Stream Bank Sediments and Nutrient Content

The 2014 Expert Panel looked at a group of studies that evaluated the capability of stream restoration projects to prevent channel enlargement within a project reach, and retain bank and floodplain sediments (and attached nutrients) that would otherwise be lost from the reach. Stream restoration practices that increase the resistance of the stream bed and banks to erosion or reduce channel and/or floodplain energy to greatly limit the ability for erosive conditions can be expected to reduce the sediment and nutrient load delivered to the stream. The magnitude of this reduction is a function of the pre-project sediment supply from channel degradation in direct proportion to the length of erosion-prone stream bed and banks that are effectively treated.

Sediment reduction due to stream restoration is largely attributed to the stabilization of the bed and banks within the channel. Sediment correlation studies indicate that upland erosion and channel enlargement are significant components of the sediment budget (Allmendinger et al., 2007) and erosion and deposition values are higher in unstable reaches (Bergmann and Clauser, 2011). In a study monitoring sediment transport and storage in a tributary of the Schuylkill River in Pennsylvania, Fraley et al. (2009) found that bank erosion contributed an estimated 43% of the suspended sediment load, with bed sediment storage and remobilization an important component of the entire sediment budget.

Most studies define the rate of bank retreat and estimate the mass of prevented sediment using bank pins and cross-sectional measurements within the restored stream reach. The studies may also sample the soil nutrient content in bank and floodplain sediments to determine the mass of nutrients lost via channel erosion. This measurement approach provides robust long-term estimates for urban streams that are actively incising or enlarging. The "prevented" sediment effect can be masked in other reach studies unless they capture the range of storms events that induce bank erosion.

Nutrient content in stream bank and floodplain sediments is therefore a major consideration. Table 1 compares the TP and TN content measured in various parts of the urban landscape, including upland soils, street solids, and sediments trapped in catch basins and BMPs. As can be seen in Table 5, the four Pennsylvania and Maryland studies that measured the nutrient content of stream sediments consistently showed higher nutrient content than upland soils, and were roughly comparable to the more enriched street solids and BMP sediments.

Table 1. TN and TP Concentrations in Sediments in Different Parts of the Urban Landscape[1]

Location	Mean TP	TP Range	Mean TN	TN Range	Location	Reference
Upland Soils	0.18	0.01-2.31	3.2	0.2-13.2	MD	Pouyat et al., 2007
Street Solids	2.07	0.76-2.87	4.33	1.30-10.83	MD	Diblasi, 2008

Catch Basin [3]	1.96	0.23-3.86	6.96	0.23-25.08	MD	Law et al., 2008
BMP Sediments	1.17	0.06-5.51	5.86	0.44-22.4	National	Schueler, 1994
Streambank Sediments	0.439	0.19-0.90	--	--	MD	BDPW, 2006
	1.78		5.41		MD	Stewart, 2012
	1.43	0.93-1.87	4.4	2.8-6.8	PA	Land Studies, 2005 [2]
	1.05	0.68-1.92	2.28	0.83-4.32	PA	Walter et al., 2007 [2,4]

[1] all units are lb/ton

[2] the Pennsylvania data on streambank sediments were in rural/agricultural subwatersheds

[3] catch basin values are for sediment only, excluding leaves

[4] median TN and TP values are reported

Streambank erosion and urban sediment yield.

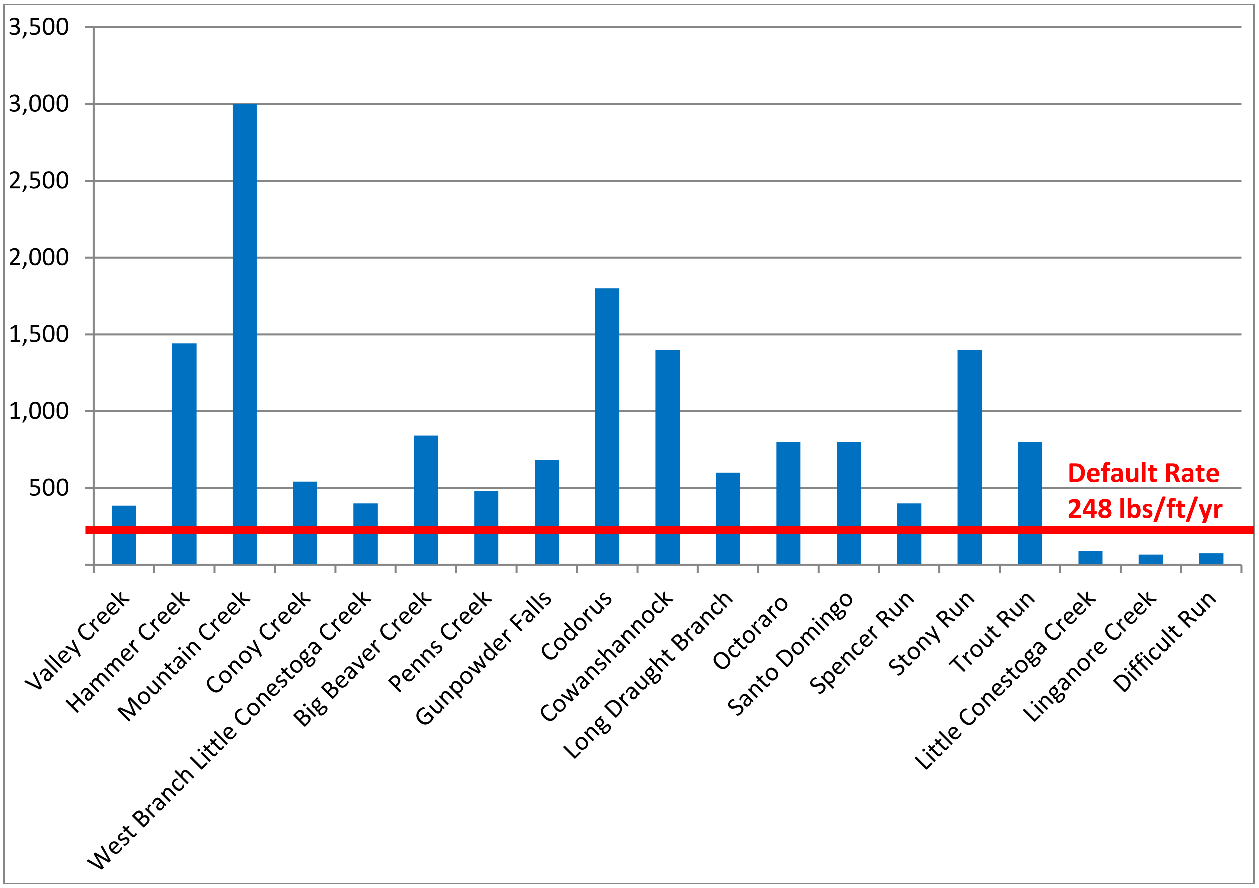
Recent research has confirmed the importance of bank erosion in urban sediment yield. Donovan et al (2015) found that bank erosion accounted for an average of 70% of annual sediment yield in 18 small watersheds sampled in Baltimore County, MD. The headwater stream network was the source of most measured erosion, a majority of which was derived from legacy sediment.

Their findings are generally consistent with other recent geomorphic research conducted across the Bay watershed (Gellis et al 2017, Allemendiger et al 2007, Bergman and Clausen 2011, Fraley et al 2009, Merritts et al 2010, Miller and Kochel 2010, Alexander et al, 2007, Smith and Wilcock, 2015 and Pizzuto et al, 2010). Stream and floodplain geomorphic condition is also influence by vegetation (Trible 2013).

Sediment reduction due to stream restoration is largely attributed to the stabilization of the beds and banks within the channel. The 2014 Expert Panel analyzed sediment loading rates from stream channel erosion in 19 unrestored streams in Maryland and Pennsylvania, which were typically found to range between 300 to 1500 lb/ft/yr (CBP 2014a; Land Studies 2005).

The graph was omitted from the panel report, but is reproduced in Figure 1. The red bar shows the stream erosion rate that was used for estimating the Default Rate in the 2014 EP Report. These estimates came from several streams in Pennsylvania and Maryland (BDPW, 2006 and Land Studies 2005).

Figure 1. Streambank Erosion Rate (lb/ft/year) at Edge of Field Across 19 Sites in Maryland and Pennsylvania.



Research on BANCS Method

The following table outlines the field research to test how well the BANCS method can estimate the rate of lateral bank retreat in watersheds across the U.S. and Canada

Table B-1 **Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review**			
Source	**Location**	**Application**	**Results/Recommendations**
Shields River Watershed WQ Planning Framework & Sediment TMDLs (MDEQ, 2009a)	Shields River Watershed, south-central MT. Confined by mountains to the west and east and flows to the Yellowstone River	The BANCS Method was applied to HUC 6 watersheds at 16 reaches along Potter Creek and Shields River and in 13 additional tributary reaches within the TMDL Planning Area to estimate bank erosion for development of a sediment TMDL. The assessment method excluded 100% naturally eroding banks from the extrapolation and potential loads are assumed to be a combination of natural loads and anthropogenic loads associated with the use of reasonable land, soil, and water conservation practices.	Bank erosion was found to contribute 103,000 tons of sediment annually to water bodies within the Shields River TMDL Planning Area. The bank erosion method focuses on both sediment production and sediment delivery and also incorporates large flow events via the method used to identify bank area and retreat rates. Therefore, a significant portion of the bank erosion load is based on large flow events versus typical yearly loading. Uncertainty in loading estimates is addressed through an adaptive management approach where the TMDL and allocations can be revised as additional information is collected.
Estimating Bank Erosion in the Wissahickon Creek Watershed - Conference Presentation (Haniman, 2009)	Wissahickon Creek Watershed near Philadelphia, PA	The BANCS Method was applied to 12 tributaries of the Wissahickon Watershed between Oct 2005 – Aug 2006. Bank pins were installed at 82 sites from 2006-2008.	The BANCS method predicted 4.2 million lbs of erosion/year. The bank pins estimated 2.3 million lbs of erosion/year (95% CI, +/- 2.5 million lbs/year). The BANCS Method predicts erosion within an order of magnitude.

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
			Bank erosion curves are difficult to develop. Understanding channel evolution is key.
Application of Rosgen's BANCS Model for NE Kansas and the Development of Predictive Streambank Erosion Curves (Sass and Keane, 2012)	The Black Vermillion Watershed, glaciated region of KS, northeast of the Flint Hills Ecoregion	3 subwatersheds were selected in the Vermillion Watershed with varied land uses and conservation practices, varied channel modification, and varied riparian corridor management. Each subwatershed included 3 study reaches. Streams in the watershed are low gradient (<0.01), typically entrenched, straightened through channelization, and have high vertical banks. The BANCS Method was conducted for the study reaches, in addition to streambank profiles (with erosion pins as a measurement check). The goal was to provide a tool that can accurately predict annual streambank erosion rates and sediment contributions from channel banks in Northeast Kansas.	The erosion prediction curves developed in this study displayed more variation than the original Yellowstone, Colorado, Piedmont, or Arkansas curves. Vegetation seems to play a vital role in maintaining bank stability in this region of NE KS. Erosion rates plotted against both BEHI score and NBS rating with each site's woody vegetation cover showed a clustering of sites with woody vegetation vs. sites without. Thus, the vegetation portion of the BEHI was modified and simplified, which resulted in consistent R^2 values of 0.84 and 0.88 and correct order of the BEHI adjective ratings. Bank materials may also play a vital role, as the soils are high in clay content that may act similar to bedrock when wetted.
Using BANCS Model to Prioritize Potential Stream Bank Erosion on Birch Creek, Shandaken, NY (Markowitz and Newton, 2011)	Birch Creek within Catskill State Park, NY	144 bank locations along 6.3 stream miles of Birch Creek (steep-gradient mountainous region) were assessed with the BANCS Method. Nine monumented stream bank cross-sections were installed and measured pre and post Hurricane Irene and Tropical Storm Lee flood events. The purpose of this investigation was to: 1) establish	The erosion processes accounted for in the BANCS model may differ in non-alluvial boundary conditions such as glacial till and/or glacio-lacustrine lake clays, and revetment as observed in the study area. These boundary conditions may influence the erosion rates in ways not predicted by the BANCS model.

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
		a baseline dataset to predict an annual stream bank erosion rate of Birch Creek using BANCS; 2) rank and prioritize site specific potential erosion; and 3) produce reach specific erosion ratings.	No apparent trend was observed when data from the 9 monumented cross-sections were plotted against the BEHI and NBS ratings. The discrepancy appears to be because of the NBS method used. Only one out of the seven methods to assess NBS was applied to all geomorphic conditions along Birch Creek. When graphed separately it became apparent that the variables associated with the BEHI rating were a much more effective predictor of bank erosion than NBS.
Great Lakes Bank Erosion 516(e) Study – Conference Presentation (Creech, 2010)	Great Lakes Region	Used bank pins and bank profile measurements to develop regional curves for the BANCS method.	The presentation does not indicate how well the BANCS method predicted erosion found with the bank pins and profile measurements. It appears they are still doing measurements so may not have drawn conclusions yet.
Northwest Branch of the Anacostia River Bank Erosion Assessment – Conference Presentation (Crawford et al., 2009)	Anacostia River, Montgomery County, MD, 15.2 sq mile watershed that is 18% impervious. Streams have 700 – 1,000 ft forested floodplains.	Goal of the stream restoration project was to reconnect the channel with its floodplain. The BANCS method was used, along with bank profile surveys at 44 individual banks.	The calibrated NW-160 curve predicted 1,040 tons/year erosion, the Colorado curve predicted 1,298 tons/year, and the North Carolina curve predicted 910 tons/year. BANCS method seems to be a reasonable first estimate of bank erosion. Only utilized 2 NBS methods. Large woody debris is an important source of NBS. Trees on top of banks contribute to stability. BANCS method should not be used to calculate sediment delivered to downstream reaches as it does not take deposition into account.

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Evaluating the BEHI on the Navajo Nation (Navajo Nation EPA, 2002)	Chuska Nation, Navajo Nation	Bank profiles and bank pins were surveyed and BEHI determined for 20 bank sites along 15 streams for the purpose of testing and calibrating the BANCS method.	Considerable error was found at most sites for the Yellowstone and Colorado regional curves. Although there is error, the model appears to operate qualitatively. All sites where erosion was predicted, experienced erosion. While considerable error exists at individual sites, values averaged or integrated across the project area were surprisingly accurate. The Yellowstone NP and Colorado USFS graphs underestimated erosion by 6% and 168% respectively. Given the great variability in bank composition, erosion mechanisms, and stream flow, it will take several additional years of data to determine the accurate predictive capability of the BEHI. Additional parameters may have to be developed to accurately characterize the Near Bank Stress in sand bed channels. Regardless of the quantitative merits of the BEHI, the field procedure provides a valuable qualitative assessment of stream bank stability for the technician, landowner, or manager.
Stony Run, Baltimore City, MD, Geomorphic Baseline Survey	Stony Run, Baltimore City, MD	This study documents active channel adjustments, and will allow the City to compare pre- and post-restoration stream	A poor correlation was found between the measured erosion rates and the predicted erosion rate determined from the draft regional

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(Eng et al., 2007)		conditions to document the benefits of the restoration. 42 stream banks were assessed using the BANCS method. 9 existing monumented cross-sections were resurveyed, and 2 new cross-sections were surveyed.	D.C. curve, which may have been due to changes in the BEHI and NBS procedures from Wildland Hydrology. Similar erosion rates were found at Moore's Run.
Impacts of land use on stream bank erosion in the NE Missouri Claypan region (Peacher, 2011)	Claypan region, NE Missouri	The goal of this project was to determine whether two ***modified*** Rosgen's Bank Erosion Hazard Index (BEHI) Procedures (SOP) used by the Michigan Department of Environmental Quality (MDEQ) would be applicable to streams in the Claypan region of NE Missouri. The procedures were tested using erosion pin data collected over three years in two sub-watersheds of the Salt River Basin. The first procedure uses a ratio of bank height to bankfull height and the 2nd procedure includes adjustment factors for bank material and soil layer stratification.	The erosion rates for the eighteen treatment reaches were weakly negatively correlated with 2008 and 2011 SOP BEHI total scores, respectively. Both 2008 and 2011 total scores covered a fairly narrow range, which suggests that one or more of the variables were scored very similarly across the treatment reaches. Another caveat to consider is that Rosgen's method incorporates near-bank velocity gradients and shear stress distributions, which are not incorporated into the survey methods of either MDEQ SOP examined here. No conclusions about the effectiveness of the BANCS method can be made.
Using a BEHI to Estimate Annual Sediment Loads from Streambank Erosion in the West Fork White River Watershed (Van Eps et al., 2004)	West Fork White River Watershed, NW Arkansas, 79,400 ac watershed	The Arkansas Department of Environmental Quality utilized a BEHI and data collected from surveys of streambank profile measurements to develop a graphical model to estimate streambank erosion rates and to estimate the annual sediment load due to accelerated streambank erosion. 24 permanent survey sites were established within 8 reaches for erosion measurement with bank	The study did not provide accuracy estimates for how well the measured erosion rates correlated with the model they developed (regional curve). Bankfull discharge was met or exceeded on many instances during the study period. The survey data should represent erosion rates for years where bankfull flow is

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		pins from 2002-2003. 192 streambanks were assessed for BEHI and NBS (2002-2004). By relating the BEHI rating, the local NBSS, and the measured erosion rate at each permanent survey site, a graphical model to predict streambank erosion rates was developed.	approached, equaled, or slightly exceeded. Lateral erosion rates predicted by the model were less than half the rates predicted by the Colorado model for a BEHI and NBSS combination rating of moderate and high. However, for other combinations of BEHI and NBSS, erosion rates predicted by the WFWR model were higher than those predicted by the other models by a factor ranging from 1.3 to 2.8 times.
Streambank Erosion Source Assessment, Upper Gallatin TMDL Planning Area (PBS&J, 2009)	West Fork Gallatin River watershed of the Upper Gallatin TMDL Planning Area, Gallatin and Madison counties, Montana	Sediment loads due to streambank erosion were estimated based on the BANCS Method at 30 monitoring sites (204 streambanks) covering 5.2 miles of stream between July and October of 2008. The reaches were located in low-gradient portions of the study streams where sediment deposition is likely to occur.	Average annual sediment load from the assessed streambanks was estimated at 397 tons/year. 30% of the erosion sediment load was attributed to accelerated streambank erosion caused by historic or current human activities, while approximately 70% was attributed to natural erosional processes and sources. The watershed streambank sediment load was estimated at 1,821 tons/year based on the stream segment sediment load extrapolated from the assessed streambanks. 33% of this load is due to anthropogenic disturbances. Through the implementation of BMPs, it is estimated that the total sediment load from anthropogenically accelerated streambank erosion can be reduced by 31% (186 tons/year).

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
			Direct measurements of streambank erosion were not made, so no conclusions can be drawn about the accuracy of the results from the BANCS Method.
A Practical Method of Computing Streambank Erosion Rate (Rosgen, 2001)	Lamar Basin in Yellowstone National Park, Montana and the Front Range of Colorado on the USDA Forest Service, Arapaho and /Roosevelt and Pike/San Isabel National Forests.	The BANCS Method is presented and is based on the idea that streambank erosion can be traced to two major factors: stream bank characteristics (BEHI) and hydraulic / gravitational forces (NBS). In 1987 and 1988, direct measurements of annual erosion were made using bank pins and profiles to test the BEHI/NBS relationship. 49 sites were selected in the Front Range Colorado and 40 sites were selected in the Lamar River Basin, MT.	The coefficients of determination, or r^2 values, for the correlation of BEHI to NBS were found to be 0.92 for Colorado and 0.84 for Yellowstone. A subsequent study in NC found that the data plots closely to the Colorado dataset, possibly due to a similar alluvial bank composition. Research in the Illinois River in OK showed that either velocity gradients or shear stress ratios predict better than cross-sectional area ratio for NBS. This study also found that flows 4 times bankfull stage generated the measured erosion rate, compared to Colorado and Yellowstone, that are associated with flows at or near bankfull. Research in the Weminuche River found that data collected at low flow can provide comparable results to the higher flows associated with Colorado and Yellowstone. Stratification by geologic and soil types should be accomplished to establish a family of curves for various geologic and hydro-physiographic provinces. Once a quantitative relationship is obtained,

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Source	**Location**	**Application**	**Results/Recommendations**
			mapping changes in the BEHI and NBS ratings can be used to estimate consequence of change in locations beyond where the measured bank erosion data is obtained.
Priority Setting for Restoration in Sentinel Watersheds (Lenhart et al., Ongoing)	Whitewater River in the Driftless Area in southeast Minnesota Elm Creek within Glacial Till Plains of the Blue Earth Basin in southern Minnesota Buffalo River within the Red River of the North Basin	This project will develop a modified BANCS model and calibrate it for different geomorphic regions of Minnesota using monitoring, modeling and historical data. BSTEM predicts erosion quantities from individual storm events, while CONCEPTS can model erosion, deposition and channel evolution over extended time periods. These analyses and assessments will be used to identify priority management zones for the intended purpose of reducing sediment and phosphorus loads in sentinel watersheds (areas that are representative of other watersheds in the same region).	This project is ongoing and is scheduled for completion December 2014.
Upper Jefferson River Tributary Sediment TMDLs and Framework Water Quality Improvement Plan (MDEQ, 2009b)	Impaired tributaries to the Upper Jefferson River - Big Pipestone, Little Pipestone, Cherry, Fish, Hells Canyon, and Whitetail creeks.	This document presents a TMDL and framework water quality improvement plan for six impaired tributaries to the Upper Jefferson River. Appendix G presents an assessment of sediment loading due to streambank erosion along stream segments listed as impaired due to sediment. The BANCS Method was done along 91 streambanks (3.89 miles of streambank).	A total sediment load of 742.4 tons/year was attributed to eroding streambanks within the monitoring sections. Erosion from the monitoring sites was extrapolated to the watershed scale. A total estimated sediment load of 44,576.3 tons/year was attributed to eroding streambanks. Direct measurements of streambank erosion were not made, so no conclusions can be drawn about the

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
			accuracy of the results from the BANCS Method.