# Recovery Potential Metrics
# Summary Form

**Indicator Name:** BANK STABILITY/SOILS

**Type:** Ecological Capacity

**Rationale/Relevance to Recovery Potential:** Specifically at the banks of rivers and streams as well as lakes, soils that are unstable are prone to continual erosion and greater likelihood of excess sediment load. Destabilizing forces can include the absence of woody and/or herbaceous vegetation, an unstable channel form (e.g. cut banks), or the soil type itself may be erosion-prone. Continual erosion and excess sediment are often linked to instream habitat degradation and diminished spawning success of lithophilic spawners, and may also add to other impairments involving nutrients or water temperature.

**How Measured:** Depending upon soil survey data available, specific soil types are rated as 'highly erosive'. Measurements for this metric could be based on % of stream length passing through highly erosive soil types, or alternatively for lakes, % of shoreline with highly erosive soil types. If a small buffer is applied to the streams and lakes, then the measurement can be based on the % of area in the buffered corridor that contains highly erosive soil types.

**Data Source:** Physical properties of soils are available for most areas as part of the US General Soils Map through the NRCS Soil Data Mart (See: http://soildatamart.nrcs.usda.gov/ ).

**Indicator Status (check one or more)**

_______ Developmental concept.
__x___ Plausible relationship to recovery.
_______ Single documentation in literature or practice.
__x___ Multiple documentation in literature or practice.
_______ Quantification.

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**Examples from Supporting Literature (abbrev. citations and points made):**

- (Hillman, M. and G Brierley. 2005) The key to developing proactive programs that pre-empt change and enhance natural recovery lies in recognizing and working with catchment-scale linkages of biophysical processes and negating the potential for off-site impacts. Projects that fail to consider current trends in sediment delivery and the dominant fluvial processes in the reach are likely to require costly maintenance, or fail to achieve their intended goal (Sear *et al.*, 1995; Sear, 1996).
- (Wang 2001) Dyer *et al*. (1998a) applied a multivariate forward stepwise regression model to determine the relative importance of water chemistry and habitat on biological indicators in the Little Miami River watershed. Their study concluded that the habitat quality was primarily responsible for the biological integrity of receiving waters in the watershed.
- (Novotny et al., 2005) The models [for assessing ecological integrity] (functions) link the individual risks and consider their synergy, addictivity, or antagonism. The risks include:
    - (1) Pollutant (chemical) risks, acute and chronic, in the water column
        - Key metrics: Priority (toxic) pollutants, DO, turbidity (suspended sediment), temperature, pH.
    - (2) Pollutant risk (primarily chronic) in sediment
        - Key metrics: Priority pollutants, ammonium, DO in the interstitial layer (anoxic/anaerobic or aerobic), organic and clay content.
    - (3) Habitat degradation risk

Key metrics: Texture of the sediment, clay and organic contents, embeddedness, pools and riffle structure, bank stability, riparian zone quality, channelization and other stream modifications.

(4) Fragmentation risk

Key metrics:
Longitudinal—presence of dams, drop steps, impassable culverts.
Lateral—Lining, embankments, loss of riparian habitat (included in the habitat evaluation), reduction or elimination of refugia.
Vertical—lack of stream-groundwater interchange, bottom scouring by barge traffic, thermal stratification/heated discharges, bottom lined channel (190).

- (Nelson and Booth 2002) Sources of fine sediment, nearly two-thirds of the sediment production, are dominated by landslides (49%), followed by forested gravel roads (10%) and urban sediment production from residential and commercial areas (9%). Other sources that contribute significant percentages of fine sediment to the budget are channel-bank erosion (8%) and gravel-residential and paved roads (7%) (Fig. 5). Only three processes evaluated for this sediment budget contribute coarse sediment to the overall budget: landslides, soil creep, and channel-bank erosion. Again, the dominant coarse sediment-producing process is landsliding activity (54%). Channelbank erosion supplies 43% of the coarse sediment, with the remainder attributed to soil creep (62).
- (Ducros and Joyce 2003) The three criteria that varied from the usual scoring range were the WFO agreement adopted, stream lower-bank stability, and vegetation type within the buffer zone. In the first exception, the WFO agreement, scores ranged from 15 to 40 with greater value placed on 20-year withdrawal and arable conversion agreements (Table 2). This scoring range recognized that the type of WFO agreement was potentially a particularly important influence on riparian condition in this study. It also reflects the long-term nature of environmental enhancement and the potential habitat and water quality benefits of converting arable cropland to more natural vegetation (Dosskey 2001, Kemp and Dodds 2001). Furthermore, it was recognized that all WFO agreements potentially have considerable environmental benefit, so the minimum score possible was raised to 15. The second exception to the normal range of scores was for stability of the lower bank of the buffered stream. This criterion featured a depressed maximum score of 25 (Table 2) as lower-bank stability is not a substantial contributor to environmental enhancement in riparian zones compared, for example, to upper-bank character (Cooper and others 1987). The final exception related to the physical type or structure of vegetation in the buffer zone, which was assessed by recording the percentage of different vegetation types in the field and allocating a score based on the proportion of each vegetation type present (Table 2). Thus, a buffer zone with 50% woodland cover and 50% open ground would score 50% of 30 points (15) for the woodland and 50% of 10 points (5) for the open ground, yielding a total of 20 points. The minimum score assigned to this criterion was 10, as even the lowest category of open vegetation, such as low grasses, represents valuable wildlife habitat and can contribute to effective buffer zone functioning (Lyons and others 2000) (255).
- (Ducros and Joyce 2003) Land use in the Yorkshire catchment featured a high proportion of crops, which in this system was not rated highly for buffer zone effectiveness, but the landscape was also characterized by positive attributes, namely gentle slopes and few rills or gullies (Figure 1) (262).
- (Ducros and Joyce 2003) The Wiltshire buffer zones featured a number of positive attributes. Most were over 40 m wide, none had severe erosion indicators such as rills and gullies, and slope and soil characteristics were generally well suited to water retention and denitrification (Figure 1). Some streambanks in the Wiltshire catchment were steep, with few plant species and low cover (especially the lower banks), but most were stable and featured little or no undercutting. Buffered stream channels were also characterized by excellent supplies of organic detritus and good habitat quality and vegetation diversity, but more variable retention features (262).

- (Ducros and Joyce 2003) High scores were due to gentle landscape and buffer slopes, wide buffer zones, little or no erosion, and soils that are suited to retain water and promote denitrification.

  The Devon catchment received an unweighted score for its buffer zones (73%) that was just below the Wiltshire catchment score and exhibited the best vegetation-related scores of the three catchments (Figure 2). This was due to the abundant cover and high diversity of vegetation in the buffer zones and on their stream banks. In contrast, the hydrology-weighted and, particularly, hydrology-only scores were relatively low for the Devon catchment, largely because the soils were likely to be ineffective for water retention and denitrification (262).
- (Ducros and Joyce 2003) Scores tended to be depressed by the poor vegetation diversity and structure in buffer zones and on stream banks, as well as bank instability and undercutting, perhaps related to the intensive arable land use that characterized the Yorkshire catchment (263).
- (Ducros and Joyce 2003) The buffer zones in Wiltshire were generally wide and located on gently sloping land with slowly permeable soils and few rills or other erosion features (Figure 1), which should encourage water retention, and consequently opportunities for denitrification (Burt and others 1999). Nonetheless, apparent weaknesses were identified on the Wiltshire buffer zones, particularly concerning bank vegetation diversity and cover. There was a uniformity of vegetation along the stream channel banks and a lack of bank habitat features, although these could be remedied through soft engineering techniques (e.g., tree planting, stream deflectors, planting shrubs and trees for bank stability) (263-264).
- (Poiani et al., 2000) Channel sinuosity and lateral channel migration rates had changed relatively abruptly over the simulation period, suggesting channel instability. The Yampa River may have crossed a geomorphic threshold from a meandering to a braided channel. Narrowleaf cottonwood requires fresh alluvial deposits for seedling establishment, where subsequent floods will not destroy newly germinated seedlings. Although sufficient fresh depositional surfaces were still being produced in recent decades, these deposits no longer formed within protected meander bends but instead formed as mid-channel islands and lateral bars. Such changes in geomorphic processes have direct implications for cottonwood establishment, and they likely result in part from decreased bank stability due to deforestation of stream banks during the past century (Richter 1999) (143).
- (Ramos-Scharrón and MacDonald 2007) The disturbance associated with land development generally increases erosion and sediment yields (Walling, 1997). The significance and potential impact of increased sediment yields is of particular concern in forested areas because natural erosion rates are so low (Dunne, 2001) (250).
- (Sheilds, Knight, and Cooper 1998) Channel incision has major impacts on stream corridor ecosystems, leading to reduced spatial habitat heterogeneity, greater temporal instability, less stream-floodplain interaction, and shifts in fish community structure. Most literature dealing with channel incision examines physical processes and erosion control. A study of incised warmwater stream rehabilitation was conducted to develop and demonstrate techniques that would be economically feasible for integration with more orthodox, extensively employed watershed stabilization techniques (e.g., structural bank protection, grade control structures, small reservoirs, and land treatment). One-km reaches of each of five northwest Mississippi streams with contributing drainage areas between 16 and 205 $km^2$ were selected for a 5-year study. During the study two reaches were modified by adding woody vegetation and stone structure to rehabilitate habitats degraded by erosion and channelization. The other three reaches provided reference data, as two of them were degraded but not rehabilitated, and the third was only lightly degraded. Rehabilitation approaches were guided by conceptual models of incised channel evolution and fish community structure in small warmwater streams. These models indicated that rehabilitation efforts should focus on aggradational reaches in the downstream portions of incising watersheds, and that ecological status could be improved by inducing formation and maintenance of stable pool habitats. Fish and

physical habitat attributes were sampled from each stream during the Spring and Fall for 5 years, and thalweg and cross-section surveys were performed twice during the same period. Rehabilitation increased pool habitat availability, and made the treated sites physically more similar to the lightly degraded reference site. Fish communities generally responded as suggested by the aforementioned conceptual model of fish community structure. Species composition shifted away from small colonists (principally cyprinids and small centrarchids) toward larger centrarchids, catostomids, and ictalurids. Fish density and species richness increased at one rehabilitated site but remained stable at the other, suggesting that the sites occupied different initial states and endpoints within the conceptual model, and differed in their accessibility to sources of colonizing organisms. These experiments suggest that major gains in stream ecosystem rehabilitation can be made through relatively modest but well-designed efforts to modify degraded physical habitats (63).

- (Yuan, Bingner, and Locke 2009) It was found that although sediment trapping capacities are site- and vegetation-specific, and many factors influence the sediment trapping efficiency, the width of a buffer is important in filtering agricultural runoff and wider buffers tended to trap more sediment. Sediment trapping efficiency is also affected by slope, but the overall relationship is not consistent among studies. Overall, sediment trapping efficiency did not vary by vegetation type and grass buffers and forest buffers have roughly the same sediment trapping efficiency (312).
- (Yuan, Bingner, and Locke 2009) Vegetative buffer strips significantly reduce sediment loading in surface runoff from agricultural fields based on above reviews. Buffers remove sediment from the overland flow by decreasing its velocity and allowing particles to settle. Increased water infiltration into the soil profile within buffer zones also aids in sediment interception by decreasing the amount of runoff. The effectiveness of buffers in removing sediment varied widely among the studies (Appendix A). Sediment trapping efficiency, which was defined as the capacity of a buffer to retain a fraction of sediment from incoming runoff, is typically used to define the buffer effectiveness. Overall results showed that the trapping efficiency in buffers depends primarily on buffer width, vegetation type, density and spacing, sediment particle size, slope gradient and length, and flow convergence. Other factors also affect sediment trapping efficiency include soil properties, initial soil water content, and rainfall characteristics (total amount and intensity) (327).
- (Wynn, Henderson, and Vaughan 2007) Streambank retreat is a function of multiple processes working in concert to cause what is casually referred to as “streambank erosion” (Lawler et al., 1997). In reality, research has identified three main processes by which most “erosion” occurs: subaerial processes, fluvial entrainment, and mass wasting (Hooke, 1979; Lawler, 1992, 1995; Lawler et al., 1997; Couper and Maddock, 2001; Wynn and Mostaghimi, 2006b) (260).
- (Wynn, Henderson, and Vaughan 2007) The study goal was to evaluate temporal changes in soil erodibility ($k_d$) and critical sheer stress ($\tau_c$) from soil desiccation and freeze–thaw cycling. Soil erodibility and critical sheer stress were measured monthly in situ using a multiangle, submerged jet test device. Soil moisture, temperature, and bulk density as well as precipitation, air temperature, and stream stage were measured continuously to determine changes in soil moisture content and state. Pairwise Mann–Whitney tests indicted $k_d$ was 2.9 and 2.1 times higher (p<0.0065) during the winter (December–March) than in the spring/fall (April–May, October–November) and the summer (June–September), respectively. Regression analysis showed 80% of the variability in $k_d$ was explained by freeze–thaw cycling alone. Study results also indicated soil bulk density was highly influenced by winter weather conditions (r2=0.86): bulk density was inversely related to both soil water content and freeze–thaw cycling. Results showed that significant changes in the resistance of streambank soils to fluvial erosion can be attributed to subaerial processes. Water resource professionals should consider the implications of increased soil erodibility during the winter in the development of channel erosion models and stream restoration designs (260).

- (Baker and Richards 2002) In Ohio, the P reductions were further allocated to individual counties, based on their cropland acreage in the Lake Erie basin. Since 75 to 80% of the TP loading was particulate P associated with total suspended sediment (TSS) transport, plans for reducing nonpoint sources of P focused exclusively on reductions associated with various erosion control programs. Phosphorus reduction credits were awarded to counties based on increasing acreage of various conservation measures relative to 1982 levels. Phosphorus reduction credits of 1.44 kg P $ha^{-1}$ were allocated for increases in set-aside, Conservation Reserve Program, and hay acreage; 1.14 kg P $ha^{-1}$ for increases in wheat *(Triticum aestivum* L.) and oat *(Avena sativa* L.); and 0.82 kg P $ha^{-1}$ for conservation tillage. These reduction credits were based on the proportional reduction in erosion associated with these practices, and the P content of the suspended sediments from northwestern Ohio rivers (96).
- (Carline and Walsh 2007) Riparian treatments, consisting of 3- to 4-m buffer strips, stream bank stabilization, and rock-lined stream crossings, were installed in two streams with livestock grazing to reduce sediment loading and stream bank erosion. Cedar Run and Slab Cabin Run, the treatment streams, and Spring Creek, an adjacent reference stream without riparian grazing, were monitored prior to (1991–1992) and 3–5 years after (2001–2003) riparian buffer installation to assess channel morphology, stream substrate composition, suspended sediments, and macroinvertebrate communities. Few changes were found in channel widths and depths, but channel-structuring flow events were rare in the drought period after restoration. Stream bank vegetation increased from 50% or less to 100% in nearly all formerly grazed riparian buffers. The proportion of fine sediments in stream substrates decreased in Cedar Run but not in Slab Cabin Run. After riparian treatments, suspended sediments during base flow and storm flow decreased 47–87% in both streams. Macroinvertebrate diversity did not improve after restoration in either treated stream. Relative to Spring Creek, macroinvertebrate densities increased in both treated streams by the end of the posttreatment sampling period. Despite drought conditions that may have altered physical and biological effects of riparian treatments, goals of the riparian restoration to minimize erosion and sedimentation were met. A relatively narrow grass buffer along 2.4 km of each stream was effective in improving water quality, stream substrates, and some biological metrics (731).
- (Selvakumar, O'Connor, and Struck 2010) This project monitored the effects of a 549 m (1,800 linear-ft) restoration of degraded stream channel in the North Fork of Accotink Creek. Restoration, which was intended to restore the stream channel to a stable condition, thereby reducing stream bank erosion and sediment loads in the stream, included installation of native plant materials along the stream and bioengineering structures to stabilize the stream channel and bank. Results of sampling and monitoring for 2 years after restoration indicated a slight improvement in biological quality for macroinvertebrate indices such as Virginia Stream Condition Index, Hilsenhoff Biotic Index, and Ephemeroptera, Plecoptera, Trichoptera taxa; the differences were statistically significant at 90% level of confidence with the power of greater than 0.8. However, indices were all below the impairment level, indicating poor water quality conditions. No statistically significant differences in chemical constituents and bacteriological indicator organisms were found before and after restoration as well as upstream and downstream of the restoration. The results indicated that stream restoration alone had little effect in improving the conditions of in-stream water quality and biological habitat, though it has lessened further degradation of stream banks in critical areas where the properties were at risk. Control of storm-water flows by placing best management practices in the watershed might reduce and delay discharge to the stream and may ultimately improve habitat and water quality conditions (127).
- (Selvakumar, O'Connor, and Struck 2010) One of the top causes of river and stream impairment is sediment or siltation. The National Water Quality Inventory 2000 Report (U.S. EPA 2002) estimated that about 30% of identified cases of water quality impairment are attributable to storm-water runoff (127).
- (Selvakumar, O'Connor, and Struck 2010) Natural streams follow meandering patterns, which dissipates energy and minimizes scouring of the streambed and banks. Increased

stream flows impact the natural stream channel morphology, which affects the physical, chemical, and biological integrity of the stream (Natural Resources Conservation Service 1998). Stream channels respond to increased stream flows by increasing their cross-sectional area through widening of the stream banks and down cutting of the stream bed. This, in turn, triggers a cycle of stream bank erosion and habitat degradation (Schueler 1994). Stream bank erosion can lead to bank instability and increased sediment loading downstream. This increased sediment load may cause water quality degradation, negatively impacting fish, benthic invertebrates, and other aquatic life in the stream. Channel instability and the loss of in-stream habitat structure, such as the loss of pool, run, and riffle sequences, also results from increased stream flows leading to degraded habitat for aquatic life. Klein (1979) noted that macroinvertebrate diversity drops sharply in urban streams in Maryland as a result of increased imperviousness (128).

- (Mattisoff, Bonniwell, and Whiting 2002) Soil cores and suspended sediments were collected within the Old Woman Creek, Ohio (OWC) watershed following a thunderstorm and analyzed for $^{7}$Be, $^{137}$Cs, and $^{210}$Pb activities to compare the effects of till vs. no-till management on soil erosion and sediment yield. The upper reaches of the watershed draining tilled agricultural fields were disproportionately responsible for the majority of the suspended sediment load compared with lower in the watershed (2.0–7.0 metric tons/ km2 [Mg/km$^2$] vs. 1.2–2.6 Mg/km$^2$ ). About 6 to 10 times more sediment was derived from the subbasins that are predominantly tilled (6.8–12.4 Mg/km$^2$) compared with the subbasins undergoing no-till practices (0.5–1.1 Mg/km$^2$ ). In undisturbed soils the $^{210}$Pb activities decreased with movement toward the bottom of the cores to the constant supported $^{210}$Pb value at a depth of about 10 cm. There was a subsurface maximum in $^{137}$Cs activity within the top 10 cm. In contrast, the $^{210}$Pb and $^{137}$Cs distributions in soils that are currently or were previously tilled were nearly homogeneous with depth, reflecting continuing or previous mixing by plowing. The activities of $^{210}$Pb and $^{7}$Be were linearly correlated and were higher in suspended sediments derived from no-till subbasins than those derived from tilled subbasins, indicating that the soil surface is the source of suspended sediment. This study demonstrates that no-till farming results in decreases in soil and decreases in suspended sediment discharges and that those eroded sediments have a radionuclide signature corresponding to the tillage practice and the depth of erosion (54).
- (Mattisoff, Bonniwell, and Whiting 2002) Sediment eroded from a soil will have a radionuclide signature corresponding to the tillage practice and the depth of erosion. Thus, radionuclide signatures in suspended sediments can provide a means of tracing particles eroded from the landscape and can identify soil sources and be used to quantify the erosion (61).
- (Calhoun, Baker, and Slater 2002) This review of previous water quality studies was to examine more closely the influence of soil properties on pollutant export. The approach used in this paper was to start with data from the two largest watersheds (Maumee and Sandusky) and then compare them on a unit area export basis with data from intermediate-size and smaller watersheds. General relationships between pollutant levels at the river mouth and upstream soil conditions are vague and seemingly contradictory at the large-watershed scale. With smaller watersheds, it can be determined that soil texture, slope, and internal drainage are controlling factors for pollutant export (47).
- (Calhoun, Baker, and Slater 2002) Clayey, lake plain soils that are not tile-drained are greater sources of suspended solids than are the loamy soils found on moraines. Tile-drained soils in the lake plains export more nutrients such as nitrates and phosphates, in solution, than do the better-drained, sloping soils on moraines. Tile-drained soils of the lake plains export substantially less sediment than do the non–tile drained soils. It is obvious that greater attention must be given to the lake plains of the Maumee and Sandusky proved agricultural management practices. The assumption that sloping moraine areas are the primary source of pollutants should be reexamined based on this review. Careful examination of upstream water quality studies reveals the importance of the soil series in explanation of pollutant export from rural landscapes (53).

- (Wynn 2006) A number of soil parameters influence the susceptibility of a cohesive soil to erosion, including grain size distribution, soil bulk density, clay type and content, organic matter content, and soil pore water content and chemistry (Grissinger, 1982). Research has shown that increases in the silt-clay content of soils increases their resistance to entrainment (Thorne and Tovey, 1981; Osman and Thorne, 1988). In contrast, soils with high silt-clay contents are more susceptible to the effects of subaerial processes, which make the soils less resistant to erosion by hydraulic forces (Couper, 2003) (5).
- (Wynn 2006) It is well recognized that the resistance of streambank soils to fluvial entrainment changes over time as soil moisture and temperature fluctuate. Several researchers have observed that bank erosion is greatest during the winter and have attributed this to freezing of streambanks (Wolman, 1959; Lawler, 1986; Stott, 1997). Freezing of the streambank surface causes a migration of soil water to the bank surface, increasing the local moisture content. Also, as the soil water freezes and expands, it increases the soil volume (Lawler, 1993). This increase in moisture content and decrease in density due to freeze-thaw cycling makes soils more susceptible to fluvial erosion (5).
- (Wynn 2006) Bank failure, also known as mass wasting, occurs when the weight of the bank is greater than the shear strength of the soil. It often results from increases in bank height or bank angle due to fluvial erosion and the presence of tension cracks (ASCE, 1998). Mass wasting depends on bank geometry and stratigraphy, properties of the bank materials, and the type and density of bank vegetation (Thorne, 1990) (5).
- (Wynn 2006) Mass failures often occur following floods. Precipitation and a rising stream stage increase the moisture content and weight of bank soils. At the same time, apparent soil cohesion is decreased through the reduction of matric suction. If rainfall is prolonged, positive pore pressures may develop, resulting in a decrease in frictional soil strength. Additionally, the bank height or angle may be increased as flood waters scour the channel bed or bank toe (basal area). These changes, combined with a rapid loss of confining pressure as the stream stage recedes, can trigger mass failures (5).
- (Wynn 2006) Riparian vegetation has multiple effects on subaerial processes. A dense cover of vegetation absorbs the energy of rainfall, reducing soil detachment by raindrop impact (Coppin and Richards, 1990). Vegetation insulates the streambank from extreme temperature fluctuations (Abernethy and Rutherfurd, 1998). This insulation minimizes the occurrence of freezing and cracking due to desiccation (Thorne, 1990). The influence of vegetation on stream hydraulics has long been recognized (Zimmerman et al., 1967). Vegetation provides increased channel roughness, directing flows towards the center of the channel and reducing flow velocities and shear stresses along the banks (Thorne and Furbish, 1995). Since sediment transport capacity is proportional to flow velocity to the sixth power (v6), small decreases in stream velocity can result in large changes in sediment transport (Thorne, 1990). Additionally, vegetation damps near bank turbulence and weakens secondary currents in river bends, further reducing fluvial erosion (Thorne and Furbish, 1995) Researchers have also found that woody and herbaceous roots significantly increased slope stability over bare conditions (Waldron and Dakessian, 1982; Shields and Gray, 1992). The root systems of woody and herbaceous plants act to stabilize banks by increasing soil shear strength (Simon and Collison, 2001) (6).
- (Zaimes, Schultz, and Isenhart 2008) Riparian land-uses can heavily influence streambank erosion. The objective of this study was to compare streambank erosion along reaches of row-cropped fields, continuous, rotational and intensive rotational grazed pastures, pastures where cattle were fenced out of the stream, grass filters and riparian forest buffers, in three physiographic regions of Iowa. ….Riparian forest buffers had the lowest Streambank erosion rate (15-46 mm⁄ year) and contributed the least soil (5-18 tonne⁄km⁄ year) and phosphorus (2- 6 kg⁄km⁄ year) to stream channels. Riparian forest buffers were followed by grass filters (erosion rates 41- 106 mm⁄ year, soil losses 22-47 tonne⁄km⁄ year, phosphorus losses 9-14 kg⁄km⁄ year) and pastures where cattle were fenced out of the stream (erosion rates 22-58 mm⁄ year, soil losses 6-61 tonne⁄km⁄ year, phosphorus losses 3-34 kg⁄km⁄ year). The streambank erosion rates for the continuous, rotational, and intensive rotational pastures were 101-171, 104-122, and 94-170 mm⁄ year, respectively. The soil losses for the continuous, rotational, and intensive

rotational pastures were 197-264, 94-266, and 124-153 tonne/km/ year, respectively, while the phosphorus losses were 71-123, 37-122, and 66 kg/km/ year, respectively (935).

- (Parker, Simon, and Thorne 2008) The study demonstrates the importance that the variability of effective bank material properties has on bank stability: at both the micro-scale within a site, and at the meso-scale between sites in a reach. This variability was shown to have important implications for the usage of the Bank Stability and Toe Erosion Model (BSTEM), a deterministic bank stability model that currently uses a single value to describe each bank material property. As a result, a probabilistic representation of effective bank material strength parameters is recommended as a potential solution for any bank stability model that wishes to account for the important influence of the inherent variability of soil properties (533).