of Annual Streambank Erosion for Sequoia National Forest, California

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Hydrology

by

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Abstract

The US EPA has consistently listed sediment as a leading cause of water quality impairment in rivers, streams, and lakes, costing approximately $16 billion annually. Yet prediction methods are not applicable to wildland systems. The Sequoia National Forest needs to understand mechanisms and rates of streambank erosion to evaluate with management issues , especially those associated with post-wildfire effects. This study uses Bank Erosion Hazard Index (BEHI) methods developed in Rosgen (2006) for predicting streambank erosion. Measurements of bank erosion over a year were evaluated using BEHI and estimates of Near Bank Stress (NBS). BEHI evaluates bank susceptibility to erosion based on bank angle, bank and bankfull height, rooting depth and density, surface protection, and stratification of material within the banks. NBS assesses energy distribution against the bank measured as a ratio of near-bank maximum depth to mean bankfull depth. BEHI and NBS were good to fair indicators of streambank erosion at or near bankfull conditions at riffle features. Individual BEHI variables and several other physical variables (e.g., elevation, drainage area, and vegetation) significantly correlated with streambank erosion but had low predictive power (i.e., r^2 0.0007 to r^2 0.18) indicating inconsistency in driving variables among locations. This indicates that a combination of several variables affects streambank erosion. A low r^2 (0.23) from multiple regression analyses shows there may be variables other than those of BEHI that affect streambank erosion. Bank angle has the lowest predictive power for erosion while rooting depth had the highest.

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Preface

This thesis is divided into two chapters. The first chapter reviews literature relevant to the thesis and justifies why this research was conducted. The second chapter is written to be submitted to *Earth Surface Processes and Landforms* and describes the creation of a graphic and statistical model to predict streambank erosion in a geographic area where this approach has not yet been tested.

Chapter 1

Literature Review

Streambank Erosion

The Issue:

According to the US Environmental Protection Agency, sediment is a leading cause of impairment in monitored rivers, streams, and lakes (USEPA, 2008). Streambank erosion supplies most sediment in some watersheds. As much as 80% of total sediment load results from incised channels in the loess area of the midwestern United States (Simon et al, 1996). The USACE (1983) attributed 59% of the sediment flux of the Sacramento River to streambank erosion. The Blue Earth River in Minnesota provides up to 44% of its sediment load from streambank erosion (Sekely et al., 2002). Willow removal along riparian areas has changed the East Fork of the San Juan River, Colorado from a meandering pool riffle channel (C4 stream type) to a braided channel (D4 stream type), and increased sediment yield by roughly 49% (Rosgen, 2001). Researchers observed 21,455 metric tons of sediment entering the West Fork of the White River in Arkansas annually from streambank erosion where the estimated natural rate should be only 739 metric tons per year (Eps et al., 2004).

Though streambank erosion occurs naturally, unnatural or accelerated rates affect people and wildlife. Every year erosion or sediment destroys standing crops, farmland, homes (UNEP, 2007; Haque and Hossian, 1988) and affects aquatic ecosystems. Increased sediment entering a stream or river can detrimentally affect aquatic ecosystems (Waters, 1995). An increase in turbidity can decrease photosynthesis and decrease oxygen production resulting in impacts to the rest of the food chain (Wood and Armitage, 1997). Fish spawning redds require free passage of oxygenated water whereas excess fine sediment can suffocate eggs. Decreased dissolved oxygen due to excess sediment following wildfires results in major fish kills in many lakes such as Lake Isabella in 2002 after the McNally Fire, Sequoia National Forest, California (Kaplan-Henry, 2007; Spencer et al, 2003).

Anthropogenic activities can increase erosion through removal or alteration of riparian vegetation. Significantly greater streambank erosion and disturbance may occur in grazed areas than in livestock-excluded areas (Trimble, 1994; Kauffman et al., 1983). Several studies throughout the globe suggest that conversion from grassland to forest led to accelerated streambank erosion. (Lyons et al., 2000; Trimble, 1997; Murgatroyd and Ternan, 1983).

To counter streambank erosion, humans have attempted to stop streambank erosion processes with channel bank infrastructure, varying from the placed car-bodies to concrete-lined channels (Florsheim et al., 2008). However, because biologic and geomorphic processes are so intertwined, construction of erosion control structures might only ameliorate one part (streambank erosion) of a larger problem made up by a chain of factors. Some other factors may include altered sediment supply, channel degradation or aggradation, altered watershed hydrology (e.g., timing or magnitude of flow), loss or alteration of riparian vegetation, and changes to channel roughness.

Though streambank erosion generally has a negative connotation among land managers and for those who live within the floodplain of a river, bank erosion can provide desirable attributes to a river. Coarse sediment can be supplied from bank erosion processes and promote formation of the physical structures of aquatic habitat (Florsheim et al., 2008). Along the Platte River, migrating whooping cranes (*Grus americana*) rely on sandbars partly built from bank erosion sediment to rest and forage upon. Here, they are protected and have a long line of sight from predators (Graf, 2005). Riparian vegetation can contribute large woody debris to a stream or river during events of bank erosion (Wyzga and Zawiejska, 2005). Large woody debris changes bed and bank morphology and increases channel complexity, providing more intricate habitat for aquatic flora and fauna (Ralph et al., 1994).

The Process:

Early pioneering work acknowledged streambank erosion as a natural and fundamental process in the development and maintenance of stream channel morphology (Leopold et al., 1964). However, its processes have been largely ignored until more recently.

Streambank erosion is a natural process that is mainly controlled by the underlying geology and precipitation of the area (Natural Resources Sciences, 2006). The process of streambank erosion is initiated by three integrating mechanisms: weathering and weakening, fluvial erosion, and mass wasting (Luppi et al., 2008; Jha et al., 2005; Land and Water Australia, 2002; Abernethy and Rutherfurd, 1998). Subaerial weathering and weakening are processes seen as the preparatory stages, weakening the bank face prior to erosion (Couper and Maddock, 2001). This may include cycles of wetting or freezing and thawing.

Typically, fluvial erosion (detachment of particles from streambanks) leads to mass wasting, or bank failure as described by the concept of basal endpoint control developed by Carson and Kirkby in 1972 (Garcia, 2008). Fluvial erosion at the toe of the bank can lead to undercutting and eventually cantilever failure from gravitational forces. Subsequently, bank failure will supply sediment to the toe of the bank and thus increase bank stability. It has been suggested that stability is attained when the bank is at an angle of repose (Carson and Kirkby, 1972) and that after incision the floodplain and meander belt width first becomes wide before gentler bank slopes predominate.

Rates and patterns of meander migration reflect the ability of hydraulic shear forces to erode bank and floodplain materials via fluvial erosion and mass wasting. Increasing hydraulic shear stress or increasing streambank erodibility often result in increased bank erosion and lateral stream migration, especially on the outside of meandering river bends (Simon et al., 1999; Howard, 1984). The cross-valley swinging and down-valley sweeping of meanders initiates vegetation succession, further diversifying biologic communities (Salo et al., 1986).

A debris flow can be an extreme event that would enlarge and alter a stream channel by scouring its banks and depositing unconsolidated material to the bed once flow slows down. Intergranular friction and collisions loosen and pull streambank particles into the stream and will eventually become part of the debris flow (Iverson, 1997).

One of the greatest resisting forces to streambank erosion lies in the ability of riparian vegetation to hold bank material with roots. Bank material composition is variably intertwined with riparian vegetation. Roots are weak in compression but strong in tension. Conversely, soil is strong in compression but weak in tension (Pollen, 2007). Thus, roots produce a reinforced matrix in which stress is transferred to the roots during soil loading (Thorne, 1990). Thorne (1990) further explains that this is similar to the reinforcement of concrete structures by steel and fiberglass. In addition to high rooting depth, a high rooting density can help the streambank resist erosion. Smith (1976) found that meadow grass and scrub vegetation increased the erosion resistance of streambanks by a factor as great as 20,000. Trimble (1997) also found that grassy reaches had the ability to store about 2100 to 9900 m^3 more sediment per kilometer than forested reaches.

Trees tend to have less rooting density but greater rooting depth while herbaceous vegetation have higher rooting densities but a shallower rooting depth. It is suggested that root density at the bank toe is more critical for bank stability since hydraulic shear stress increases with stream depth (Gregory and Gurnell, 1988). As a consequence, undercutting of grassy banks and nonforested banks is commonly observed (Davis-Colley, 1997; Lyons et. al., 2000).

Zimmerman et at. (1967) found that headwater streams are significantly narrower and smaller under grassy sod cover and vice versa for forested settings. They explain that vegetation influences channel form by altering the roughness and shear strength of bed and banks. Forests supply much woody debris to channels and may focus shear stress on banks. Grassy areas have a tendency to “build” stable stream banks by trapping and storing fine suspended sediments. Davies-Colley (1997) tested the hypothesis in New Zealand by observing channel widths that were measured upstream and downstream of "transitions" from native forest to pasture in 20 streams of different size in marginal ranges of the Waikato Basin. Small streams (catchment area <1 km^2, width in forest

<2 m) were found to be half the width in grassy reaches as in forest. The degree of channel narrowing decreased as stream size increased and was minimal in large streams (catchment area >30 km^2, width in forest >10 m).

Coring studies have also shown that in forested areas, the root density on the bank face may be almost an order of magnitude higher from cores taken 30 cm from the top edge of the bank (Wynn et al., 2004). Additionally, vegetative liter cover and roots reduce frost susceptibility and slow weathering and weakening (Bohn, 1987). Vegetation can readily be manipulated through anthropogenic activities.

In a fluvial system out of equilibrium (e.g., removal of riparian vegetation), streambank erosion may have a domino effect on its morphology. Assuming no major changes in discharge, increased streambank erosion increases width-depth ratio. Increased width-depth ratio increases the cross sectional area. From the basic continuity equation:

$$Q=VA$$

where Q is discharge, V is velocity, and A is cross section area, the effect of increasing area when discharge remains the same is a decrease in velocity will have to decrease (Potter and Wiggert, 2002). With reduced velocity, the capacity to suspend and transport bedload sediment decreases and may lead to deposition and aggradation (Bartholow, 2000) and affect aquatic habitat (Rosgen, 1996). Excess suspended sediment reduces light penetration in the water. In turn, photosynthesis and oxygen is reduced and so on.

Evaluation of Streambank Erosion (Measurement and Prediction)

Many techniques measure streambank erosion. Lawler (1993) and Zonge et al. (1996) describe several field methods in a comparison study: 1) sedimentological evidence, 2) botanical evidence, 3) historical sources, 4) planimetric resurvey, 5) repeated cross-profiling, 6) erosion pins, and 7) terrestrial photogrammetry. Sedimentological evidence, botanical evidence and historical sources are long-term evaluation methods and focus on channel and floodplain development over time. These methods require intensive study and often focus on climatic conditions to evaluate rates of change, growth, and accumulation of material. Planimetric and repeated cross-profiling are labor intensive and intermediate in time scale. They involve recording two- or three- dimensional forms of the river channel at various intervals over time. Erosion pins and terrestrial photogammetry are efficient and can be accomplished over a short time frame. These types of investigations emphasize processes, not just rates. The researcher can relate meteorological events and types of management to amounts of erosion.

A GIS-based technique was developed for estimating streambank erosion rates using statistical relationships between lateral erosion rates and watershed characteristics such as curve number, grazing animal density, topographic slope, soil erodibility, and degree of urban development (Evans et al., 2003). An algorithm was then developed to reflect these relationships and was incorporated into a larger model predicting total sediment yield for an entire watershed. Comparisons between this total sediment yield and observed sediment yield from twenty-eight watersheds in Pennsylvania produced similar rates. However, total sediment yields, not actual amounts of streambank erosion were measured, leading to an uncertainty about the accuracy of the streambank erosion predictions.

CONCEPTS (Conservational Channel Evolution and Pollutant Transport System) is a model developed by the National Resource Conservation Service (NRCS) and National Sedimentation Laboratory, that dedicates a section for streambank erosion prediction (Langendoen et al., 2001). However, several assumptions or limitations in this model make it inappropriate for use in evaluation of wildland streambank erosion (Langendoen, 2000). Limitations of the CONCEPTS model for use in natural systems include requirements for: straight channels or very low sinuosity; homogenous cohesive bank material; slab or planar type of bank failure; and cross sectional channel geometry which is like a pipe, box, or trapezoid. Natural channels range in sinuosity; some are pool-riffle systems while others are step-pool systems; bank material is rarely homogenous; and stream channel shapes are rarely like a pipe, box, or trapezoid. Additionally, this model and the GIS-based model do not include a variable for vegetation which can play an important role in controlling streambank erosion (Pollen, 2007; Wynn et al, 2004).

Winward (2000) estimated streambank erosion hazard ratings based on the composition of riparian vegetation at the “greenline,” where the “first perennial vegetation forms a lineal grouping of community types near the water’s edge,” usually at or slightly below the bankfull stage. Stability is rated at the community-type level, based on rooting capacity to resist erosion. Burton et al. (2007) has modified this method to rate dominant species.

Several attempts have been made at establishing bank erosion data and predictions using field-intensive and empirically-derived relationships with erosion pins. This work was developed by Dave Rosgen of Wildland Hydrology and has taken place mainly east of the Rockies (Rosgen, 2001; Eps et al., 2004; Harmel et al., 1999). Each data set differs as a function of geologic substrate and local geomorphology. The Rosgen studies were located in glaciated-vulcanized and sedimentary-metamorphic settings; the study performed by Eps et al. (2004) was in a sandstone-siltstone-shale area; and the study performed by Harmel et al. (1999) was located in an area of limestone-chert substrate. All studies except Harmel et al. (1999) have shown good results (e.g., regression values (r^2) such as 0.92 and 0.84). The study completed by Harmel et al. (1999) in northeast Oklahoma had high variability and did not yield good regression scores. However, it must be noted that the data were compiled for flows up to three times bankfull discharge**.** The other two studies measured streambank erosion for events at or around bankfull flows. So far, erosion prediction methods from Wildland Hydrology are only applicable for bankfull discharges. Bankfull flows maintain and shape a stream's morphology (Leopold et al., 1964). Analysis of over 40 years of gage station data throughout North America indicates a range in bankfull return interval from 1.05-1.8 years (Rosgen, 2006). According to Dunne and Leopold (1978), "The bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphologic characteristics of channels". Wolman and Miller (1960) observed that large catastrophic floods may transport large amounts of sediment, cause great erosion and incise channels. However, "they occur so rarely that their cumulative effectiveness is less than that of the smaller and more frequent floods (Wolman and Miller, 1960). This is mainly true in areas with perennial and intermittent flow. The same however, cannot be said for ephemeral systems in arid regions (Wolman and Gerson, 1977).

Justification of Study

The US Environmental Protection Agency has consistently listed sediment as a leading cause of water quality impairment in rivers, streams, and lakes, costing $16 billion annually (USEPA, 2008). Numerical water quality standards for clean sediment have been hard to establish due to the evolving nature of landscapes. While many management decisions aim to prevent streambank erosion, not all may be based on sound science.

Particularly for the US Forest Service (USFS), wildfire season often means making management decisions quickly. Burned Area Emergency Response (BAER) teams comprised of scientists and managers assemble during or immediately after a fire to help evaluate the severity of watershed impairment. Hydrologists predict post fire flows while soil scientists predict soil losses (Fish and Wildlife Service, 2004). Yet, streambank erosion under these conditions is rarely evaluated and often ignored (Kaplan-Henry, 2009).

Since implementation of the BAER program in 1974, effectiveness of restoration/mitigation projects has not been systematically tested or validated (Neary et al., 2000). Many BAER team evaluation techniques may not apply locally. After the 2002 McNally Fire that burned roughly 150,000 acres in the Kern River Basin, Sequoia National Forest hydrologists relied on discharge equations from *Magnitude and Frequency of Floods in California* (Wannen and Crippen, 1977) for ungaged streams.

However, extensive local studies consistently show discharge yield at least an order of magnitude higher than predicted (Kaplan-Henry 2007). This prompted the Sequoia to locally develop and use regional discharge curves. The Sequoia would also like to examine other aspects of the BAER program to improve management decisions.

A current recommended tool for soil loss estimation is the Universal Soil Loss Equation. USLE predicts soil loss from sheet or rill erosion on a single slope and does not account for gully, wind, or tillage erosion (Hilborn and Stone, 2000). A more recently introduced method is the Erosion Risk Management Tool, or ERMiT. This model requires inputs such as climate, soil texture, soil-rock content, hillslope, gradient and horizontal length, soil burn severity class and range/chaparral pre-fire plant community (Robichaud et al., 2007). Both USLE and ERMiT models predict hillslope erosion not streambank erosion.

It seems illogical to use tools developed for upland soil erosion such as USLE or ERMiT to predict streambank erosion. However, no other tool has locally predicted streambank erosion and often it is estimated or ignored.

Thus, in conjunction with Sequoia National Forest, this project locally tested a streambank erosion prediction tool. If successful, this tool can quickly inventory and evaluate channel stability, assess priorities for restoration, and provide information for riparian habitat management. Future research may build upon this BEHI/NBS baseline data to study longer-term streambank erosion rates, erosion after fire, or the efficacy of various restoration techniques to stabilize streams and reduce bank erosion.

Chapter 2

Prediction of Annual Streambank Erosion for Sequoia National Forest, California

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(Formatted for submission to Earth Surface Processes and Landforms)

Abstract

The Sequoia National Forest needs to understand mechanisms and rates of streambank erosion to evaluate management issues and post-wildfire effects. This study used Bank Erosion Hazard Index (BEHI) methods developed by Rosgen (2006, 2001) for monitoring and predicting streambank erosion. Measurements of bank erosion over a year were evaluated using BEHI and estimates of Near Bank Stress (NBS). BEHI evaluates bank susceptibility to erosion based on bank angle, bank and bankfull height, rooting depth and density, surface protection, and stratification of material within the banks. NBS assesses energy distribution against the bank measured as a ratio of near-bank maximum depth to mean bankfull depth. BEHI with NBS were good to fair indicators of streambank erosion at riffle features during a year with peak flow at or near bankfull conditions. Individual BEHI variables and several other physical variables (e.g., elevation, drainage area, and vegetation) significantly correlated with streambank erosion but had low predictive power (i.e., r^2 0.0007 to r^2 0.1809) indicating inconsistency in driving variables among locations. This indicates that no single variable controls streambank erosion. A low r^2 (0.23) from multiple regression analysis suggested that variables other than those of BEHI affect streambank erosion. Bank angle had the lowest predictive power for erosion while rooting depth had the highest.

Introduction

Early pioneering work acknowledges streambank erosion as a natural and fundamental process in the development and maintenance of stream channel morphology

(Leopold et al., 1964). Most erosion studies have focused on hillslope erosion (Rosgen, 2001). Several observational studies concluded that streambank erosion can be a major contributor to the total sediment yield (Eps et al., 2004; Rosgen, 2001; Sekely et al., 2002; Simon et al., 1996; USACE, 1983), social and economic impacts (USEPA, 2008; UNEP, 2007; Haque and Hossain, 1988), ecological problems (Wood and Armitage, 1997) or benefits (Graf, 2005; Wyzga and Zawiejska, 2005). Humans can influence processes and rates of streambank erosion. Significantly greater streambank erosion and disturbance may occur in poorly managed grazed areas than in excluded areas (Trimble, 1994; Kauffman, et al. 1983) or well managed areas (Wyman et al., 2006; Platts, 1991; Kauffman and Krueger, 1984). Lyons et al. (2000), Trimble (1997) and Murgatroyd and Ternan (1983) suggested that conversion from grasslands to forests led to accelerated streambank erosion. Alterations (or removal) of riparian vegetation changed streambank resistance to erosion by its roots. Yet efforts to prevent and stop streambank erosion through channel bank infrastructure fail to understand streambank erosion mechanisms and attributes (Florsheim et al., 2008).

Streambank erosion occurs within the context of the area’s underlying geology and climate (Natural Resources Sciences, 2006). It is initiated by three integrating mechanisms: weathering and weakening, fluvial erosion, and mass-wasting (Luppi et al., 2008; Jha et al., 2005; Abernethy and Rutherfurd, 1998). Riparian vegetation intertwining bank material with roots provides one of the greatest resisting forces to streambank erosion. Roots are weak in compression but strong in tension. Conversely, soil is strong in compression but weak in tension (Pollen, 2007). Well rooted soil thus produces a reinforced matrix which transfers stress to roots during loading (Thorne, 1990).

Due to the evolving and complex nature of landscapes, generalized predictions of streambank erosion are challenging. Severe limitations of current models have restricted their use in wildland stream systems. Unrealistic assumptions include: straight channels or very low sinuosity, homogenous cohesive bank material, slab or planar type of bank failure, and an instream cross sectional channel shape approximated by a pipe, box, or trapezoid (Langendoen, 2000). Additionally, some do not include a variable for vegetation which can play an important role in controlling streambank erosion (Pollen, 2007; Wynn et al., 2004). A GIS-based prediction model using statistical relationships between lateral erosion rates and watershed characteristics included streambank erosion in the calculation of total sediment yield (Evans et al., 2003). Observed sediment yield correlated with predictions from twenty-eight watersheds in Pennsylvania. However, streambank erosion was not measured leaving uncertainty about the streambank erosion predictions.

Winward (2000) estimated streambank erosion hazard ratings based on composition of riparian vegetation at the “greenline,” where the “first perennial vegetation forms a lineal grouping of community types near the water’s edge,” usually at or slightly below bankfull stage. He rated stability at the community-type level, based on rooting capacity to resist erosion. Burton et al. (2007) modified this method to rate by dominant species.

Methods by Rosgen (2007, 2001) predict bank erosion and used field-intensive and empirically-driven relationships measured with erosion pins. Annual predictions for streambank erosion were successful in Colorado and Wyoming (i.e., r^2 values 0.92 and 0.84, respectively) within low-gradient meandering or braided streams (C & D types [Rosgen, 1996]). Physical factors used to predict streambank erosion include: bank height to bankfull height ratio, rooting depth and density, bank angle, surface protection and the amount of stress on banks (Rosgen, 2001).

This study replicated these methods to predict streambank erosion in a geographic area not previously tested. Previous studies using these methods did not confirm whether BEHI variables were statistically important to the model. This study analyzed BEHI and additional variables that may influence streambank erosion such as greenline vegetation and other characteristics such as drainage area, elevation and forested versus meadow sites.

Study Area

The Sequoia National Forest in California lies in the Sierra Nevada Physiographic Province and is largely underlain by granitic and metamorphic rocks.

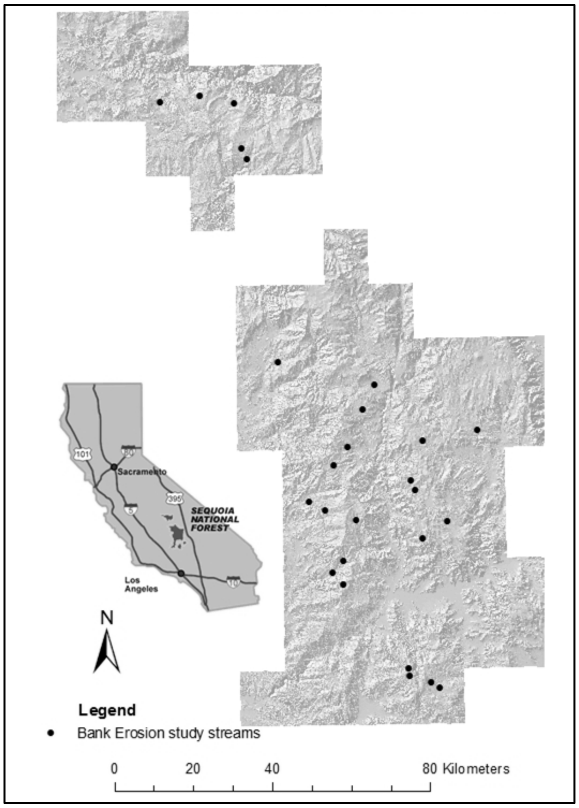

Figure 1. Map of study sites in Sequoia National Forest.

The Sierra Nevada fault (now inactive) brought the range to their present height about 3 million years ago. The crest of the range was heavily glaciated during ice ages within the last one million years. Glaciers extended down to the headwaters of the Little Kern River. The mountain range runs in a northwesterly direction and turns southwest at the southern end. Deeply incised canyons (generally less than 4% slope) drain the well watered western slope while the eastern slope lies in a rain shadow and has shorter steeper canyons. Many of the streams resulted from influence of structural contact zones, faults, joints, and colluvial-alluvial deposits. They tend to have narrow valleys with limited development of a wide floodplain and as a result are moderately entrenched. Mean annual precipitation at the study sites ranges from 35 to 129 cm, with 79 to 90 percent falling between November and April. Annual flow generally peak in late spring, although weather phenomenon such as El Nino may affect this timing. In such case, a rain on snow event would cause peak flow to occur earlier in the year. Additionally, post fire flows during late summer months due to localized thunderstorms may cause large local flood events. Elevations of the study sites range from 670 m to 2530 m. (Hanes et al., 1996). Refer to Table 1 for site specifics.

Table 1. Streams used for streambank erosion study.

Creek	Soil Name	Elevation (m)	Drainage Area (km^2)	Forest	Meadow
Bear Creek at Greenhorn	Holland	1720	2.62	X	
Bear Creek at Scicon	Tollhouse	662	54.78	X	
Bull Run Creek	Wind River	1958	6.92		X
Cannell Creek	Dome	2195	14.24		X
Capinero Creek	Bohna	1253	24.60	X	
Cedar Creek	Auberry	1427	9.48	X	
Cedar Creek at Alder Ck. Cmpg	Auberry	1172	26.94	X	
Clear Creek at Burton Mill	Wind River	2060	6.29	X	
Clear Creek at Brown Meadow	Dome	2242	2.28		X
Converse Creek	Shaver	1806	4.82	X	
Deer Creek	Bohna	919	43.07	X	
Fish Creek	Dome	2207	97.44	X	
Freeman Creek	Chaix	1704	20.82	X	
French Gulch	Monache	2049	3.52	X	
Holby Creek	Chaix	2095	12.07	X	
Kelso Creek	Monache	1874	38.69		X
Last Chance	Holland	1766	13.73		X
Parker Meadow Creek	Dome	1878	11.27		X
Poison Creek	Dome	2280	1.61		X
Salmon River	Monache	2220	67.91		X
Sampson Creek	Holland	923	26.34	X	
Stony Creek	Cagwin	1989	38.18	X	
Taylor Creek	Siskiyou	2142	9.06	X	
Tornado Creek	Chaix	1791	4.66	X	
Trib. to Woodward Creek	Cagwin	2150	3.60	X	
Trout Creek	Cagwin	2528	11.14	X	

Within the forest, most streams have gradients greater than 2%. Rosgen B stream type (2-4 %) associate with valley type II; moderately steep, gentle-sloping side slopes often in colluvial valleys. Steeper Rosgen A (4-10% gradient) stream types generally occur in valley type I; steep, confined, “V” notched canyons with rejuvenated side slopes. A few are intermittent, low gradient, meandering Rosgen C (<2% gradient) and E (<2% gradient) channel types (both valley type II) in mountain meadows that transition to Rosgen B channels downstream (Kaplan-Henry, 2009).

The Forest has established Stream Condition Inventory (SCI) (Frazier et. al., 2005) reaches on over 60 streams to monitor downstream aquatic conditions pre/post management activities. Twenty six of these reaches were used in this study, each containing 1 to 6 study banks. They were chosen to include as many wadeable streams as possible within the allotted study timeframe. Forty to fifty percent of the SCI reaches in each major watershed (i.e., Deer, Kern, and Kaweah) were used in the study. One hundred study banks located at riffle features included a variety of erodibility factors.

Baseline data were collected in 2008 and 2009. Thus, several sites have two years of monitoring data while the remainders have one. The 2008-2009 season had flows that were about 65% of bankfull discharge while the 2009-2010 season had flows up to bankfull discharge according to the Onyx Gage station (11189500) monitored by the US Geological Survey. Figure 2 shows the peak flow for the 2009-2010 season and represents a typical hydrograph for the region.

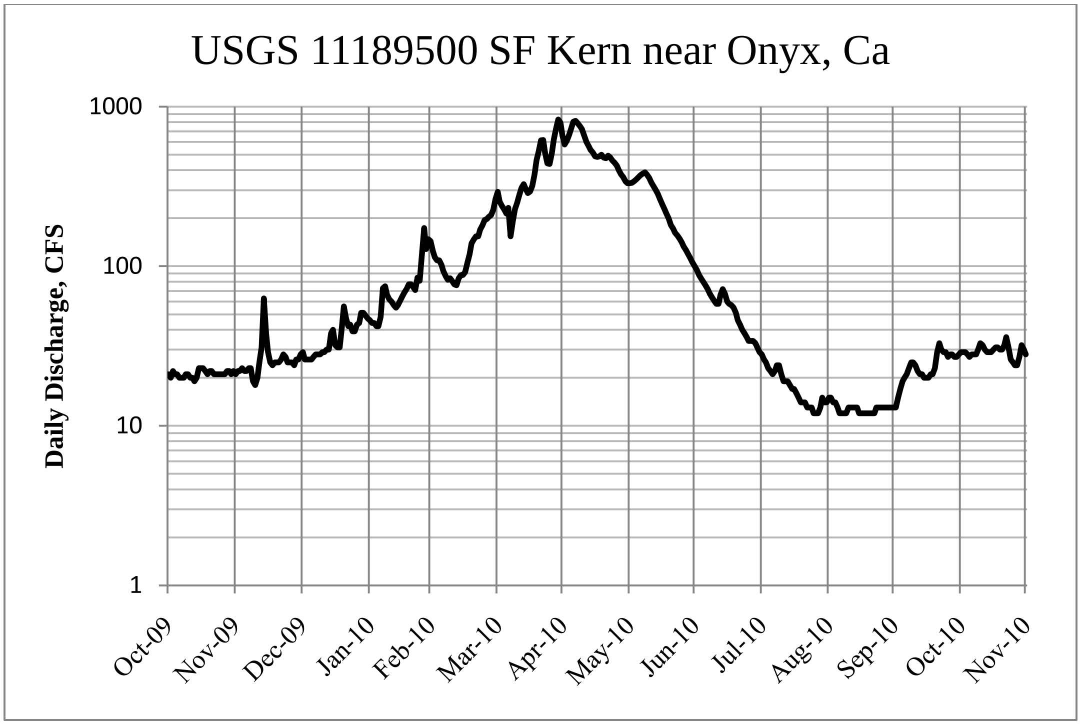

Figure 2. Hydrograph for 2009-2010 season in Kern River (gage 11189500).

Methods

Field Setup

Field setup and bank measurements used near bank stress (NBS) and bank erosion hazard index (BEHI) methods (Rosgen 2006 and 2001). Materials needed per bank study were rebar (rigid and smooth), rebar caps, sledgehammer, measuring rods, rod levels and line levels. A toe pin (19 mm thick rebar, 1 meter long) was vertically hammered into the stream bed adjacent to the bank of study while smooth rebar (8.5 mm thick, 1 meter long) were horizontally hammered into study banks (Figure 2). Bank pins visually indicated bank erosion and guided survey accuracy by providing a “line” from toe pin to a top pin (13 mm thick rebar, 2/3-1 meter long) hammered vertically above the study bank. Bank pins were not placed where bank material was not uniform, (e.g., mixture of cobbles, gravel and sand) since pins could cause an increase in bank erosion. In such cases, only the toe and top pin were used.

Field Measurements

Bank Profiles

Bank profiles were taken of the study banks at bank pin sites. A surveying rod was placed above the toe pin and a rod level was used to keep the rod vertical while distances to the bank were measured using a pocket rod. A line level was tied to the pocket rod to ensure it was parallel to the ground (Figure 3). Horizontal and vertical measurements (to 1/100 meter) were repeated in subsequent years to estimate annual erosion rates.

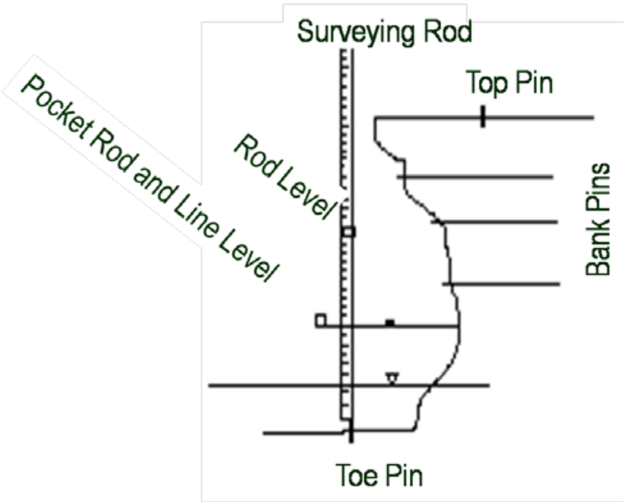

Figure 3. Measurement of Bank Profile using surveying rod, pocket rod, and line level.

Bank Erosion Hazard Index

The Bank Erosion Hazard Index (BEHI) evaluates the susceptibility of channel banks to erosion, using a process-integration approach that considers multiple processes of erosion (e.g., surface erosion, fluvial entrainment, freeze/ thaw cycles, wetting/drying cycles, animal activity or mass erosion such as slumping, although possibly not debris flows). Erosion risk was estimated for individual BEHI variables and collectively they are used to estimate streambank erosion rates. Measurements included: study bank height, bankfull height, root depth, root density, bank angle, surface protection, bank material adjustment and stratification adjustment. Table 2 highlights the effect of each variable on erosion.

BEHI variables are defined as follows:

-Study Bank Height (m): Measured from the top of the toe pin to the top of the study bank (i.e., base of visible top pin). Placement of top pin therefore influenced measured bank height. So, care was taken to place the top pin close enough to represent bank height and yet far enough away to persist in place after bank erosion.

-Bankfull height (m): Measured from the top of the toe pin to the bankfull elevation. Leopold and Wolman (1957) suggested that the bankfull stage is the elevation of the active floodplain. Bankfull was identified by deposition/elevation features and/or a change in vegetation (Leopold et al., 1995). Bankfull width was then verified in the field with regional curves developed by the Sequoia National Forest to correspond to drainage area (Kaplan-Henry, 2007).

-Root Depth (m): Roots help maintain internal soil strength and can reduce fluvial entrainment from individual particle detachment. If roots do not extend to the full bank height, undercutting of banks can cause bank collapse. Measurements were taken from the top of the study bank down through the average extent of roots exposed from banks.

The measurement was neither to the longest nor shortest exposed root, but to where the majority extend.

-Root Density (%): The method Rosgen (2006, 2001) used for rooting density is simply an ocular measurement taken at the bank face. It is evaluated as the percent of the soil composed of roots through the root depth. In addition to taking an ocular measurement, a destructive sample using a soil auger was taken at the bank face downstream of the study site where vegetative and rooting conditions remained the same.

-Bank Angle (°): Bank angle was measured as an average slope from water surface to top of bank. The steeper the bank (as measured from a horizontal plane in degrees), the more susceptible streambanks are to mass erosion processes (e.g., planar failures, cantilever collapse etc). It has been suggested that stability is attained when the bank is at an angle of repose (Carson and Kirkby, 1972). An undercut bank would have an angle $\geq 90^o$.

-Surface Protection (%): The lack of surface protection exposes a streambank to the agents of erosion. The presence of vegetative cover and roots reduces frost susceptibility and thus slows weathering and weakening processes (Bohn, 1987). Sod mats, willows, large woody debris and bedrock are types of surface protection measured as a percentage within the study bank surface area.

-Bank Material Adjustment: This variable adjusts for a streambank composed of material more or less susceptible to erosion. Bank material made up of a composite mix of gravels and sand would increase the BEHI score as such materials are considered more erodible. Comparison studies have shown that soil with cohesive properties (e.g., soils with clay) tend to withstand increased critical shear stress significantly compared to noncohesive sediments (e.g., sand) (Nalluri and Alvarez, 1992). The model adjusts the overall BEHI rating by adding points with the presence of sand or sand-mixture and subtracting points with the presence of bedrock, boulders and cobbles. No adjustments are made for silt or clay.

-Stratification Adjustment: A streambank with stratified layers is adjusted for this model by adding points to the overall BEHI score. Layers can concentrate water and create weak spots meanwhile stability of the bank can be affected by the weaker strata prone to slip failures or disintegration (Rosgen, 2006; Gutub et al., 1995).

Table 2. Summary of BEHI variables' affect on erosion.

BEHI Variable	Effect on Erosion
Study Bank Hight/ Bankfull Height	Measurement of incision. An incising stream may eventually lower its water table and prevent roots from accessing water. Also, higher banks put more gravitational stress on soil cracks. A stream not incised has better access to its floodplain for energy dissipation during large flows.
Root Depth/ Bank Height	Roots that extend down to the base of the bank reinforce the whole bank structure. This comes from the idea that roots and soil create a reinforced matrix. Roots extending down to the base of the bank may prevent undercutting and cantilever failure.
Weighted Rooting Density	Larger rooting densities have a tendency to "build" stable streams by trapping and storing sediments. Reinforcing fiber in the rooted part of the bank works to prevent tension cracks and make soil particles cohesive with root hairs or exuded chemicals.
Bank Angle	Steep banks increase the relative magnitude of the vertical or gravitational component of shear and overhanging banks may break as a cantilever.
Surface Protection	Vegetative/bedrock cover helps protect and slow banks from erosion and weathering.
Bank Material Adjustment	Soils of different particle size distribution are differentially erodible bedrock, boulders and cobbles are less likely to erode while sands having less cohesion will be more prone to erosion.

Stratification Adjustment	Layers in soil matrix can concentrate water, create weak layers, and provide weak zones associated with slip failures.

The following figures (4 and 5) show examples from both low and extreme) overall BEHI.

Figure 4. Low BEHI example showing the combined influence of a low bank well vegetated by stabilizing plants.

Figure 5. Extreme BEHI example showing the erosion likely at high banks with weak dehydrated vegetation.

Near Bank Stress

Near Bank Stress (NBS) is the assessment of energy distributed against the bank. There are seven methods suitable for determining NBS selection of approach is based on the desired precision and time available in the field (see Table 3).

Table 3. Level of accuracy with various NBS methods.

Method	Level of Prediction
Field Observations	Reconnaissance

Ratio of Radius of Curvature and Bankfull Width	General/bank specific
Ratio of Pool Slope and Average Slope	General/reach scale
Ratio of Pool Slope and Riffle Slope	General/reach scale
Ratio of Near bank max-depth and Bankfull Mean depth	Detailed/bank specific
Ratio of Near bank shear stress and Bankfull shear stress	Detailed/bank specific
Velocity Gradient	Validation/bank specific

For this study, NBS was estimated using the ratio of near-bank maximum depth to bankfull mean depth (method 5, detailed/bank specific prediction) (Rosgen, 2006). A cross section was measured at each bank study site. To ensure accuracy, regional curves (Kaplan-Henry, 2007) predicting bankfull width by drainage area were used to verify field observations of bankfull width and depth. “Near bank maximum depth” was observed in the 1/3 of channel width closest to the bank of interest (figure 6).

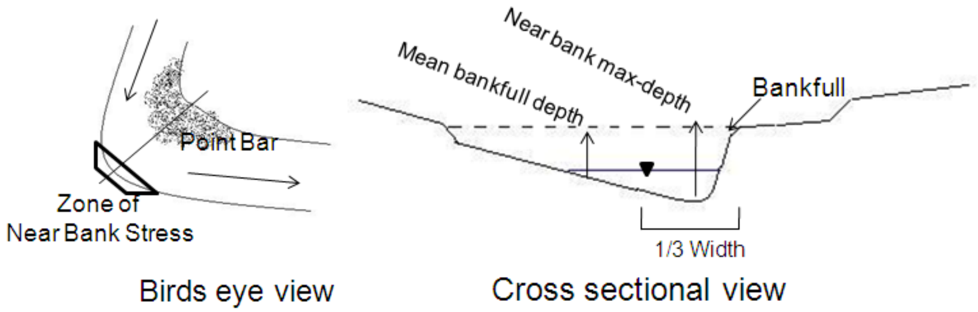

Figure 6. Illustration of near bank max-depth for right bank of interest; bankfull width divided into thirds.

The ratio was then converted to a NBS value (0-3) and rating (i.e., very low to extreme). For creation of the prediction graph, the NBS value was multiplied by two.

Data Adjustments

Although 100 bank sites were monitored during this study, five were deemed unfit to be included in all or some analyses. Stark Creek is ephemeral while the remaining study sites are perennial or intermittent. Ephemeral channels behave differently and often do not have riparian vegetation (Daniels and Gillman, 1997; Reid and Larrone, 1995).

One toe pin could not be relocated (Burton Mill, station 4) and bank pins were not inserted there due to bank fragility. Without an azimuth, a bank profile could not be accurately remeasured.

Resurvey of two bank sites (Burton Mill, station 6 and Bull Run Creek, station 1) showed excessive slumping prohibiting detection of erosion. Moreover, measurements showed a net gain of soil and bank material.

Lastly, one bank (Brown’s Meadow, station 3) did not reveal any streambank erosion. Because log-graphs cannot have zero values, this point was not used in creation of streambank erodibility graphs. However, the point was included in the statistical analysis.

Data Analyses

Graphs of predicted erosion based on BEHI and NBS were made as in past studies (figures 8-11). Using the software Rivermorph (Rivermorph, 2009), observed data from study banks were overlain with each other to calculate a difference in area and average vertical distance (figure 7).

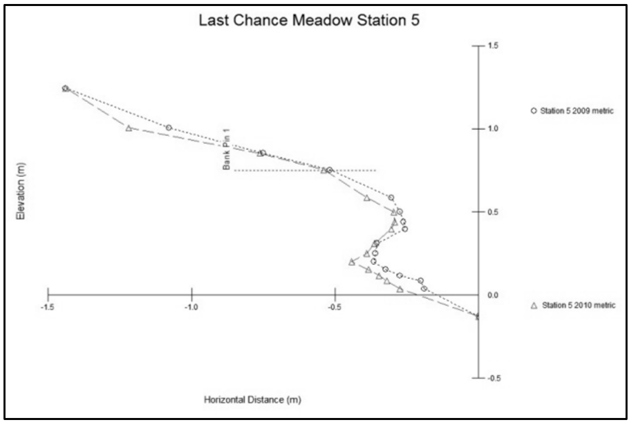

Figure 7. Examples of overlain banks.

BEHI were grouped by their rating (Figure 8) and plotted against NBS and annual erosion rates.

The general linear model (GLM) in Statistical Analysis System (SAS), an analysis of variance general purpose procedure (SAS Institute, 1996) was used to calculate correlations between BEHI, NBS and annual erosion rates. In addition, data from the field and Sequoia National Forest's Soil Survey were used to determine if elevation, drainage area, forest versus meadow may have affected streambank erosion rates. A multiple regression analysis rated BEHI variables and their ability to predict streambank erosion.

Root volume/unit volume of soil samples were estimated from extracted oven-dried roots using volumetric water displacement in a graduated cylinder. Overstory tree species were recorded in the field but not the distance from base of the tree to the streambank. High resolution photographs were taken for further identification of streambank herbaceous species composition. Using Winward (2000) and/or Burton et al. (2007), the bank stability of each site was estimated based on the vegetation type, with each site rated from one to ten, with ten being most resistant to bank erosion.

Results and Discussion

BEHI and NBS were statistically correlated to erosion (p=0.032). Low BEHI had a r^2 value of 1. However, there were only three points and additional sites are needed to understand variance in the relationship.

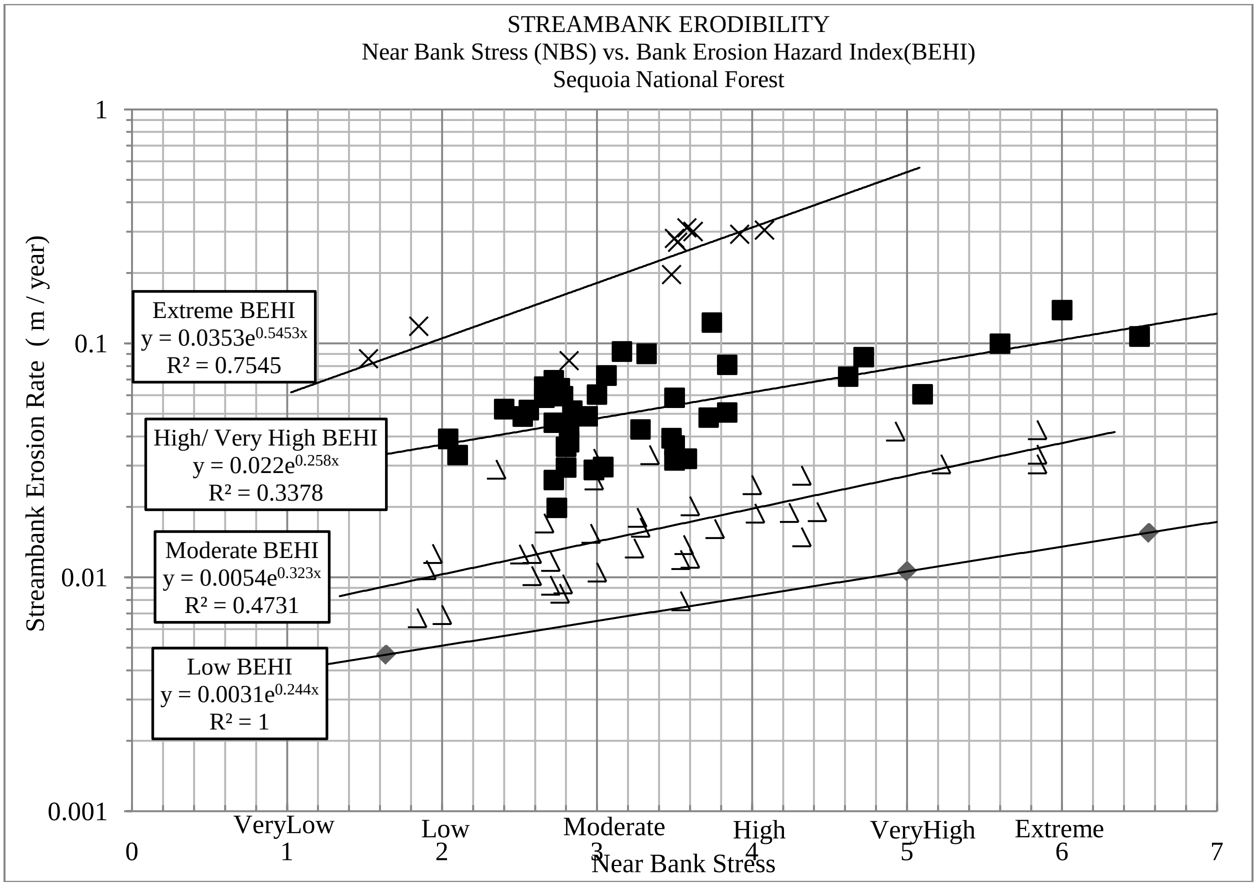

Figure 8. Relationship of BEHI and NBS to predict annual streambank erosion for Sequoia National Forest.

Even though moderate and high/very high BEHI/NBS erosion correlations were not high, BEHI ratings clearly clustered around BEHI trend lines.

BEHI/NBS graphs from Colorado and from Yellowstone National Park (Rosgen, 2006) showed clustering as did a replicate study in Arkansas (Eps et al., 2004). A replicate study in northeastern Illinois (Harmel et al., 1999) resulted in high variability and low correlation. However, it was conducted during a year with flows three times bankfull discharge. So, these erosion prediction methods by Rosgen (2006) may only apply during years with peak flows at or near bankfull. Analyses of over 40 years of gage station data throughout North America indicate a range in bankfull return intervals from 1.05-1.8 years (Rosgen, 2006). “The bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphologic characteristics of channels” (Dunne and Leopold, 1978). From observations by Wolman and Miller (1960), they acknowledge that large catastrophic floods may transport large amounts of sediment, cause great erosion and incise channels. However, “they occur so rarely that from the standpoint of transport their over-all effectiveness is less than that of the smaller and more frequent floods” This is mainly true in areas with perennial and intermittent flow. The same however, cannot be said for ephemeral systems in arid regions (Wolman and Gerson, 1977).

Three major watersheds within the Forest (i.e., Kern, Kaweah, and Deer) exhibited differences in hydrology (primarily in drainage area and discharge), so bank erosion prediction graphs were made for each (figures 9 though 11). Correlations improved in graphs by watershed due to reduced variations. Yet ANOVA testing indicated that there was not enough difference (p=0.2688) to warrant analysis by watershed.

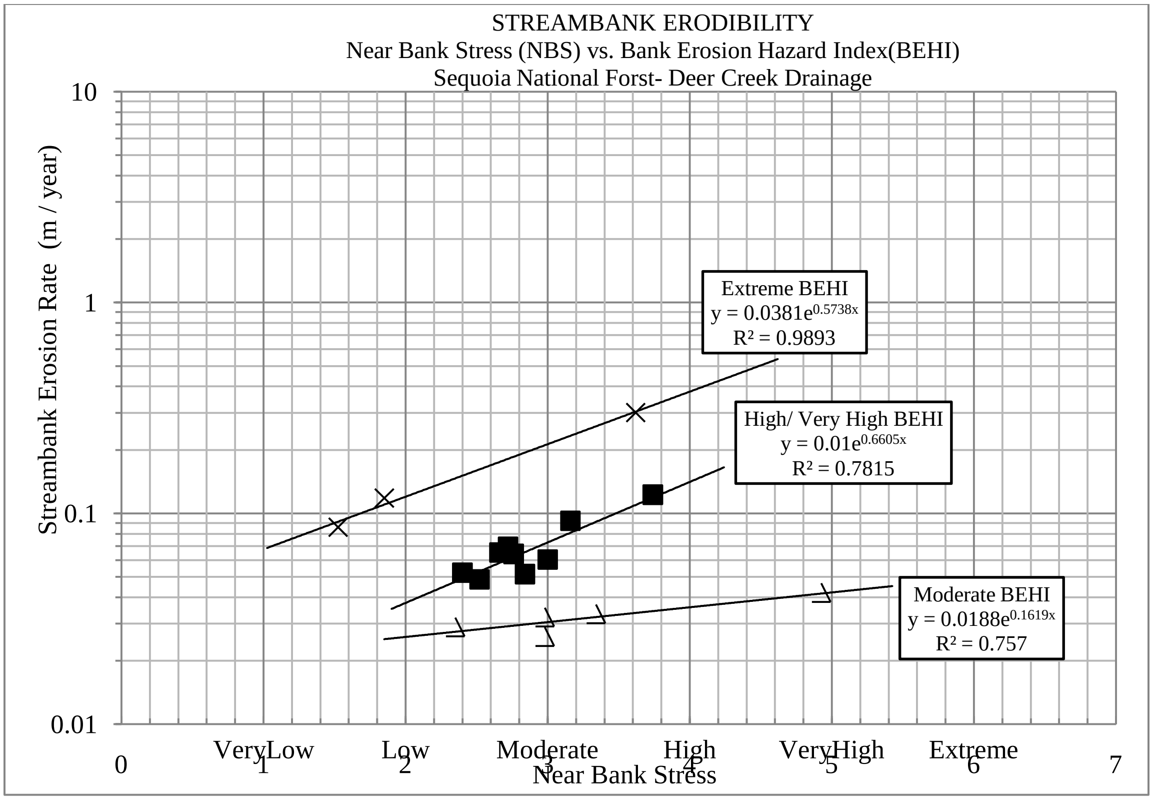

Figure 9. Streambank Erosion rates from Deer Creek Watershed.

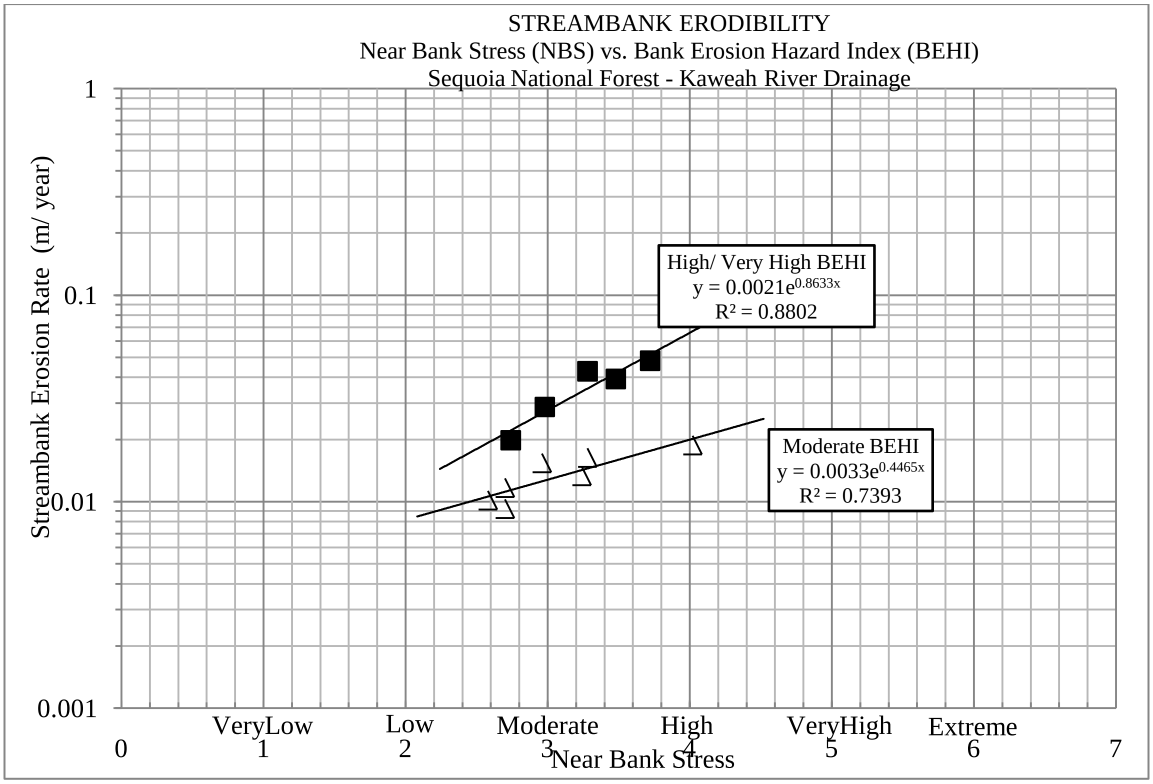

Figure 10. Streambank Erosion rates from Kaweah River Watershed.

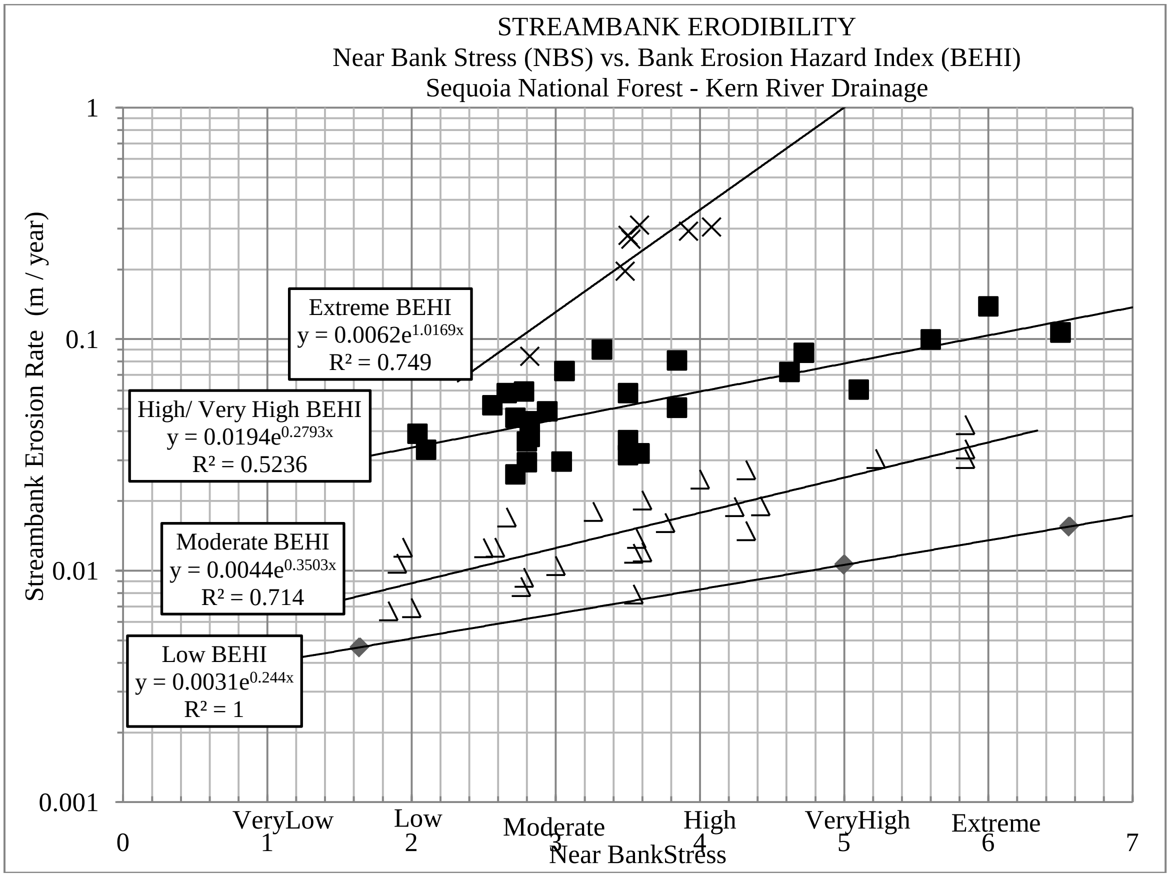

Figure 11. Streambank erosion rates from Kern River Watershed.

Each BEHI variable significantly correlated with streambank erosion: bank angle ($p<0.0001$, $r^2=0.0116$); surface protection ($p<0.0001$, $r^2=0.1809$); root density ($p<0.0001$, $r^2=0.1172$); rooting depth ($p=0.0035$, $r^2=0.0023$); and study bank to bankfull height ratio ($p=0.0011$, $r^2=0.0184$). However, each r^2 value was low, suggesting that no single factor controls streambank erosion. As with many complex natural systems streambank erosion is a result of many integrated variables.

The influence of BEHI variables and NBS on erosion is depicted in the following multiple regression equation:

$$Y= 0.2648 – 0.0547A + 0.0126B + 0.00114C - 0.00067313D – 0.000463E+ 0.000414F$$

where Y is rate of erosion (m/year), A is the rooting depth, B is near bank stress, C is study bank height to bankfull height ratio, D is the degree of surface protection, E is rooting density and F is the bank angle. Bank angle was shown to have the weakest effect in this model while rooting depth had the strongest. Negative variables indicated that as rooting depth, surface protection, and rooting density increased, erosion decreased as expected. The multiple regression analysis yielded a low r^2 of 0.2578 (adjusted r^2 = 0.206), indicating that variables other than those tested influenced streambank erosion.

Contrary to past studies (Lyons et al., 2000; Trimble, 1997; Murgatroyd and Ternan, 1983), there was no statistical difference in erosion rates between forested sites and meadow sites (p=0.2833) as indicated in Figure 9.

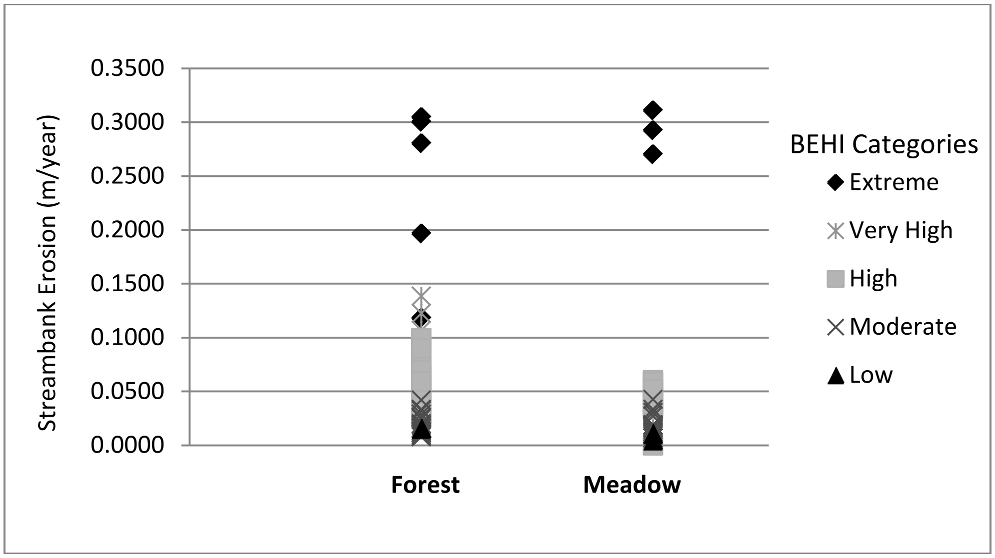

Figure 12. Comparison of streambank erosion rates in forested and meadow settings.

There appeared to be a bimodal distribution of erosion rates in meadow sites whereas forested sites were more variable (Figure 12). The bimodal distribution may have resulted from three meadow sites reaching a “threshold” of incision. The three points had bank height to bankfull ratios approaching or exceeding two. In Rosgen’s channel classification (1996), floodable area was measured at twice bankfull depth. A bank-height ratio greater than two is considered entrenched until the incision widens substantially. Such high banks are often designated as gully banks rather than streambanks. Generally, more severe BEHI ratings corresponded to a higher percentage of incision and lower rooting depth to study bank height ratio (Table 4). The greater the incision (and BEHI rating), the less roots affect streambank erosion. Higher banks require deeper roots to reach a water table or capillary fringe yet the dryness of soil may preclude this. Thus, 26% of banks with the highest BEHI ratings (Extreme and Very High) accounted for 58% of total erosion. These banks were mostly incised and have minimal influence by roots.

Table 4. Percent incision (bank height ratio $\geq$ 1.9) within BEHI category and overall erosion.

BEHI Group	Percentage of sites incised (within BEHI group)	Rooting depth to study bank height ratio (average per BEHI group)	Number/ percent of sites	Percentage of total erosion
Extreme	80%	0.15	10/10.5%	41.0%
Very High	86%	0.21	15/15.8%	17.5%
High	46%	0.28	30/31.5%	28.0%
Moderate	5.40%	0.43	37/39%	13.0%
Low	0%	0.61	3/3.2%	0.5%

Drainage size was statistically related to erosion (p=0.0114). However, contrary to the notion that larger drainages have more streambank erosion due to accumulation of flow (Kozlowski et al., 2010), Figure 13 suggests that larger drainage areas had less streambank erosion. Similarly, elevation was significantly correlated with erosion (p=0.0078) but had an r^2 of only 0.0007. Higher elevation (corresponding to smaller drainage areas) sites had more erosion and vice versa. Larger drainage areas in the Sequoia National Forest coincided with streams in canyons containing large boulders on banks. Drainage area and elevation did not appear to be good proxies in relating discharge to streambank erosion.

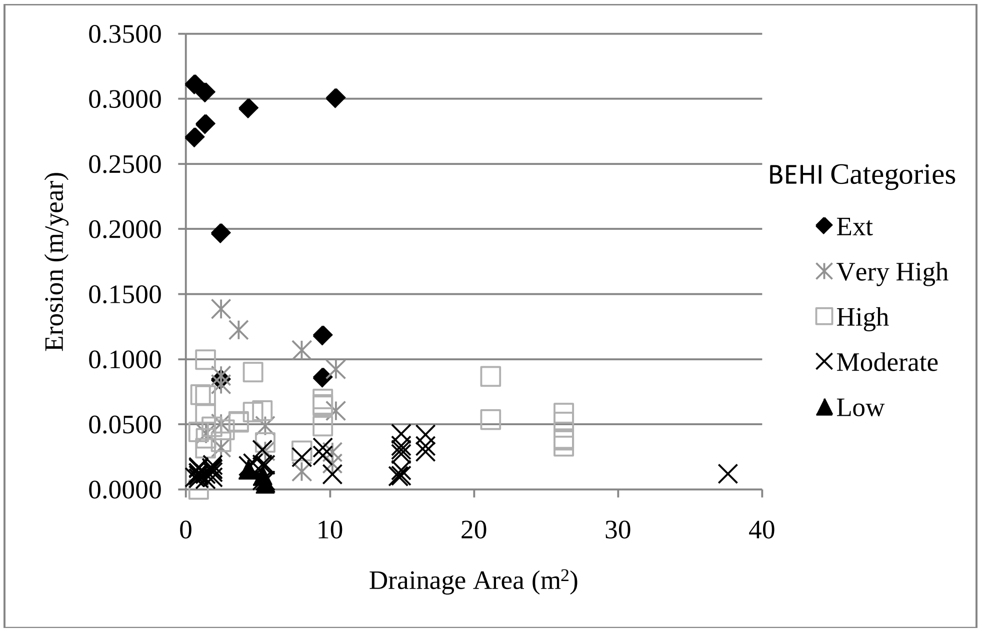

Figure 13. Relationship between streambank erosion and drainage size.

The addition of elevation and drainage area variables to the multiple regression analyses did not increase adjusted r^2 (0.20).

Measured rooting density did not alter the overall BEHI ratings when they replaced ocular field estimates even though measured rooting density was consistently lower (figure 14). This may be due to the laboratory method of separating roots from soil. Finer roots were harder to pick out, especially if extreme desiccation through over-drying may have broken down the finer roots. Or, field ocular estimates may have been too high.

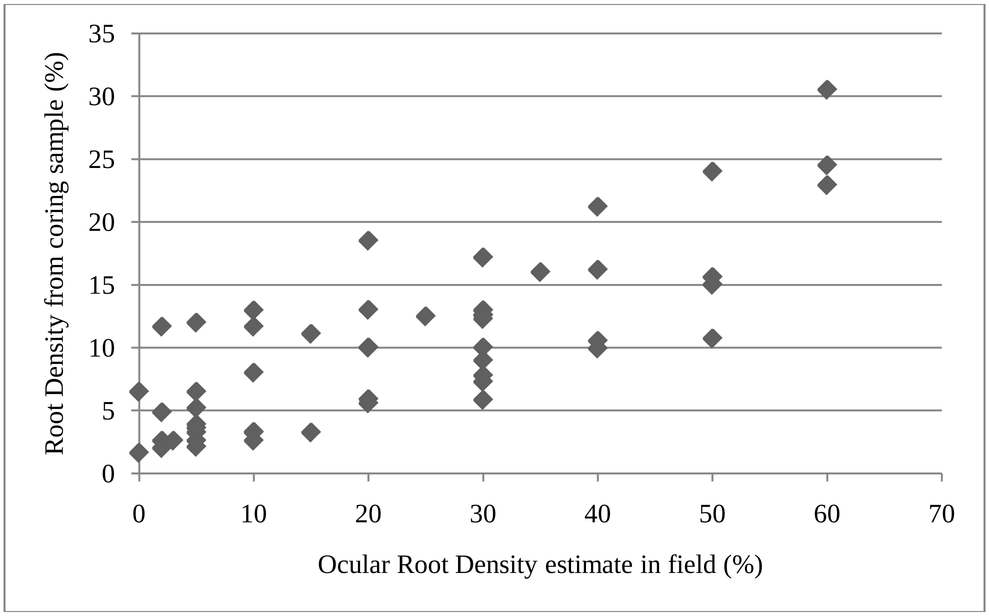

Figure 14. Ocular rooting density plotted against coring samples.

Since rooting densities were converted to a 1 through 10 rating within the BEHI model, they could easily be replaced with results of the 1-10 vegetation ratings for greenline bank stability. Doing so changed the overall BEHI numeric and adjective rating of many sites but did not increase the strength of the model (figure 15).

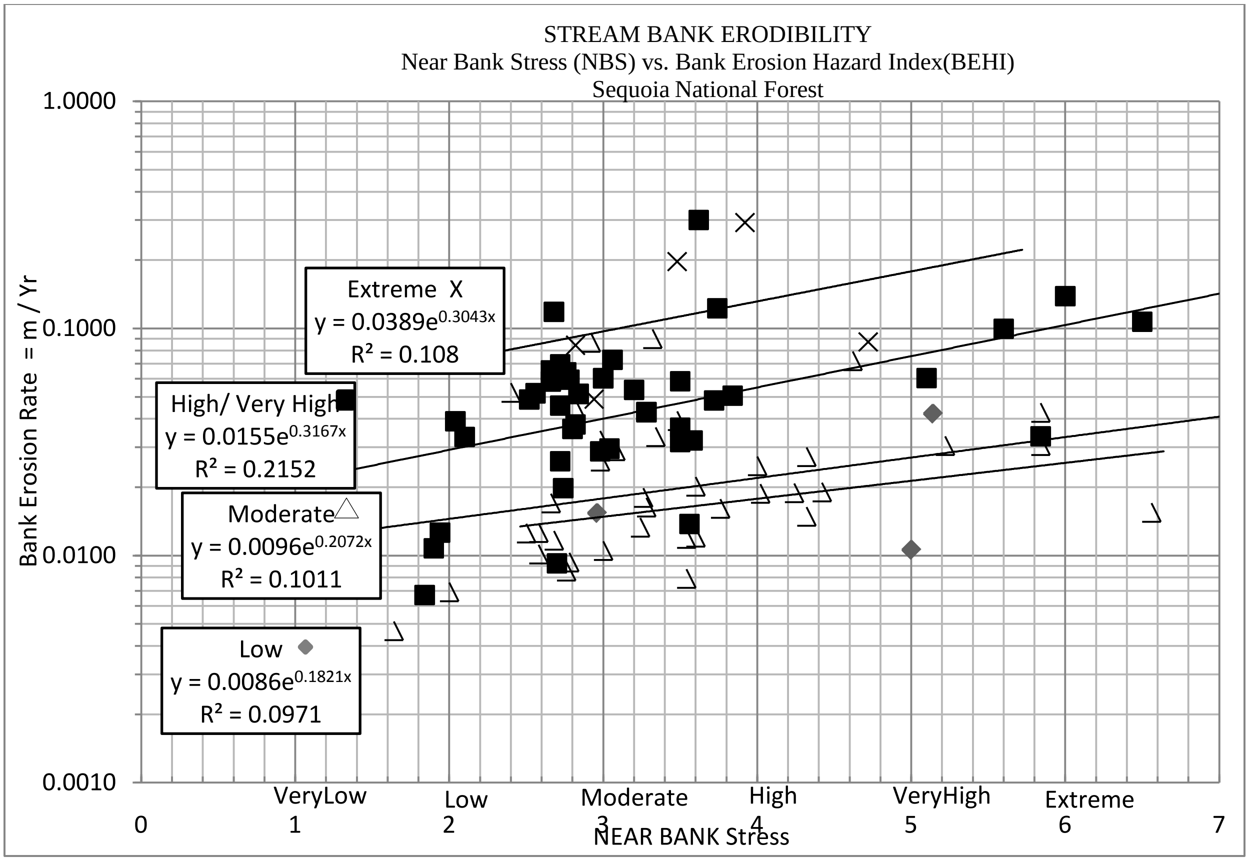

Figure 15. Relationship of BEHI and NBS to predict annual streambank erosion for Sequoia National Forest using Greenline method instead of rooting densities.

Trend lines are still ranked in order from extreme to low, but r^2 values significantly decreased and clustering of BEHI within their own categories disappeared.

Conclusions

Models of sediment transport assume cohesionless materials, yet streambanks are often cohesive or variously stable. Methods for predicting streambank erosion have been inappropriate for use in wildland systems. This study replicated methods developed by Rosgen (2006, 2001) to create a graphical model to predict streambank erosion in a physiographic province and in valley geomorphic settings where the model had not yet been tested. Prediction curves created for the Sequoia National Forest yielded fairly good relationships. The BEHI model has been tested in alluvial settings (Eps et al., 2004; Rosgen 2001; Harmel et al., 1999), and may not apply as well in colluvial valleys which dominate the Sequoia National Forest. This may explain our lower r^2 correlations for the BEHI model.

The proposed graphical model is appropriate for use where discharge is near or at bankfull at riffle features. Like past replicate studies using the same model, developed BEHI/NBS curves were localized to the various physiographic province and should not be applied outside the boundary; doing so may result in erroneous values.

It will be useful to continue monitoring the sites in subsequent years to further test or refine accuracy of the graphical model and observe how it responds to a range of flow conditions. Adjustments may be required for the model and field methods for flows not at bankfull discharge. Especially if the Forest Service considers using this model in post-fire assessments, more work will have to be done to relate various flows to erosion since post fire flows tend to increase due to a decrease in infiltration (Helvey et al., 1985; Helvey, 1980) and evapotranspiration. Also, debris flows are not uncommon in the southern California region post fire. The physics and magnitude of power within a debris flow no doubt is different and greater from that of flowing water that would require additional observations and consideration of alternative methods.

The model may also be strengthened by including additional points to the graph. Since study sites were limited to riffles, it may be useful to see whether similar erosion rates hold with similar BEHI/NBS classifications within pool, glide, and run features. These features differ in their ability to dissipate energy of flowing water, hence NBS would vary. Riffles are shallow and have a steeper slope while runs are deeper. Pools may be wider and always deep while glides have adverse slopes. These features differ in cross sectional geometry, and this would cause variation in BEHI and NBS. Throughout a watershed they change on a larger scale.

BEHI variables had not been individually tested in previous studies. We determined that each variable was significantly but weakly related to erosion, as were elevation and drainage area. Overall, the BEHI variables collectively not individually affect streambank erosion. Multiple regression analyses indicated that other variables (not tested) may influence streambank erosion. Since vegetation roots are such an integral factor in bank stability, it may be useful to do further research for evaluating rooting density using field-friendly methods. Laboratory based data for rooting density could be used to possibly develop a pictorial guide of rooting densities. Replacement of rooting density with the Greenline bank stability data in BEHI may obviate the need for suggestions mentioned above since the greenline method was developed to evaluate streambank stability based on vegetation. However, further research and explicitly following Multiple Indicator Monitoring procedures will be needed.

Afforestation and stream restoration projects have become highly popular among land management and conservation agencies which also have to respond to fire and other emergencies. Predicting streambank erosion rates can inform such planning. To predict annual streambank erosion sediment yield, one would determine BEHI and NBS values. The predicted bank erosion rate (lateral distance) would then be multiplied by respective bank heights and the lengths. To focus such efforts, they could be performed on only nonfunctional or at-risk reaches (Prichard et al., 1998). However, because the processes of collecting field data can be highly time consuming, trying to determine streambank erosion for an entire watershed may be unrealistic.

Future research may build upon this BEHI/NBS baseline data to study streambank erosion rates after fire or the efficacy of various restoration techniques to stabilize streams and reduce bank erosion. Direction of continued research should try to make the model more time efficient (e.g., perhaps integrating a GIS component or pictorial guide), especially when trying to evaluate streambank erosion for an entire watershed. Since incision appears to be such an integral factor affecting erosion (also affecting other variables in BEHI, i.e., rooting depth, rooting density, bank angle), it may be useful to explore whether it can predict streambank erosion based on the bank height ratio. Also, Rosgen stream types include a qualitative evaluation of streambank erosion based on morphological trends within a stream type (Rosgen, 2006). With an adequate variety of stream types, it may be feasible to associate them with streambank erosion rates within a geologic domain. This way, it would be possible to evaluate streambank erosion on a larger scale.

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Literature Cited

Abernethy B, Rutherfurd ID. 1998. Where along a river's length will vegetation most effectively stabilize stream banks? *Geomorphology* **23**: 55-75.

Bartholow, JM. 2000. Estimating cumulative effects of clearcutting on stream temperatures. *Rivers*, **7**(4), 284-297.

Bohn C. 1987. Management of winter soil temperatures to control streambank erosion. In: R.E. Gresswell, B.A. Barton, and J.L. Kershner (Editors), Practical Applications to Riparian Restoration. Management and Educational Workshop: 69-71.

Burton TA, Cowley ER, Smith SJ. 2007. *Monitoring Stream Channels and Riparian Vegetation—Multiple Indicators*. U.S. Department of Interior, BLM, Idaho State Office, Boise, Idaho, and Intermountain Region U.S. Forest Service. Idaho Technical Bulletin 2007-01, BLM/ID/G1-07/001+1150.

Carson MA, Kirkby MJ. 1972. *Hillslope Form and Process*. Cambridge University Press, NY.

Couper PR, Maddock IP. 2001. Subaerial river bank erosion processes and their interaction with other bank erosion mechanisms on the River Arrow, Warwickshire, UK. *Earth Surface Processes and Landforms* **26**: 1095-1114.

Daniels RB, Gilliam JW. 1997. Sediment and chemical load reduction by grass and riparian filters. *Soil Science Society of America Journal* **60**:246–51.

Davies-Colley RJ. 1997. Stream channels are narrower in pasture than in forest. *New Zealand Journal of Marine and Freshwater Research* **31**: 599-608.

Dunne T, Leopold L. 1978. *Water in environmental planning*. San Francisco, Ca; W.H. Freeman and Company.

Eps VMA, Formica SJ, Morris TL, Cotter AS. 2004. Using a Bank Erosion Hazard Index to Estimate Annual Sediment Loads From Streambank Erosion in the West Fork White River Watershed. Arkansas Department of Environmental Quality, Environmental Preservation Division, Little Rock, AR.

Evans BM, Sheeder SA, Lehning D. 2003. A Spatial Technique for Estimating Streambank Erosion Based on Watershed Characteristics. *Journal of Spatial Hydrology* **3**: 3-13.

Fish and Wildlife Service. 2004. BAER Incident Qualifications and Certification System (IQCS) Position Transition Plan. http://www.fws.gov/fire/ifcc/Esr/BAER/Mobilization%20and%20Directories/BAER%20transition%20plan.pdf Last accessed 8/20/2009.

Florsheim JL, Mount JF, Chin, A. 2008. Bank Erosion as a Desirable Attribute of Rivers. *BioScience* **58** (6): 519-529

Frazier JW, Roby KB, Boberg JA, Kenfield K, Reiner JB, Azuma DL, Furnish JL, Staab BP, Grant SL. 2005. Stream Condition Inventory Technical Guide, Version 5.0. USDA Forest Service, Pacific Southwest Region - Ecosystem Conservation Staff. Vallejo, CA.

Garcia MH. 2008. *Sedimentation Engineering Processes, Measurements, Modeling and Practice*. ASCE Manuals and Reports on Engineering Practice No. 110 Reston, Va; 1050pp.

Graf WL. 2005. Platte River: Water for people and wildlife. In Stanley W, Stewart BA, Howell TA. Encyclopedia of Water Science. New York: Marcel Dekker. 45-453

Gregory KJ, Gurnell AM. 1988. Vegetation and river channel form and process. In: Viles, H., Biogeomorphology Blackwell, Oxford: 11-42.

Gutub MZA, Awadalla SA, Gutub SA. 1995. The Influence of Soil Stratification of Stability of Slopes Under Unsaturated Conditions. The Fourth Saudi Engineering Conference Nov. 1995. **2**: 377-383.

Hanes RO, Plocher SE, Martynn DZ. 1996. Soil Survey of Sequoia National Forest Area, California. United Stated Department of Agriculture. Natural Resources Conservation Service and Forest Service.

Harmel RD, Haan CT, Dutnell RC. 1999. Evaluation of Rosgen's Streambank Erosion Potential Assessment in Northeast Oklahoma. *Journal of the American Water Resources Association* **35**: 113-121.

Haque CE, Hossian Z. 1988. Riverbank Erosion in Bangladesh. *Geographical Review* **78**: 20-31.

Helvey JD, Tiedemann AR, Anderson TD. 1985. Plant Nutriend Losses by Soil Erosion and Mass Movement After Wildfire. *Journal of Soil and Water Conservation* **40**: 168-173.

Helvey JD. 1980. Effects of a North Central Washington Wildfire on Runoff and Sediment Production. *Journal of the American Water Resources Association* **16** (4): 627-634.

Hilborn D, Stone RP. Universal Soil Loss Equaion. Fact Sheet published by Canadian Ministry of Agriculture. May 2000. http://www.omafra.gov.on.ca/english/engineer/facts/00-001.htm. Last accessed 8/25/2008

Howard A. 1984. Sufficient conditions for river meandering: a simulation approach. *WaterResources Research* **20**(11): 1659–1667.

Iverson RM. 1997. The Physics of Debris Flow. *Reviews of Geophysics **35** (3): 245-296.*

Jha S, Western AW, Rutherfurd ID, Grayson RB. 2005. Testing Uncertainty in a Model of Streambank Erosion. In Zerger, A. and R.M. Argent (Eds) MODSIM 2005 International Congress on Modeling and Simulation Society of Australia and New Zealand: 2714-2720.

Kaplan-Henry T. 2007. McNally Post-Fire Discharge and the Relationship of Sierra Nevada-wide Flood Frequency Curves and Local Kern River Discharge Curves. In Advancing the Fundamental Sciences. Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA. 18-22 October 2004. Ed. Furniss, Michael K. Catherine F. Ronnenberg, Katheryn L. 2007. USDA, FS, Pacific Northwest Research Station. PNW-GTW-689: 27-35.

Kaplan-Henry T. 2009. Personal communication regarding stream /valley types of Sequoia National Forest and BAER reports. United States Forest Service.

Kauffman JB, Kruger WC. 1984. Livestock impacts on riparian ecosystems and streamside management implications…a review. *Journal of Range Management* **37** (5): 430-438.

Kauffman JB, Krueger WC, Vavra M. 1983. Impacts of cattle on streambanks in Northeastern Oregon. *Journal of Range Management* **36**: 683-685.

Kozlowski D, Swanson S, Schmidt K. 2010. Channel changers in burned streams of northern Nevada. *Journal of Arid Environments* **74** (11): 1494-1506.

Land and Water Australia. 2002 Fact Sheet 2: Streambank stability. *Land and Water, Australia*. Pp 1-14. http://products.lwa.gov.au/files/PF020254.pdf. Last accessed 12/5/2009

Langendoen EJ. 2000. CONCEPTS—Conservational channel evolution and pollutant transport system, Research Report 16, Agriculture Research Services., U.S. Department of Agriculture. Oxford, Miss.

Langendoen EJ, Simon A, Thomas RE. 2001. CONCEPTS- A process-based modeling tool to evaluate stream-corridor restoration designs. Proceedings, 2001 Wetland Engineering & River Restoration Conference, American Society of Civil Engineers, Reston, VA.

Lawler DM. 1993 The Measurement of River Bank Erosion and Lateral Channel Change: A Review. *Earth Surface Processes and Landform*. **18**: 777-821.

Leopold LB, Rosgen DL, Silvey HL, Emmett WW. 1995. A Guide to Field Identification of Bankfull Stage in the Western United States. USDA Forest Service Rocky Mountain Forest and Range Experiment Station Stream Systems Technology Center, Fort Collins, CO. Video.

Leopold LB, Wolman MG, Miller JP. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Company, San Francisco, California.

Leopold LB, Wolman MG. 1957. River Channel Patterns: Braided, Meandering and Straight, *U.S. Geological Survey Professional Paper.* 282-B.

Luppi L, Rinaldi M, Teruggi LB, Darby SE, Nardi L. 2008. Monitoring and numerical modeling of riverbank erosion processes: a case study along the Cecina River (Central Italy). *Earth Surface Processes and Landforms* **34**: 530–546.

Lyons J, Trimble SW, Paine LK. 2000. Grass versus trees: managing riparian areas to benefit streams of Central North America. *Journal of the American Water Resources Association* **36** (4): 919-930.

Murgatroyd AL, Ternan JL. 1983. The Impacts of Afforestataion on Streambank Erosion and Channel Form. *Earth Surface Processes and Landforms* **8**: 357-369.

Natural Resources Sciences. 2006. What Causes Bank Erosion? Fact Sheet published by Queensland Department of Natural Resources and Water.

Nalluri C, Alvarez EM. 1992. The Influence of Cohesion on Sediment Behaviour. *Water Science and Technology* WSTED4 **25** (8): 151-164.

Neary DG, Robichaud PR, Beyers JL. 2000. Burned Area Emergency Watershed Rehabilitation: Program Goals, Techniques, Effectiveness and Future Directions in the 21st Century. USDA Forest Service Proceedings RMRS-P-13; 375-378.

Platts WS 1991. Livestock grazing. In: *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats.* American Fisheries Society Special Publication 9. American Fisheries Society, Bethesda, MD: 389-423

Pollen N. 2007. Temporal and spatial variability in root reinforcement of streambanks: Accounting for soil shear strength and moisture. *Catena* **69** (3): 197-205.

Potter MC, Wiggert DC. 2002. *Mechanics of Fluids.* Pacific Grove, CA: Brooks/Cole.

Prichard D, Anderson J, Correll C, Gebhardt K, Krapf R, Leonard S, Mitchell B, Staats J. 1998. Riparian area management: A user guide to assessing proper functioning condition and the supporting science for lotic areas. US Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. Technical Reference 1737-15.

Ralph SC, Poole GC, Conquest LL, Naiman RJ. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. *Canadian Journal of Fisheries and Aquatic Science* **5**: 37–51.

Reid I, Laronne JB. 1995. Bed Load Sediment Transport in an Ephemeral Stream and a Comparison with Seasonal and Perennial Counterparts, *Water Resources Research* ***31***(3):773–781.

RIVERMorph. 2009. RIVERMorph Stream Assessment and Restoration Software. Ver. 4.2. Louisville, Kentucky. RIVERMorph, LLC.

Robichaud PR, Elliot WJ, Pierson FB, Hall DE, Moffet CA, Ashmun LE. 2007. Erosion Risk Management Tool (ERMiT) user manual. US Department of Agriculture. Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA. General Technical Report RMRS-GTR-188.

Rosgen, DL. 1996. *Applied River Morphology*. Wildland Hydrology. Fort Collins, Co.

Rosgen DL. 2001. A Practical Method of Computing Streambank Erosion Rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference, March 25-29, 2001, Reno, NV. **2**: 9-15.

Rosgen DL. 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSSS).* Wildland Hydrology. Fort Collins, Co.

Salo J, Killiola R, Hakkinen I, Makinen Y, Niemela P, Puhakka M, Coley PD. 1986. River dynamics and the diversity of Amazon lowland forest. *Nature* **322**: 254–258.

SAS Institute. 1996. SAS/STAT User's Guide. Release 6.12 Edition, SAS Institute, Inc., Cary, North Carolina.

Sekely AC, Mulla DJ, Bauer DW. 2002. Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation* **57**(5): 243-250.

Simon A, Thorne CR. 1996. Channel Adjustment of an Unstable Coarse-Grained Alluvial Stream: Opposing Trends of Boundary and Critical shear stress, and the Applicability of Extreme Hypothesis. *Earth Surface Processes and Landforms* **21**: 155-180.

Simon A, Curini A, Darby SE, Langendoen EJ. 1999. Bank and near-bank processes in an incised channel. *Geomorphology* **35**: 193-217.

Smith DG. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. *Geologic Society of America Bulletin* **87**: 857-860.

Spencer NC, Gabel OK, Hauer RF. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Park, USA. *Forest Ecology and Management* **178** (1-2): 141-153.

Thorne CR. 1990. Effects of vegetation on riverbank erosion and stability. In: Thornes, J.B. Vegetation and Erosion. John Wiley and Sons Inc. Chichester: 125-143.

Trimble SW. 1994. Erosional effects of cattle on streambanks in Tennessee, USA. *Earth Surface Processes and Landforms* **19**(5): 451-464.

Trimble, SW. 1997. Stream Channel erosion and change resulting from riparian forests. *Geology* **25** (5): 467-469.

United Nations Environmental Program (UNEP). 2007. Sudan. Post Conflict Environmental Assessment. http://www.unep.org/sudan/. Last accessed 9/6/2010.

U.S. Army Corps of Engineers (USACE). 1983. Sacramento River and tributaries bank protection and erosion control investigation. California sediment transport studies, Sacramento District. Sacramento, Ca: USACE.

U.S. Environmental Protection Agency (USEPA). 2008. Introduction to Sediment and River Stability. http://epa.gov/warsss/sedsource/index.htm. Last accessed 9/23/2008

Waananen AO, Crippen JR. 1977. Magnitude and frequency of floods in California. *US Geological Survey Water-Resources Investigation* 77-21.

Waters TF. 1995. Sediment in streams. American Fisheries Society Monograph 7. American Fisheries Society, Bethesda, Maryland, 251 pp.

Winward A. 2000. Monitoring the vegetation resources in riparian areas. USDA Forest. Service. General Technical Report. RMRS-47.

Wolman M, Gerson R. 1977. Relative Scales of Time and Effectiveness of Climate in Watershed Geomorphology. *Earth Surface Processes* **3**: 189-208.

Wolman M, Miller JP. 1960. Magnitude and Frequency of forces in geomorphic processes. *Journal of Geology* **68**: 54-74.

Wood PJ, Armitage PD. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* **21**: 203–217.

Wyman S, Bailey D, Borman M, Cote S, Eisner J, Elmore W, Leinard B, Leonard S, Reed F, Swanson S, Van Riper L, Westfall T, Wiley R, Winward A. 2006. Riparian area management: Grazing management processes and strategies for riparian-wetland areas. U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. Technical Reference 1737-20. BLM/ST/ST-06/002+1737.

Wynn TM, Mostaghimi S, Burger JA, Harpold AA, Henderson MB, Henry L. 2004. Ecosystem Restoration. Variation in Root Density along Stream Banks. *Journal of Environmental Quality* **33**: 2030- 2039.

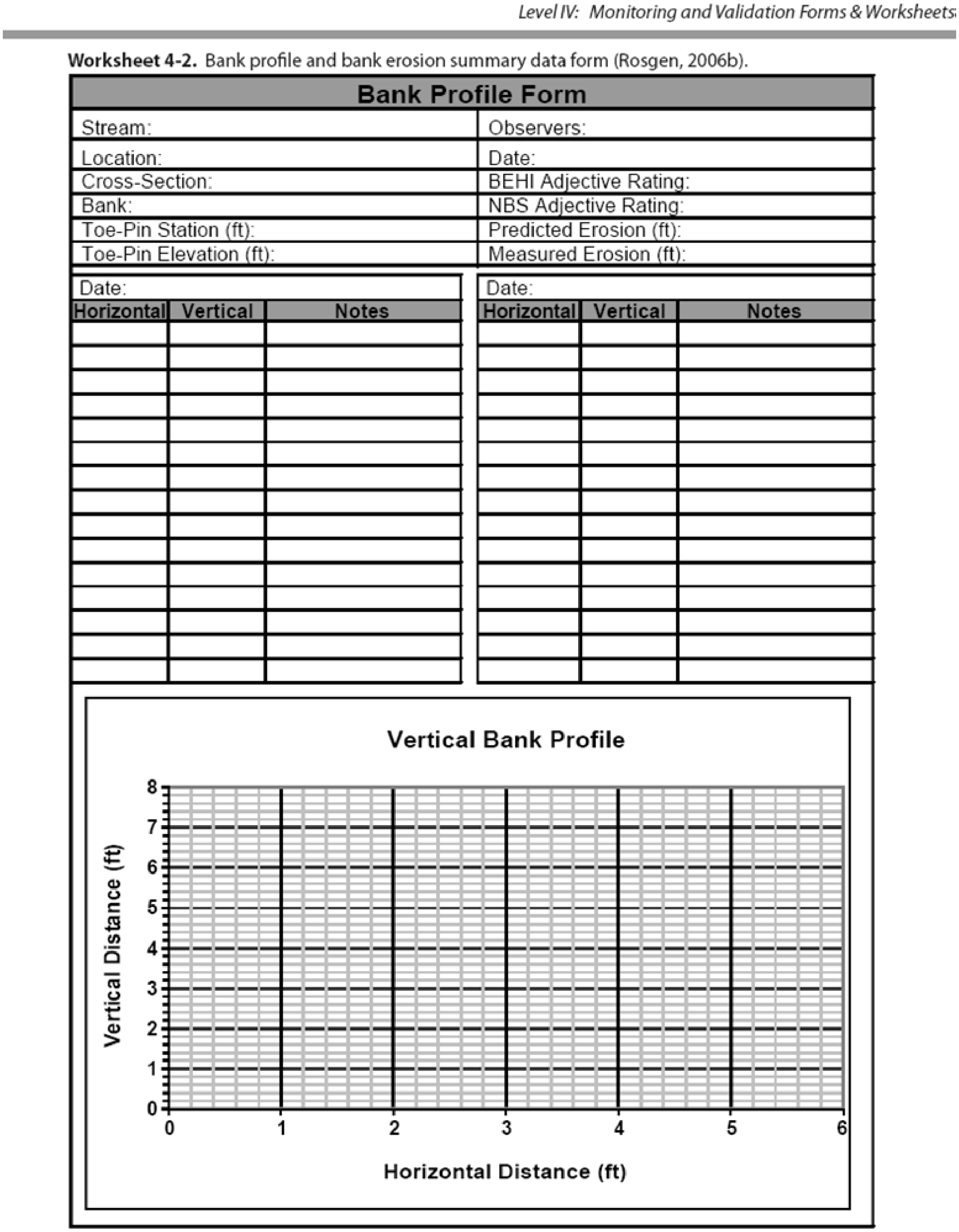
Wyzga B, Zawiejska J. 2005.Wood storage in a wide mountain river: Case study of the Czarny Dunajec, Polish Carpathians. *Earth Surface Processes and Landforms* **30**: 1475–1494.

Zimmerman RC, Goodlet JC, Comer CH. 1967. The influence of vegetation on channel form of small streams. *International Association of Scientific Hydrology Publication* **75**: 255-275.

Zonge KL, Swanson S, Myers T. 1996. Drought year changes in streambank profiles on incised streams in the Sierra Nevada Mountains *Geomorphology* **15**: 47-56.

Appendices

Appendix A- Forms (From Rosgen, 2006, used with permission)



Level IV: Monitoring and Validation Forms & Worksheets

Worksheet 4-2. Bank profile and bank erosion summary data form (Rosgen, 2006b).

Bank Profile Form

Stream:	Observers:
Location:	Date:
Cross-Section:	BEHI Adjective Rating:
Bank:	NBS Adjective Rating:
Toe-Pin Station (ft):	Predicted Erosion (ft):
Toe-Pin Elevation (ft):	Measured Erosion (ft):

Date:			Date:		
Horizontal	**Vertical**	**Notes**	**Horizontal**	**Vertical**	**Notes**

Worksheet 3-11. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001b, 2006b). Use **Figure 3-7** with BEHI variables to determine BEHI score.

Stream:		Location:
Station:		Observers:
Date:	Stream Type:	Valley Type:

BEHI Score (Fig. 3-7)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)	

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)	

Weighted Root Density (G)

Root Density as % =	(F)	(F)×(E) =	(G)	

Bank Angle (H)

Bank Angle as *Degrees* =	(H)	

Surface Protection (I)

Surface Protection as % =	(I)	

Bank Material Adjustment:

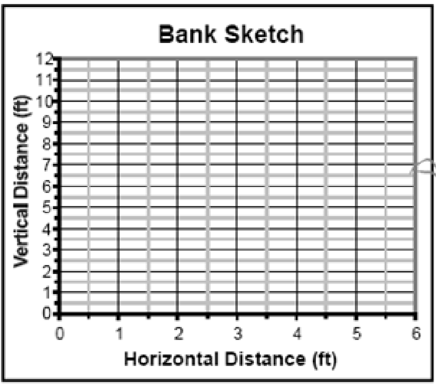
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform med. to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (No adjustment)

Bank Material Adjustment

Stratification Adjustment

Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme	**Adjective Rating** and **Total Score**
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	



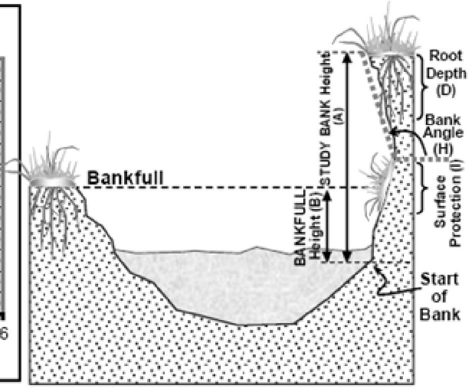
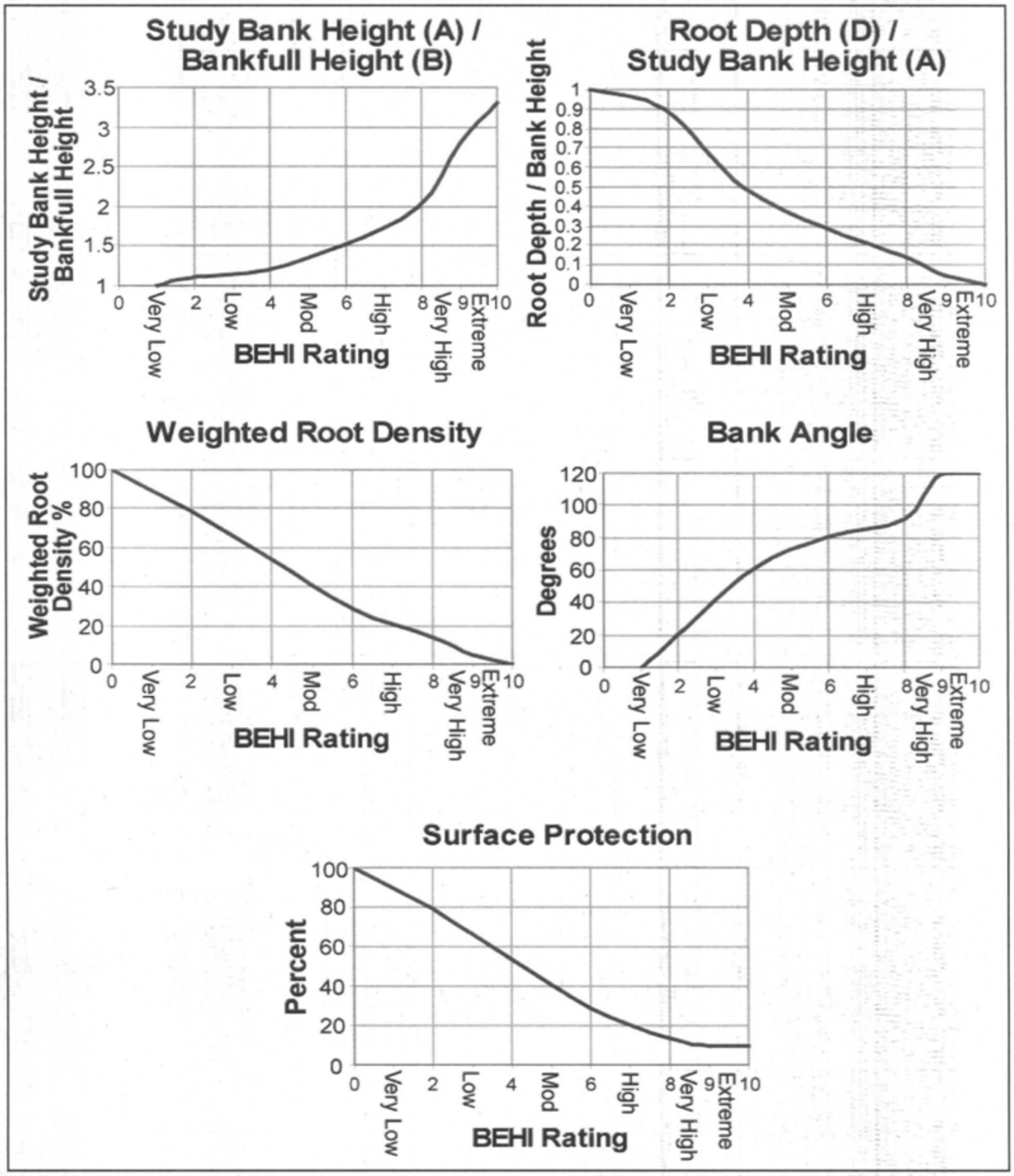
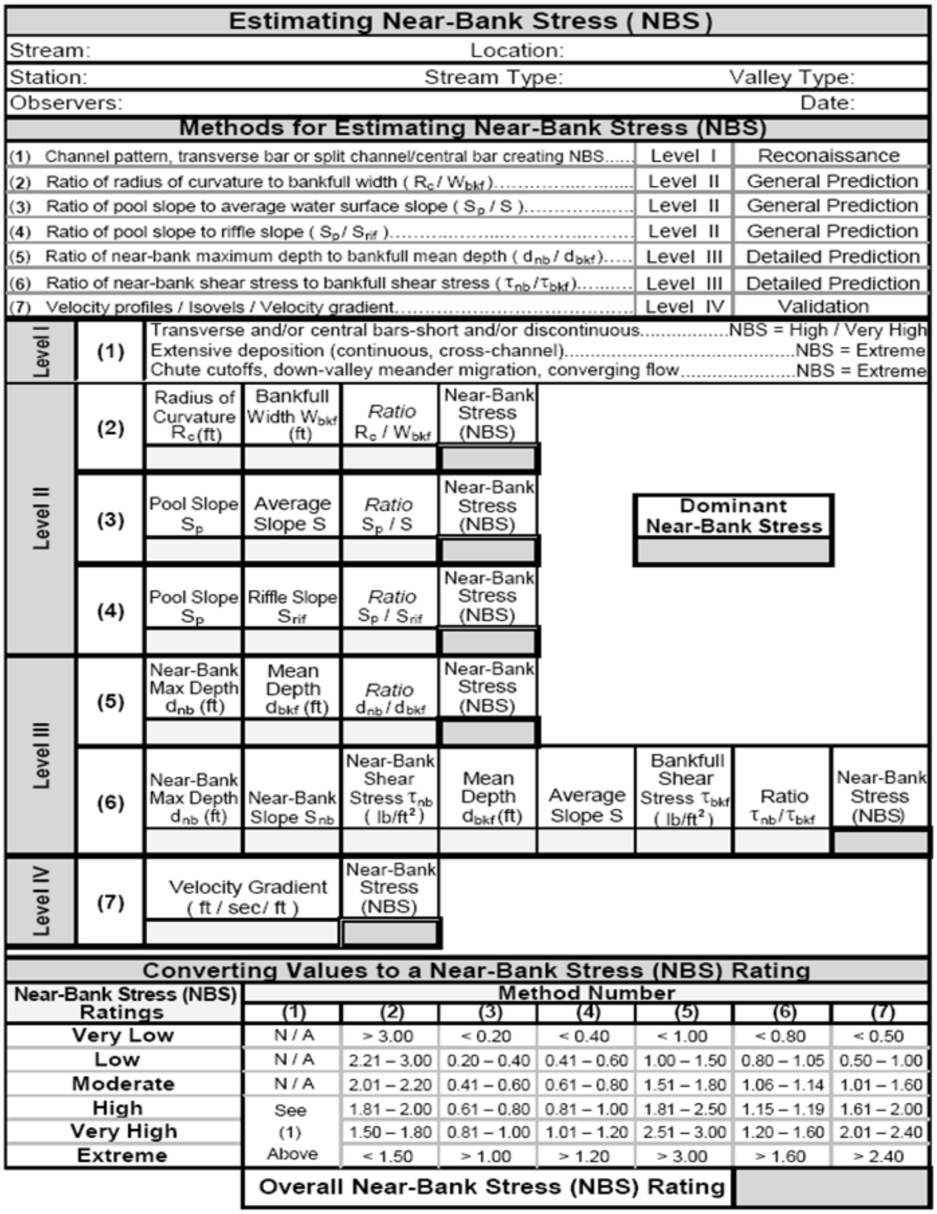


Figure 3-7. Streambank erodibility criteria showing conversion of measured ratios and bank variables to a
rating. Use **Worksheet 3-11** variables to determine BEHI score.



Worksheet 3-12. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate (Rosgen, 2006b).



Estimating Near-Bank Stress (NBS)

Stream: Location:
Station: Stream Type: Valley Type:
Observers: Date:

Methods for Estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS……	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})……	Level II	General Prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)……	Level II	General Prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})……	Level II	General Prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})……	Level III	Detailed Prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})……	Level III	Detailed Prediction
(7) Velocity profiles / Isovels / Velocity gradient……	Level IV	Validation

Level I

(1)
Transverse and/or central bars-short and/or discontinuous……NBS = High / Very High
Extensive deposition (continuous, cross-channel)……NBS = Extreme
Chute cutoffs, down-valley meander migration, converging flow……NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV

(7)

Velocity Gradient (ft / sec/ ft)	Near-Bank Stress (NBS)

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) Ratings	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See (1) Above	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High		1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme		< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) Rating

Hilda Kwan <hildakwan857@gmail.com>

BANCS forms - Permission

1 message

Darcie <Darcie@wildlandhydrology.com> **Tue, Oct 12, 2010 at 4:11 PM**
To: Hilda Kwan <hildakwan857@gmail.com>

Hi Hilda!

You certainly can use the forms in your thesis. Please make sure you send Dave a copy when it's complete!

We're in Minnesota conducting a Level II and luckily it's not snowing yet…it was actually hot in the field.

Take Care,

Darcie

From: Hilda Kwan [mailto:hildakwan857@gmail.com]
Sent: Monday, October 11, 2010 5:13 PM
To: Darcie
Subject: Re: Additional Downloads - AGU NCD Chapter and Chapter 11

Hey Darcie! Hope all is well on your end! I'm not sure the best way to get a hold of Dave, but I wanted to know if it would be okay for me to include several of his field forms from the BEHI/NBS evaluations at the appendix section of my thesis. Thanks for everything!

-Hilda

On Fri, Oct 1, 2010 at 8:17 AM, Wildland Hydrology <darcie@wildlandhydrology.com> wrote:

Hello again!
A few people have requested that I send along copies of the manual so you can see it in color.
I have uploaded the pertinent chapters, Chapter 4 (AGU Chapter submission) and Chapter 11 (Structures).
Chapter 4 is Dave's latest submission manuscript that has been accepted by AGU.
It is updated from the draft you have in your manuals and hopefully flows and reads better!
The AGU book should be out in January.

Also in this download is "The Gliffler" song written by Mark Ray!
To download, copy and paste the following link into your internet browser and choose "SAVE" ("OPEN" will not work):
http://www.wildlandhydrology.com/files/ManualPDFs.zip
The download shouldn't take too long...the file size is less than 10 MB.
Enjoy!

Darcie Geenen
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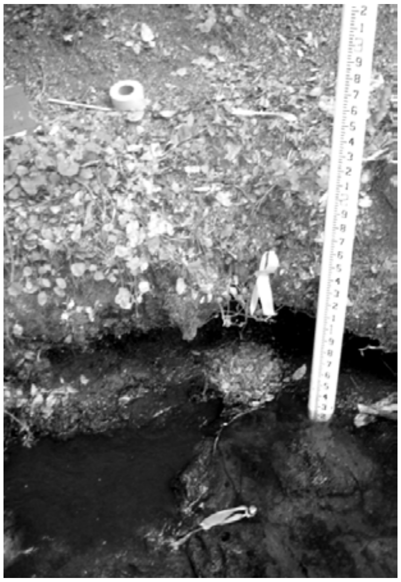
Appendix B- Pictorial examples of BEHI

LOW BEHI- Trout, STA 3

Moderate BEHI- Last Chance Meadow, STA1

High BEHI- Salmon, STA -1



Very High BEHI- Cedar Creek ,STA 3

Extreme BEHI- Parker Creek,

Appendix C- Site Specifics

Bank- L= left bank, R= right bank (looking downstream)

BEHI- Adjective rating of BEHI from its numeric value.

BEHI numeric- Total score of compiled BEHI variables.

Bkf Ht- Bankfull Height (meters)

Elev- Elevation (meters)

Forest/ Meadow- F= forested sites, M= meadow sites

Major WHSD- D=Deer, K= Kern, Ka= Kaweah, T- Tule

MIMs- Results from Greenline Method (rating between 1-10, 10 being more erosion resistant)

NBS- Adjective rating of NBS from its numeric value.

NBS numeric- Numeric score of NBS.

Rd/ Study Bk Ht- Ratio of Rooting Depth to Study Bank Height

Sta- station

Study Bk Ht- Study Bank Height (meters)

UTM’s N and E- Universal Transverse Mercator coordinate (all in 11S grid)

Weighted RD- Weighted Rooting Density (root density multiplied by the ratio of rooting depth to study bank height)

Year- Year surveyed

Stream	Sta	Year	Elev (m)	Forest/ Meadow	Bank	BEHI	BEHI numeric	NBS	NBS numeric	Erosion (m/yr)	Major WSHD (D-Deer, K-Kern, Ka-Kaweah, T-Tule)	UTM's N (NAD 83)	UTM's E (NAD 83)
Capinero	1	2008	1253	F	L	Mod	27.6	Mod	2.98	0.0260	D	352409	3969956
Capinero	1	2008	1253	F	R	H	38.9	Low	2.76	0.0642	D	352429	3969944
Capinero	2	2008	1253	F	L	Ex	48.3	Low	2.42	0.0859	D	352485	3970006
Capinero	3	2008	1253	F	L	Ex	45.6	Low	2.68	0.1183	D	352495	3969977
Capinero	1	2009	1253	F	L	Mod	26.3	Low	2.98	0.0322	D	352409	3969956
Capinero	1	2009	1253	F	R	H	34.4	Low	2.72	0.0695	D	352429	3969944
Capinero	2	2009	1253	F	L	H	37.4	Low	2.52	0.0486	D	352485	3970006
Capinero	3	2009	1253	F	L	H	37.4	Low	2.66	0.0652	D	352495	3969977
Cedar @ Alder	1	2009	1172	F	R	VH	43.7	Mod	3	0.0604	D	354052	3953812
Cedar @ Alder	2	2009	1172	F	L	VH	47	Mod	3.16	0.0922	D	354144	3953900
Cedar @ Alder	3	2009	1172	F	R	Ext	32.3	H	3.62	0.3004	D	354166	3953911
Cedar @ Cedar	1	2009	1427	F	R	H	36.9	Low	2.4	0.0523	D	356808	3956768
Cedar @ Cedar	2	2009	1427	F	R	H	39.4	Low	2.84	0.0515	D	356804	3956771
Cedar @ Cedar	3	2009	1427	F	R	VH	43.4	H	3.74	0.1226	D	356772	3956788
Deer	1	2009	919	F	R	Mod	20.1	VH	5.14	0.0421	D	348593	3971912
Deer	2	2009	919	F	L	Mod	23.2	Mod	3.08	0.0289	D	348603	3971903
Deer	2	2009	919	F	R	Mod	27.8	Mod	3.34	0.0334	D	348605	3971898
Bear @ Greenhorn	1A	2009	1720	F	R	H	38.7	Mod	3.06	0.0728	K	356751	3950993
Bull Run	1.5	2009	1958	M	R	H	38.4	L	2.72	0.0458	K	360496	3967112
Burton Mill	1	2008	2060	F	R	VH	44.2	Low	3.84	0.0808	K	372388	3929403
Burton Mill	2	2008	2060	F	L	VH	48.1	H	4.72	0.0873	K	372413	3929377
Burton Mill	3	2008	2060	F	R	EX	56.9	Low	2.82	0.0843	K	372422	3929340
Burton Mill	5	2008	2060	F	R	H	37.9	Mod	3.5	0.0365	K	372440	3929328
Burton Mill	6	2008	2060	F	L	EX	56.5	Mod	3.48	0.1967	K	372434	3929305
Burton Mill	1	2009	2060	F	R	VH	42.8	H	3.84	0.0506	K	372388	3929403
Burton Mill	3	2009	2060	F	R	VH	45.2	Ext	6	0.1386	K	372422	3929340
Burton Mill	5	2009	2060	F	R	VH	45.4	Mod	3.58	0.0321	K	372440	3929328
Cannell	2	2008	2195	M	L	VH	43.8	VL	2.8	0.0294	K	376896	3962142
Cannell	3	2008	2195	M	R	L	17.7	VL	1.64	0.0047	K	376880	3962170
Cannell	4	2008	2195	M	R	Mod	27.5	VL	1.84	0.0067	K	376877	3962210
Cannell	2	2009	2195	M	L	VH	45.4	Low	2.94	0.0488	K	376896	3962142
Cannell	3	2009	2195	M	R	Mod	21.1	H	4.24	0.0189	K	376880	3962170
Cannell	4	2009	2195	M	R	H	26.6	Low	2.8	0.0361	K	376877	3962210
Clear Creek @ Brown	1	2008	2242	M	L	Mod	29.8	VL	1.9	0.0108	K	372553	3927497
Clear Creek @ Brown	2	2008	2242	M	R	Mod	26.1	VL	1.94	0.0126	K	372532	3927482

Stream	Sta	Year	Elev (m)	Forest/ Meadow	Bank	BEHI	BEHI numeric	NBS	NBS numeric	Erosion (m/yr)	Major WSHD (D-Deer, K-Kern, Ka-Kaweah, T-Tule)	UTM's N (NAD 83)	UTM's E (NAD 83)
Clear Creek @ Brown	3	2008	2242	M	L	H	39.2	VL	1.76	0.0000	K	372462	3927477
Clear Creek @ Brown	1	2008	2242	M	L	Mod	26.5	Low	2.5	0.0126	K	372553	3927497
Clear Creek @ Brown	2	2008	2242	M	R	H	30.1	Low	2.82	0.0441	K	372532	3927482
Clear Creek @ Brown	3	2008	2242	M	L	Mod	24	Low	2.66	0.0170	K	372462	3927477
Clear Creek @ Brown	1	2009	2242	M	L	Mod	22.6	H	3.76	0.0161	K	372553	3927497
Clear Creek @ Brown	2	2009	2242	M	R	Mod	27.3	Low	2.58	0.0126	K	372532	3927482
Clear Creek @ Brown	3	2009	2242	M	L	Mod	26.3	Low	2.76	0.0085	K	372462	3927477
Fish (Plateu)	1	2009	2207	F	L	Mod	23.1	Mod	3.6	0.0120	K	391558	3989190
Freeman	1	2009	1704	F	L	VH	36.3	Mod	3.56	0.0138	K	365987	4000967
Freeman	2	2009	1704	F	L	H	34.4	Mod	3.04	0.0296	K	365983	4000961
Freeman	3	2009	1704	F	R	VH	43.3	Ex	6.5	0.1069	K	365987	4000942
Freeman	4	2009	1704	F	R	Mod	24	H	4	0.0248	K	366031	4000919
French Gluch	1	2008	2049	F	L	H	46.3	Mod	3.5	0.0316	K	377838	3925850
French Gluch	1	2008	2049	F	R	Mod	29.7	Mod	3.54	0.0079	K	377841	392832
French Gluch	2	2008	2049	F	R	H	35	H	5.6	0.0996	K	377829	3925870
French Gluch	1	2009	2049	F	L	Ext	46.9	Mod	3.5	0.2805	K	377838	3925850
French Gluch	1	2009	2049	F	R	Mod	29.7	Mod	3.54	0.0119	K	377841	392832
French Gluch	2	2009	2049	F	R	Ext	46.6	H	4.08	0.3048	K	377829	3925870
French Gluch	3	2009	2049	F	R	H	35.7	Low	2.66	0.0585	K	377821	3925913
French Gluch	3	2009	2049	F	L	H	32.2	H	4.62	0.0721	K	377811	3925925
Holby	1	2009	2095	F	L	Mod	28.8	Mod	3.6	0.0202	K	362877	3994727
Holby	1	2009	2095	F	R	High	31.8	Mod	3.32	0.0901	K	362877	3994727
Holby	2	2009	2095	F	L	High	35.1	Low	2.78	0.0594	K	362909	3994586
Kelso	1	2008	1874	M	L	Mod	26.2	VH	5.84	0.0427	K	380091	3924241
Kelso	1	2008	1874	M	L	Mod	22.3	VH	5.84	0.0305	K	380091	3924241
Kelso	3	2008	1874	M	L	Mod	29.2	H	4.32	0.0149	K	380091	3924241
Kelso	1	2009	1874	M	L	Mod	28.9	VH	5.84	0.0335	K	380091	3924241
Kelso	3	2009	1874	M	L	Mod	29.1	H	4.32	0.0272	K	380091	3924241
Kelso	4	2009	1874	M	R	Mod	26.5	L	3	0.0105	K	379998	3924402
Last Chance	1	2009	1766	M	R	Mod	25.6	L	2	0.0069	K	358891	3985369
Last Chance	4	2009	1766	M	R	Mod	25.1	H	4.42	0.0191	K	358882	3985463
Last Chance	5	2009	1766	M	L	H	30.6	VH	5.1	0.0605	K	358880	3985776
Last Chance	6	2009	1766	M	R	M	24	VH	5.22	0.0305	K	358879	3985495
Last Chance	7	2009	1766	M	L	L	17.8	H	5	0.0106	K	358908	3985517
Parker	1	2009	1878	M	L	Ext	55.2	H	3.92	0.2926	K	355113	3981133

Stream	Sta	Year	Elev (m)	Forest/ Meadow	Bank	BEHI	BEHI numeric	NBS	NBS numeric	Erosion (m/yr)	Major WSHD (D-Deer, K-Kern, Ka-Kaweah, T-Tule)	UTM's N (NAD 83)	UTM's E (NAD 83)
Parker	3	2009	1878	M	L	M	29.5	M	3.26	0.0180	K	355094	3980989
Poison	2	2009	2280	M	L	Ext	46.1	Mod	3.52	0.2703	K	374600	3976871
Poison	2	2009	2280	M	R	Ext	46.6	Mod	3.58	0.3110	K	374594	3976906
Poison	3	2009	2280	M	R	Mod	29.6	Low	2.78	0.0094	K	374605	3976878
Salmon	1	2008	2220	M	L	H	38.2	L	2.04	0.0390	K	375569	3974000
Salmon	2	2008	2220	M	R	H	34.4	L	2.1	0.0333	K	375558	3973995
Salmon	-1	2009	2220	M	R	H	36.5	Mod	3.5	0.0585	K	375602	3974001
Salmon	1	2009	2220	M	L	H	36.3	L	2.82	0.0378	K	375569	3974000
Salmon	2	2009	2220	M	R	H	36	L	2.56	0.0518	K	375558	3973995
Taylor	1	2009	2142	F	R	H	38	L	2.72	0.0260	K	383410	3965904
Trout	3	2009	2528	~~F~~	R	L	19.6	Ext	6.56	0.0155	K	377790	3986358
Converse	1	2009	1806	~~F~~	R	Mod	28.3	Mod	3.24	0.0133	Ka	323939	4075289
Converse	1.5	2009	1806	~~F~~	L	Mod	26.1	H	4.02	0.0188	Ka	323928	4075270
Converse	2	2009	1806	~~F~~	L	Mod	33.1	Low	2.7	0.0092	Ka	323938	4075266
Converse	3	2009	1806	~~F~~	L	Mod	16.7	Low	2.96	0.0154	Ka	323954	4075253
Kellog (Trib to Wood..)	2	2009	2150	~~F~~	L	H	29.1	Mod	3.48	0.0393	Ka	334187	4061983
Kellog (Trib to Wood..)	3	2009	2150	~~F~~	L	VH	42.4	Mod	3.28	0.0428	Ka	334180	4062020
Sampson	1	2009	923	~~F~~	L	VH	45.9	L	2.98	0.0287	Ka	313927	4074200
Sampson	1	2009	923	~~F~~	R	VH	42.4	L	2.74	0.0198	Ka	313924	4074196
Sampson	1.5	2009	923	~~F~~	R	Mod	21.6	L	2.68	0.0117	Ka	313914	4074200
Stony	1	2009	1989	~~F~~	R	Mod	24.2	L	2.58	0.0101	Ka	334383	4059715
Tornado	1	2009	1791	~~F~~	L	H	37.9	L	3.72	0.0481	Ka	332681	4072982
Tornado	3	2009	1791	~~F~~	R	Mod	28.3	Mod	3.28	0.0163	Ka	332722	4072979
Bear @ Scicon	1	2009	662	~~F~~	L	H	37.7	Mod	3.2	0.0536	T	341715	4007306
Bear @ Scicon	1.5	2009	662	~~F~~	R	H	32.7	Low	2.92	0.0868	T	341715	4007306

Stream	Sta	Year	Study Bk Ht (m)	Bkf Ht (m)	Study ht/BKF ht	Root Depth (m)	RD/ Study BK Ht	Root Density (%) Field	Root Den (%) Lab	Weighted RD (using field root density)
Capinero	1	2008	0.74981	0.69190	1.08370	0.15240	0.20325	30		0.0610
Capinero	1	2008	1.12776	0.62789	1.79612	0.03048	0.02703	2		0.0005
Capinero	2	2008	1.81661	0.33223	5.46789	0.24384	0.13423	2		0.0027
Capinero	3	2008	1.32283	1.10033	1.20222	0.21336	0.16129	40		0.0645
Capinero	1	2009	0.76200	0.70409	1.08225	0.15240	0.20000	10		0.0200
Capinero	1	2009	0.72542	0.64618	1.12264	0.00000	0.00000	0	6.48	0.0000
Capinero	2	2009	1.72517	0.31699	5.44231	0.39624	0.22968	20		0.0459
Capinero	3	2009	1.32283	1.10033	1.20222	0.36576	0.27650	30	7.27	0.0829
Cedar @ Alder	1	2009	0.60960	0.30480	2.00000	0.00000	0.00000	0	1.62	0.0000
Cedar @ Alder	2	2009	1.05766	0.27432	3.85556	0.15240	0.14409	5	3.24	0.0072
Cedar @ Alder	3	2009	0.28042	0.27127	1.03371	0.06096	0.21739	5	2.1	0.0109
Cedar @ Cedar	1	2009	1.04851	1.04851	1.00000	0.30480	0.29070	5	5.18	0.0145
Cedar @ Cedar	2	2009	0.98755	0.49987	1.97561	0.09144	0.09259	3	2.59	0.0028
Cedar @ Cedar	3	2009	0.25603	0.18593	1.37705	0.03048	0.11905	2	4.85	0.0024
Deer	1	2009	0.81686	0.73152	1.11667	0.24384	0.29851	50		0.1493
Deer	2	2009	0.39624	0.37490	1.05691	0.12192	0.30769	50		0.1538
Deer	2	2009	0.42672	0.26822	1.59091	0.06096	0.14286	10	11.66	0.0143
Bear @ Greenhorn	1A	2009	0.14326	0.10058	1.42424	0.06096	0.42553	5	6.48	0.0213
Bull Run	1.5	2009	0.83210	0.19507	4.26563	0.03048	0.03663	25	12.48	0.0092
Burton Mill	1	2008	0.43586	0.21336	2.04286	0.42672	0.97902	40		0.3916
Burton Mill	2	2008	1.47523	0.17678	8.34483	0.24384	0.16529	60		0.0992
Burton Mill	3	2008	2.99009	0.41758	7.16058	0.67056	0.22426	20		0.0449
Burton Mill	5	2008	0.59436	0.19812	3.00000	0.60960	1.02564	20		0.2051
Burton Mill	6	2008	1.80746	0.28346	6.37634	0.16764	0.09275	20		0.0185
Burton Mill	1	2009	2.13360	0.21946	9.72222	0.91440	0.42857	2	2.59	0.0086
Burton Mill	3	2009	2.99009	0.41758	7.16058	0.60960	0.20387	10		0.0204
Burton Mill	5	2009	1.96596	0.50292	3.90909	0.45720	0.23256	20	10	0.0465
Cannell	2	2008	0.88392	0.36576	2.41667	0.15240	0.17241	60		0.1034
Cannell	3	2008	0.39624	0.31699	1.25000	0.30480	0.76923	70		0.5385
Cannell	4	2008	0.41148	0.30480	1.35000	0.33528	0.81481	50		0.4074
Cannell	2	2009	0.88392	0.36576	2.41667	0.12192	0.13793	30	12.97	0.0414
Cannell	3	2009	0.40538	0.28042	1.44565	0.24384	0.60150	50	10.72	0.3008
Cannell	4	2009	0.39929	0.05791	6.89474	0.30480	0.76336	60	30.51	0.4580
Clear Creek @ Brown	1	2008	0.51816	0.21336	2.42857	0.42672	0.82353	70		0.5765
Clear Creek @ Brown	2	2008	0.44196	0.27432	1.61111	0.42672	0.96552	70		0.6759

Stream	Sta	Year	Study Bk Ht (m)	Bkf Ht (m)	Study ht/BKF ht	Root Depth (m)	RD/ Study BK Ht	Root Density (%) Field	Root Den (%) Lab	Weighted RD (using field root density)
Clear Creek @ Brown	3	2008	0.43586	0.30480	1.43000	0.13716	0.31469	40		0.1259
Clear Creek @ Brown	1	2008	0.51816	0.51816	1.00000	0.15240	0.29412	50		0.1471
Clear Creek @ Brown	2	2008	0.44196	0.42672	1.03571	0.06096	0.13793	50		0.0690
Clear Creek @ Brown	3	2008	0.28042	0.24384	1.15000	0.18288	0.65217	30		0.1957
Clear Creek @ Brown	1	2009	0.46330	0.41758	1.10949	0.15240	0.32895	30	12.56	0.0987
Clear Creek @ Brown	2	2009	0.44196	0.26822	1.64773	0.15240	0.34483	20	5.56	0.0690
Clear Creek @ Brown	3	2009	0.38710	0.28956	1.33684	0.21336	0.55118	20	5.89	0.1102
Fish (Plateu)	1	2009	0.44196	0.73152	0.60417	0.24384	0.55172	50	15	0.2759
Freeman	1	2009	1.07899	0.71933	1.50000	0.15240	0.14124	10	8	0.0141
Freeman	2	2009	0.75895	0.27737	2.73626	0.30480	0.40161	20	13	0.0803
Freeman	3	2009	3.23088	0.57912	5.57895	0.60960	0.18868	10		0.0189
Freeman	4	2009	0.60960	0.51816	1.17647	0.51816	0.85000	20	10	0.1700
French Gluch	1	2008	0.77419	0.32918	2.35185	0.03048	0.03937	10		0.0039
French Gluch	1	2008	0.46939	0.40538	1.15789	0.15240	0.32468	10		0.0325
French Gluch	2	2008	0.37990	0.31992	1.18750	0.03048	0.08023	2		0.0016
French Gluch	1	2009	0.77419	0.21336	3.62857	0.03048	0.03937	10		0.0039
French Gluch	1	2009	0.46939	0.40538	1.15789	0.15240	0.32468	10		0.0325
French Gluch	2	2009	0.32918	0.17069	1.92857	0.03048	0.09259	2		0.0019
French Gluch	3	2009	0.31699	0.23774	1.33333	0.03048	0.09615	5		0.0048
French Gluch	3	2009	0.33833	0.23774	1.42308	0.15240	0.45045	5		0.0225
Holby	1	2009	0.43586	0.34442	1.26549	0.00000	0.00000	50	15	0.0000
Holby	1	2009	0.56693	0.34442	1.64602	0.06096	0.10753	20	10	0.0215
Holby	2	2009	0.43891	0.18898	2.32258	0.00000	0.00000	30	10	0.0000
Kelso	1	2008	0.30480	0.27737	1.09890	0.21336	0.70000	50		0.3500
Kelso	1	2008	0.31090	0.28346	1.09677	0.09144	0.29412	60	22.92	0.1765
Kelso	3	2008	1.45085	1.07899	1.34463	0.15240	0.10504	30	17.167	0.0315
Kelso	1	2009	0.30480	0.32614	0.93458	0.15240	0.50000	40	9.92	0.2000
Kelso	3	2009	0.74981	0.38710	1.93701	0.30480	0.40650	30	17.167	0.1220
Kelso	4	2009	0.67056	0.57912	1.15789	0.30480	0.45455	40	16.19	0.1818
Last Chance	1	2009	0.14630	0.30480	0.48000	0.09144	0.62500	10	3.29	0.0625
Last Chance	4	2009	0.91440	0.55169	1.65746	0.30480	0.33333	40	10.53	0.1333
Last Chance	5	2009	1.13386	1.17043	0.96875	0.30480	0.26882	10	2.59	0.0269
Last Chance	6	2009	0.70714	0.61570	1.14851	0.30480	0.43103	30	12.27	0.1293
Last Chance	7	2009	0.42672	0.42672	1.00000	0.15240	0.35714	30	5.83	0.1071
Parker	1	2009	1.74346	0.29261	5.95833	0.64008	0.36713	10	12.95	0.0367

Stream	Sta	Year	Study Bk Ht (m)	Bkf Ht (m)	Study ht/BKF ht	Root Depth (m)	RD/ Study BK Ht	Root Density (%) Field	Root Den (%) Lab	Weighted RD (using field root density)
Parker	3	2009	0.75286	0.45720	1.64667	0.18288	0.24291	30	12.59	0.0729
Poison	2	2009	0.81382	0.45720	1.78000	0.09144	0.11236	10	3.24	0.0112
Poison	2	2009	0.98146	0.45720	2.14667	0.09144	0.09317	15	11.09	0.0140
Poison	3	2009	0.70104	0.62179	1.12745	0.15240	0.21739	15	3.24	0.0326
Salmon	1	2008	0.76200	0.54864	1.38889	0.60960	0.80000	50		0.4000
Salmon	2	2008	0.67056	0.39624	1.69231	0.51816	0.77273	50		0.3864
Salmon	-1	2009	0.66142	0.34747	1.90351	0.28956	0.43779	30		0.1313
Salmon	1	2009	0.87782	0.65227	1.34579	0.21336	0.24306	30	8.97	0.0729
Salmon	2	2009	0.61570	0.43891	1.40278	0.36576	0.59406	5	3.59	0.0297
Taylor	1	2009	1.26187	0.43891	2.87500	0.21336	0.16908	5	11.98	0.0085
Trout	3	2009	0.41989	0.49987	0.84000	0.30480	0.72590	35	16	0.2541
Converse	1	2009	0.16459	0.12497	1.31707	0.15240	0.92593	5	3.88	0.0463
Converse	1.5	2009	0.67666	0.51816	1.30588	0.30480	0.45045	50	24	0.2252
Converse	2	2009	0.51999	0.39014	1.33281	0.06096	0.11723	30	12.95	0.0352
Converse	3	2009	0.24079	0.21946	1.09722	0.12192	0.50633	60	24.5	0.3038
Kellog (Trib to Wood..)	2	2009	1.13995	0.42062	2.71014	0.15240	0.13369	50	15.6	0.0668
Kellog (Trib to Wood..)	3	2009	0.49987	0.02134	23.42857	0.00000	0.00000	2	11.66	0.0000
Sampson	1	2009	2.52070	0.19812	12.72308	0.30480	0.12092	40	21.2	0.0484
Sampson	1	2009	1.35941	0.25603	5.30952	0.06096	0.04484	5	2.59	0.0022
Sampson	1.5	2009	0.46330	0.43282	1.07042	0.30480	0.65789	30	7.77	0.1974
Stony	1	2009	0.54864	0.62984	0.87108	0.09144	0.16667	20	18.5	0.0333
Tornado	1	2009	0.86868	0.13411	6.47727	0.06096	0.07018	80		0.0561
Tornado	3	2009	0.53986	0.43891	1.23000	0.15240	0.28229	90		0.2541
Bear @ Scicon	1	2009	1.03022	0.53645	1.92045	0.01524	0.01479	2	2	0.0003
Bear @ Scicon	1.5	2009	1.05156	0.35357	2.97414	0.12192	0.11594	50	15.6	0.0580

Stream	Sta	Year	Bank Angle (º)	Surface Protection (%)	Bank Material Adjutment	Drainage Area (m^2)	MIMS
Capinero	1	2008	60	30		9.5	5
Capinero	1	2008	20	2		9.5	5
Capinero	2	2008	40	20	10	9.5	5
Capinero	3	2008	160	5	5	9.5	5
Capinero	1	2009	100	10	-10	9.5	5
Capinero	1	2009	25	0		9.5	5
Capinero	2	2009	50	20	-5	9.5	5
Capinero	3	2009	108	0		9.5	5
Cedar @ Alder	1	2009	85	10		10.4	7
Cedar @ Alder	2	2009	120	10		10.4	5
Cedar @ Alder	3	2009	45	30	5	10.4	7
Cedar @ Cedar	1	2009	70	0	5	3.66	1
Cedar @ Cedar	2	2009	43	5		3.66	5
Cedar @ Cedar	3	2009	120	5		3.66	7
Deer	1	2009	25	80		16.63	6
Deer	2	2009	40	40		16.63	6
Deer	2	2009	20	80		16.63	7
Bear @ Greenhorn	1A	2009	110	0		1.01	5
Bull Run	1.5	2009	70	60		2.67	8
Burton Mill	1	2008	90	5	7	2.43	5
Burton Mill	2	2008	140	5	2	2.43	5
Burton Mill	3	2008	90	5	7	2.43	5
Burton Mill	5	2008	125	5		2.43	5
Burton Mill	6	2008	90	5	5	2.43	5
Burton Mill	1	2009	45	0	5	2.43	5
Burton Mill	3	2009	40	0		2.43	5
Burton Mill	5	2009	100			2.43	5
Cannell	2	2008	50	30	10	5.5	8
Cannell	3	2008	70	80		5.5	9
Cannell	4	2008	30	70	10	5.5	9
Cannell	2	2009	70	10	5	5.5	8
Cannell	3	2009	60	75		5.5	9
Cannell	4	2009	30	80	5	5.5	9
Clear Creek @ Brown	1	2008	50	80	10	0.88	7
Clear Creek @ Brown	2	2008	65	90	10	0.88	7

Stream	Sta	Year	Bank Angle (º)	Surface Protection (%)	Bank Material Adjutment	Drainage Area (m^2)	MIMS
Clear Creek @ Brown	3	2008	90	80	10	0.88	8
Clear Creek @ Brown	1	2008	115	70		0.88	7
Clear Creek @ Brown	2	2008	120	80		0.88	7
Clear Creek @ Brown	3	2008	90	70		0.88	8
Clear Creek @ Brown	1	2009	50	65		0.88	7
Clear Creek @ Brown	2	2009	70	80		0.88	7
Clear Creek @ Brown	3	2009	80	60		0.88	8
Fish (Plateu)	1	2009	90	70		37.62	9
Freeman	1	2009	50	10		8.04	3
Freeman	2	2009	85	40		8.04	7
Freeman	3	2009	80	2		8.04	5
Freeman	4	2009	75	40		8.04	6
French Gluch	1	2008	20	10	7	1.36	5
French Gluch	1	2008	17	10		1.36	5
French Gluch	2	2008	30	5		1.36	5
French Gluch	1	2009	20	10	6	1.36	5
French Gluch	1	2009	17	10		1.36	5
French Gluch	2	2009	30	5	8	1.36	5
French Gluch	3	2009	30	5		1.36	5
French Gluch	3	2009	30	5		1.36	5
Holby	1	2009	40	90		4.66	8
Holby	1	2009	70	75		4.66	6
Holby	2	2009	30	50		4.66	7
Kelso	1	2008	45	70	10	14.94	8
Kelso	1	2008	50	90	2	14.94	8
Kelso	3	2008	70	40	-4	14.94	5
Kelso	1	2009	60	60	10	14.94	8
Kelso	3	2009	65	60		14.94	5
Kelso	4	2009	30	10		14.94	7
Last Chance	1	2009	90	80		5.3	8
Last Chance	4	2009	55	90		5.3	9
Last Chance	5	2009	83	20		5.3	8
Last Chance	6	2009	85	90		5.3	8
Last Chance	7	2009	20	95		5.3	8
Parker	1	2009	130	1	10	4.35	5

Stream	Sta	Year	Bank Angle (°)	Surface Protection (%)	Bank Material Adjutment	Drainage Area (m^2)	MIMS
Parker	3	2009	35	40		4.35	8
Poison	2	2009	80	5	5	0.62	6
Poison	2	2009	120	5		0.62	6
Poison	3	2009	40	20		0.62	6
Salmon	1	2008	150	50	10	26.22	8
Salmon	2	2008	110	90	10	26.22	8
Salmon	-1	2009	135	90	5	26.22	8
Salmon	1	2009	145	30		26.22	8
Salmon	2	2009	115	85	10	26.22	8
Taylor	1	2009	45	20		3.62	6
Trout	3	2009	110	95		4.3	7
Converse	1	2009	40	10		1.86	6
Converse	1.5	2009	110	90		1.86	7
Converse	2	2009	38	20		1.86	6
Converse	3	2009	55	90		1.86	7
Kellog (Trib to Wood..)	2	2009	10	80		1.39	6
Kellog (Trib to Wood..)	3	2009	30	0		1.39	6
Sampson	1	2009	55	10	5	10.17	5
Sampson	1	2009	30	3		10.17	6
Sampson	1.5	2009	85	70		10.17	7
Stony	1	2009	70	90		14.74	7
Tornado	1	2009	80	50		1.8	7
Tornado	3	2009	130	90		1.8	6
Bear @ Scicon	1	2009	100	80		21.15	5
Bear @ Scicon	1.5	2009	55	80		21.15	5