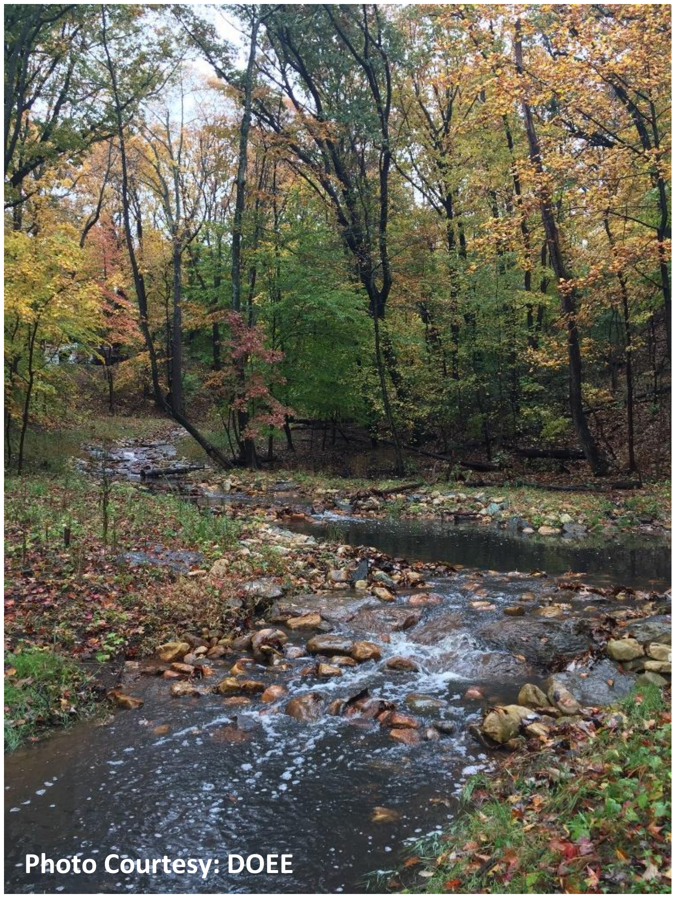
FINAL USWG REVIEW DRAFT

Consensus Recommendations for Improving the Application of the Prevented Sediment Protocol for Stream Restoration Projects Built for Pollutant Removal Credit



Drew Altland, Joe Berg, Bill Brown, Josh Burch,
Reid Cook, Lisa Fraley-McNeal, Matt Meyers,
Josh Running, Rich Starr, Joe Sweeney,
Tess Thompson, Jeff White and Aaron Blair

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Executive Summary

The prevented sediment protocol has become the most widely applied stream restoration credit in the Bay watershed. With a rapidly evolving stream restoration market and thousands of miles of projects planned in the coming years, a group of experts was convened to provide guidance on the Prevented Sediment Protocol to ensure the best possible projects are being selected and implemented.

This memo advances the original Prevented Sediment Protocol in the following ways:

- It clearly and unambiguously defines "bank armoring" for the entire steam restoration community. This memo outlines a simple, narrative definition of bank armoring and divides the most common techniques into three categories: Non-Creditable, Creditable with Limits, and Creditable. These categories incentivize the use of natural and biodegradable materials to dissipate energy and reduce erosion, while clearly discouraging the crediting of techniques that are prone to failure and provide little or no functional uplift.
- It replaces default rates with individual site-level data collection. Soil conditions vary considerably between stream restoration sites, so guidance is provided on the collection of bulk density and nutrient concentration data to inform site-specific pollutant load calculations.
- It expands upon the numerous alternative bank erosion monitoring methods that can be used to calculate prevented sediment loads. Guidance is provided on traditional, fixed-station methods, such as bank pin monitoring, as well as new modeling approaches using Digital Elevation Model (DEM) Differencing.
- It outlines recommended ways to reduce variability in BANCS assessments. Training assessors, performing assessments in teams, and focusing on the most sensitive BEHI and NBS parameters are all ways to better calibrate assessments across project sites.

Collectively, these recommendations should improve confidence that the projects selected and credited are providing the greatest pollutant reduction benefit and functional uplift.

Grandfathering Existing Projects

The group recommends that all new definitions, qualifying conditions and Protocol 1 methods take effect in 2021. This "ramp-up" period will allow practitioners the opportunity to adjust to meet the new guidelines set forth in this document. Any projects already in the ground or under contract as of January 1, 2021 should not be subject to the new recommendations, but should adhere to the definitions, qualifying conditions and Protocol 1 calculations laid out in the Stream Restoration Expert Panel Protocols (2014). The final authority for making crediting decisions for qualifying projects falls to the appropriate state regulatory agencies.

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The following memo documents how pollutant reduction credits are earned for modifications to existing stream restoration practices, as outlined by policy approved by the Urban Stormwater Work Group (USWG, 2016).

1. Charge and Roster of the Working Group

The prevented sediment protocol (#1) has become the most widely applied stream restoration credit in the Bay watershed. Stakeholders from both the public and private sector have sought to clarify how it should be used on individual restoration projects, given the great variability in reported stream sediment loss that occurs from reach to reach. The Urban Stormwater Workgroup (USWG) convened an ad hoc team to review the prevented sediment protocol and provide additional guidance on its application. The members of the team are provided in Table 1.

Table 1. Membership for Group 3

Name	Affiliation	E-mail Address
Drew Altland	RKK	daltland@rkk.com
Lisa Fraley-McNeal	Center for Watershed Protection	lfm@cwp.org
Joe Berg	Biohabitats	jberg@biohabitats.com
Rich Starr	Ecosystem Planning and Restoration	rstarr@eprusa.net
Josh Running	Stantec	Josh.running@stantec.com
Matt Meyers	Fairfax County, VA DPWES	Matthew.meyers@fairfax.county.gov
Bill Brown	PADEP	Willbrown@pa.gov
Jeff White	MDE	Jeff.white@maryland.gov
Josh Burch	DOEE	Josh.burch@dc.gov
Reid Cook	RES Consultants	rcook@res.us
Aaron Blair	EPA	Blair.aaronm@epa.gov
Tess Thompson	Virginia Tech	tthompson@vt.edu
Joe Sweeney	Water Science Institute	joe@waterscienceinstitute.org

The group has been charged to review and recommend in the following areas:

- Provide more guidance on the minimum qualifying conditions for protocol 1 projects, with an emphasis on defining the maximum amount of bank armoring that can be used to stabilize banks and prevent erosion, while still maintaining stream habitat and functions in the project reach.

- Establish quality control standards for measuring key BANCS parameters in the field to ensure crews collect consistent and unbiased data that can be replicated by others. Some potential areas to focus on include:

    - Define bank full elevations properly
    - Accurately estimate NBS and BEHI scores
    - Ensure data quality control over entire project reach

- Determine whether it is possible to define regional default values for streambank soil bulk density and nutrient content (or whether designers need instead to collect soil samples within the project reach to estimate these two important parameters for protocol 1).

- Provide an update on the ongoing development of regional BANCS curves and recommend which curves are most appropriate for different physiographic regions and stream channel conditions across the Bay watershed.

- Provide more detailed guidelines on how to estimate stream sediment loss using alternative field monitoring and modeling options allowed under Protocol 1. Any recommendations on project study design and benchmarks for data quality control and/or model documentation would be very welcome.

2. Background on Prevented Sediment Protocol

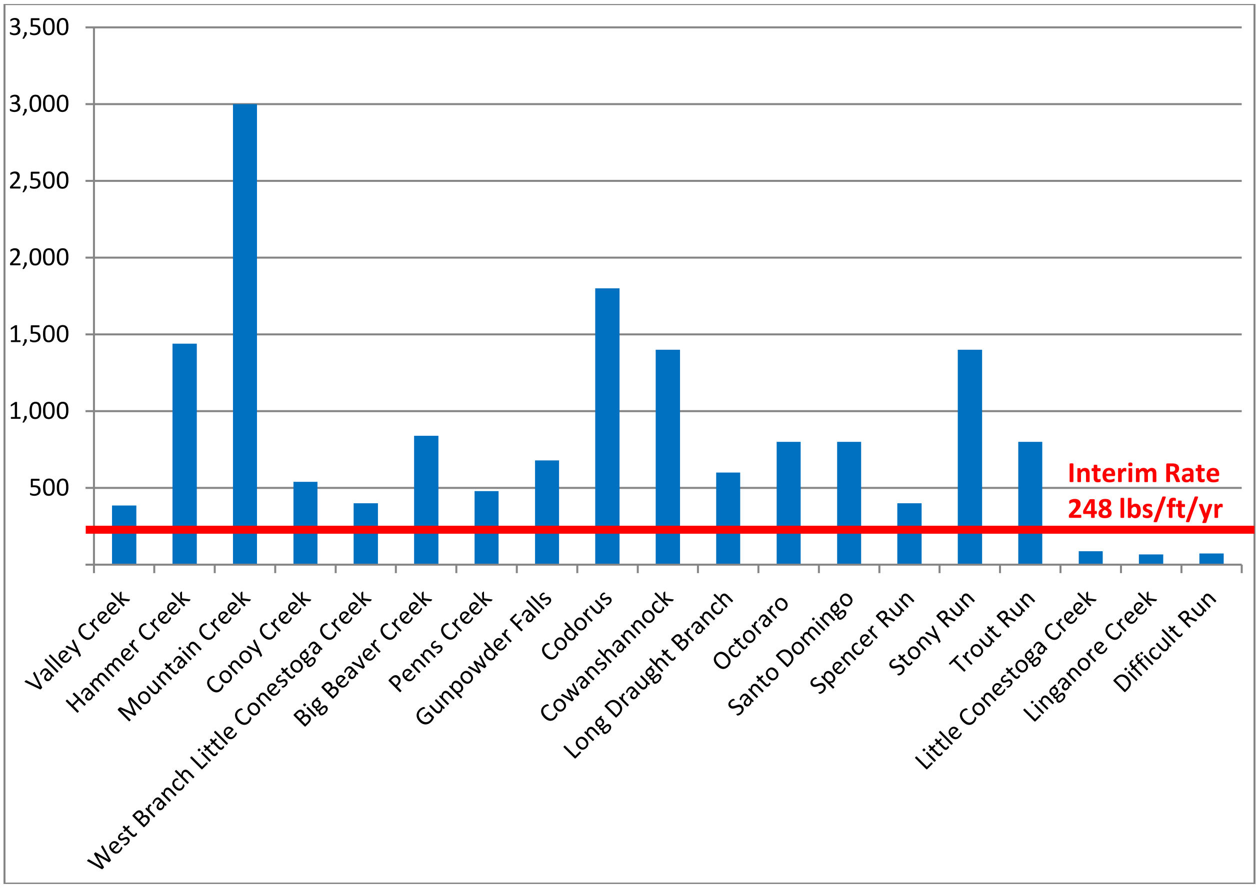
This section introduces the problem of stream bank erosion as a major sediment source in urban watersheds. It will also provide background on the 2014 Stream Restoration Expert Panel's prevented sediment protocol, and how recent efforts to apply the protocol led to the need for new guidance.

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 sediments. 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 Pizzutto et al, 2018).

Sediment reduction due to stream restoration is largely attributed to the stabilization of the beds and banks within the channel. The 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.

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



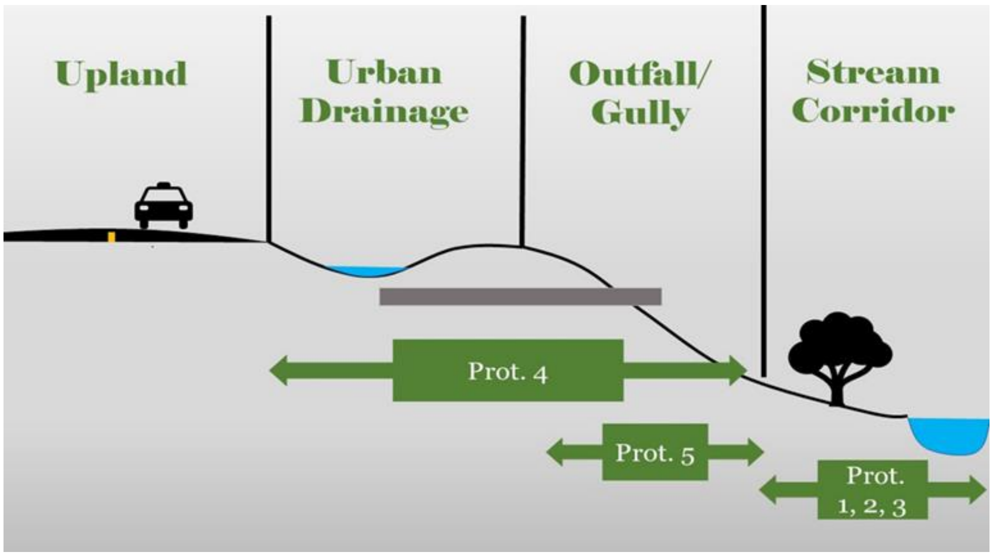
The Urban Stream Network

Urbanization and channel position within the stream network also play a role in determining potential sediment loss. Urbanization diminishes the functional capacity of streams to retain both sediments and nutrients, and further research has shown increased rates of channel erosion and sediment yield in urbanizing streams (Trimble, 1997; Booth and Henshaw, 2001; Langland and Cronin, 2003; Allmendinger et al., 2007; Fraley et al., 2009).

It is also important to clearly define where in the stream network restoration work is occurring, and how that impacts the practices and crediting methods used. The urban watershed stream network can be thought of as four distinct zones: Upland Zone, Urban

Drainage Zone, Outfall/Gully or Headwater Transition Zone, and the Stream Corridor. These zones represent the flow of stormwater from upland land uses into altered urban drainage (swales, ditches and storm drain pipes), which then discharge into the beginning of the urban stream network (Figure 2).

Figure 2. The Four Zones of the Urban Watershed Stream Network.



Each zone has unique characteristics that are therefore restored and credited differently. There are currently five protocols to define the nutrient and sediment removal rates associated with stream restoration practices. All protocols apply to both urban and non-urban streams:

- Protocol 1 (Prevented Sediment): provides credit for projects occurring in first through third order streams with perennial flow that stabilize banks and prevent sediment erosion in actively degrading channels.
- Protocol 2 (Hyporheic Exchange): provides credit for projects that include design features to promote denitrification during base flow.
- Protocol 3 (Floodplain Reconnection): provides credit for projects that reconnect the stream channel with its natural floodplain, encouraging floodplain deposition, plant uptake and denitrification.
- Protocol 4 (Dry Channel Regenerative Stormwater Conveyance): is for zero order channels with intermittent flow and is credited as a stormwater retrofit practice. These practices occur in the urban drainage zone to directly capture upland runoff or are used at the stormwater outfall to capture and treat stormwater in the headwater transition zone.
- Protocol 5 (Outfall and Gully Restoration): is designed to create a stable channel to dissipate energy that extends from the storm drain outfall to the perennial stream network. The new channel is re-constructed to achieve an equilibrium state where future sediment loss is minimized or eliminated altogether. These projects may only be applied within the headwater transition zone and active headcut areas (Group 2, 2019).

Summary of Protocol 1: Prevented Sediment Credit

Sediment reduction due to stream restoration is largely attributed to the stabilization of the bed and banks within the channel. To account for this approach, the original expert panel developed the Prevented Sediment Protocol to estimate the annual erosion rates from actively degrading or incised stream channels and calculate the prevented sediment loss due to restoration. The three key steps for applying the protocol are provided in Table 2.

Table 2: Summary of Protocol 1: The Prevented Sediment Credit

Step 1: Estimate stream sediment erosion rates

The most common technique to estimate bank erosion rate is the BANCS Method (Rosgen, 2001), where field surveys are used to calculate BEHI and NBS scores, which in turn, are entered into regional bank erosion curves to determine the annual rate of streambank retreat.

Designers also have the option to directly measure the rate of bank retreat in the project reach using bank pins, cross section surveys or other alternative methods that were not explicitly defined in the original expert panel report.

The pre-restoration erosion rate for the project reach is then entered into the following equation to determine its potential prevented sediment load:

$$S = \frac{\sum(cAR)}{2{,}000} \qquad \text{(Eq. 1)}$$

where: S = sediment load (ton/year) for reach or stream
c = bulk density of soil (lbs/ft^3)
R = bank erosion rate (ft/year) (from regional curve)
A = eroding bank area (ft^2)
2,000 = conversion from pounds to tons

Step 2: Convert erosion rates to nitrogen and phosphorus loadings.

In this step, the nutrient load associated with the prevented sediments are calculated using a unit conversion, based on the measured or default estimate of its sediment nutrient content. The expert panel defined default values to aid in the calculations, though site-specific measurement was encouraged.

Step 3: Estimate restoration reduction efficiency.

In the last step, sediment and nutrient load reductions are conservatively reduced by 50% to account for the presumed efficiency of stream restoration practices.

Erosion rate monitoring through methods such as cross section surveys and bank pins was recommended by the panel, but with limited guidance. As an alternative, the panel encouraged the use of the "Bank Assessment for Non-point Source Consequences of Sediment" or BANCS method (Rosgen, 2001; U.S. EPA, 2012; Doll et al., 2003) to estimate sediment and nutrient load reductions. The BANCS method was developed by Rosgen (2001) and utilizes two commonly used bank erodibility estimation tools to predict stream bank erosion; the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) methods.

The Need for New Protocol 1 Guidance

Since the release of the expert panel report, thousands of miles of new stream restoration projects have been implemented across the Chesapeake Bay watershed. From those projects, several key needs were identified to improve the quality and consistency of Protocol 1:

- Guidance on application of the BANCS method to improve consistency
- Clarification on key qualifying conditions
- Updates to sediment delivery simulation in Phase 6 Watershed Model
- Guidance on the development of appropriate monitoring strategies

The literature indicates that the BANCS Method generally predicts streambank erosion within an order of magnitude. However, a limitation of the method is the variability in NBS and BEHI estimates by different practitioners (Bingham et al. 2018). Further concerns about using NBS as a way of quantifying flow energy for estimating streambank retreat is described in Appendix A.

The use of different default rates and erosion rate curves provides further opportunity for variability in Protocol 1 calculations. For example, a bulk density value provided in a design example in the original expert panel report has been frequently used as a default, in place of site-level data, resulting in potentially skewed results. The two most commonly used erosion rate curves (Hickey Run and North Carolina) can also provide significantly different erosion estimates.

There have also been many requests for clarification regarding bank armoring. The original expert panel report stated that stream restoration projects that are primarily designed to protect public infrastructure by bank armoring or rip rap do not qualify for a credit but did not elaborate on the definition of bank armoring or specify how much is too much.

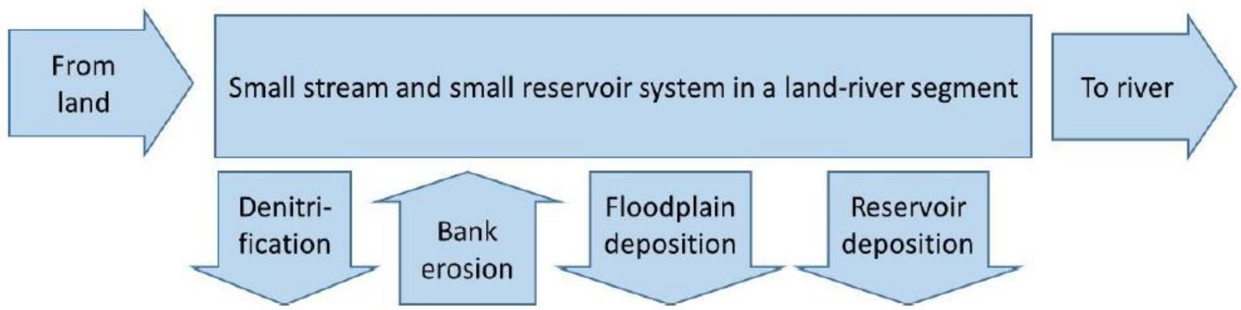
Note on Watershed Sediment Delivery and the Phase 6 Model

Some fraction of the sediment load from headwater streams is deposited on downstream channels and floodplains, where they may be stored for decades or more. Sediment storage complicates the issue how sediments travel from the headwaters to the head of the bay estuary. The original expert panel recommended a fixed sediment delivery ratio, depending on whether a stream was located in the coastal plain or not. After some significant improvements in sediment modeling were adopted, the Phase 6 Chesapeake Watershed Model (CBP, 2018) now explicitly calculates sediment delivery for individual stream reaches.

In the new Phase 6 Chesapeake Bay Watershed Model, sediment delivery in first through third order streams is now simulated using data from the Chesapeake Floodplain Network (Noe et al, 2015a). Results indicate that on average, long-term fluxes of sediment and nutrients in streambank erosion and floodplain deposition are in equilibrium, so there is no long-term net change in load in small-order streams from these processes. However, watersheds under development or other form of disturbance (e.g. breach of mill dam, change in agricultural practice, increase in impervious cover) are not in equilibrium, resulting in higher peak flows in streams, with resulting additional streambank erosion.

There are also the impacts from reservoirs and impoundments, which trap sediments and lower their delivery to larger rivers and the Bay. The conceptual approach to sediment delivery is describe in Figure 3.

Figure 3. Processes Represented in Phase 6 Model Stream to River Deliver (CBP, 2018)



There are several key takeaways for planners and managers looking to implement stream restoration projects to meet their Chesapeake Bay TMDL goals:

- In the Phase 6 Model, streambank loads are accounted for separately from upland land use loads. All reductions from stream restoration BMPs will be taken from the stream bed and bank load. They will not be credited as an urban or an agricultural BMP.
- Each catchment will have different total nutrient and sediment delivery factors, depending on the travel time of the stream reaches and presence of reservoirs in its transport path downstream. Therefore, the overall effectiveness of a project will vary based on its location.
- The coastal plain and non-coastal plain sediment delivery factors are no longer part of BMP credit calculations. Sediment delivery factors will vary by project location and should NOT be applied to the calculated sediment reductions prior to reporting.

If you know the geographic address of your project, its specific sediment delivery ratio from the stream reach to the Bay can be quickly determined using the Chesapeake Assessment and Scenario Tool (CAST - EPA, CBP, 2018). Some guidance on a step by step method to estimate the unique sediment delivery factor for the land-river segment in which a project resides can be found in Appendix B.

3. Additional Definitions

The Stream Restoration Expert Panel (2014) used a range of terminology, some of which require additional clarification to improve the application of Protocol 1. Those revisions and clarifications are provided in this section.

Legacy Sediment Removal and Valley Restoration

For the purposes of the Chesapeake Bay management effort, legacy sediment is defined as sediment stored in the landscape as a byproduct of accelerated erosion caused by landscape disturbance following European settlement (Miller et al 2019). The presence and subsequent breaches of mill dams throughout the mid-Atlantic region and the Chesapeake Bay watershed, commonly lead to channel incision, bank erosion and increased suspended sediment loads (Merritts et al 2011).

One common design approach for stream restoration in watersheds impacted by legacy sediments, is Legacy Sediment Removal or Stream Valley Restoration. This approach removes legacy sediments from the floodplain and restores the natural potential of aquatic resources including a combination of streams, floodplains, and palustrine wetlands (CBP 2014).

This design approach may be credited using Protocol 1-3 of the Stream Restoration BMP. However, recent research conducted at Big Spring Run suggests that a separate protocol may be warranted to properly account for the pollutant removal benefits of the design approach. Thus, the Group recommends that a separate team be convened to review the research specific to Legacy Sediment Removal projects and determine whether a separate protocol will be developed, and how the pollutant removal will be calculated, reported and verified.

Definition of Bank Armoring:

Armoring must be clearly and unambiguously defined for the entire steam restoration community. The definition has three parts:

(1) a narrative definition of what constitutes bank armoring

(2) a table designating individual armoring practices into three categories, and

(3) guidance on how those three designations affect how the prevented sediment credits are applied to individual stream restoration projects.

(1) Narrative Definition:

Armoring involves the placement of hard structures along the stream channel for the express purpose of limiting the movement of a stream along its horizontal and/or vertical dimensions. Engineers use bank armoring to protect and fix streams within constrained urban stream corridors so they will not move or erode at design flow rates and shear stress.

(2) Designation of Armoring Practices

The original Expert Panel stated that stream restoration projects that are primarily designed to protect public infrastructure by bank armoring or rip rap do not qualify for a credit. The Prevented Sediment Group reinforced that bank armoring installed for the sole purpose of infrastructure protection (i.e. sanitary lines that run perpendicular and/or parallel to the stream), do not meet the Expert Panel's goals for stream restoration and therefore should not be credited. The goal of all creditable stream restoration projects should be functional uplift, and projects should be selected in accordance with a watershed-based approach that maximizes upland stormwater treatment and improves in-stream habitat.

The use of softer natural materials (i.e. vegetation and wood) -- combined with floodplain reconnection -- to stabilize banks and dissipate energy are still recommended because of the functional uplift and habitat benefits provided by these approaches. Boulder and cobble may also be appropriate for use in restoration design if they are commonly found in the natural substrate of the project's physiographic region. For example, in-stream cobble represents ideal habitat for benthic macroinvertebrates in the Piedmont, while large rock structures do not provide the interstitial spacing that is desirable for benthic habitat and thus would not be appropriate for use in the coastal plain.

However, in some cases, site constraints such as steepness, erodible soils, or hydraulic factors present barriers to these preferred restoration design approaches. Sites drained by highly impervious subwatersheds may experience velocities that require other engineering solutions to provide stable downstream conditions. Large restoration projects may also contain limited sections where existing buildings or infrastructure require protection even if the larger reach is designed to restore the channel and achieve functional uplift.

To address these realities, the Prevented Sediment Group has defined three categories of armoring practices and grouped the most commonly applied techniques into these categories (Table 3). Narrative descriptions are provided to assist with determinations for new and innovative techniques not captured below. Final decisions regarding crediting are reserved for the appropriate state regulatory agency.

Table 3. Designation of streambank armoring practices

Tier	Examples
Non-Creditable **Definition: Highly engineered, permanent structures used to protect critical infrastructure and stabilize banks.**	• Concrete Retaining Wall • Sheet Piling/ Planking • Gabion • Engineered Block Walls • A-Jacks • Dumped Rip Rap
Creditable w/ Limits **Definition: Large rock or boulder structures that harden a limited portion of a bank or bank toe in a localized area.**	• Angular Rip Rap for bank protection or localized toe protection • Boulder Revetments • Non-biodegradable soil stabilization mats • Imbricated Rip Rap
Creditable **Definition: Structures that mimic naturally occurring streambank materials, features that provide aquatic habitat function, and limited in-stream grade control.**	• Root wad Revetments • Live stakes/coir logs • Soil lifts • Riffle-weir series • Berm-pool cascades • J-hooks and cross-veins

(3) Guidance on How Designation Affects Credit Calculations

Non-Creditable Armoring Practices

- These practices should not be used in any creditable stream restoration practice unless required for the protection of critical infrastructure.
- Any length of the reach that does require an infrastructure protection practice should be subtracted from the total reach length when determining pollutant load reductions.
    - Example: A stream restoration project with 1,000 ft of restored banks requires 50 ft of infrastructure protection. When using Protocol 1, the 50 ft of armored stream bank should be excluded from the bank erosion estimate and only 950 ft of the reach are credited.
- In addition, these armoring practices may require on-site or off-site mitigation to replace stream habitat and ecosystem service functions lost during their construction, at the discretion of the appropriate permitting or resource agency.

Figure 4. Examples of infrastructure protection practices.

Creditable with Limits Armoring Practices

- These practices are allowable, with full credit, on up to 30% of the restored banks (both sides). The 30% maximum is based on the professional judgment of the group members that application of these techniques should be limited to outer bends and areas of high shear stress where additional protection is required to stabilize the banks. For most stream restoration projects, no more than 30% of the restored banks should require these techniques.

- Any bank length armored by a practice in this category that exceeds the 30% limit will be proportionally subtracted from final pollutant load reduction using the prevented sediment protocol.

    - Example: A stream restoration with 1,000 ft of restored banks includes 400 ft of rip-rap. This exceeds the 30% limit by 100 ft, or 10% of the total bank length. Therefore, if the project earned 200 lbs of reduction using Protocol 1, you may only claim 180 lbs.

- All creditable armoring practices are subject to ongoing field inspection requirements to verify they are performing adequately.

Figure 5. Examples of “creditable with limits” bank armoring practices

Creditable armoring practices

- No crediting limitations on the use of these armoring practices, which help to dissipate energy and stabilize streambanks while mimicking naturally occurring streambank materials. Many of these practices are designed to be biodegradable, providing stabilization until the channel can adjust to a sustainable condition.

Figure 6. Examples of "creditable" armoring practices.

Note on Armoring in Outfall and Gully Stabilization Projects

Outfall and Gully Stabilization Projects (Protocol 5) use a less stringent version of the Protocol 1 qualifying conditions for projects in the headwater transition zone. Protocol 5 allows for limited use of pipe extensions and drop structures in the headwater transition zone if they are needed to sustain channel stability and do not introduce new aquatic organism passage issues. The headwater transition zone is defined as the slope or channel that extends from an upland runoff source to the perennial stream network.

Protocol 5 projects applied within the perennial stream network to address active headcut areas may not include pipe extensions or drop structures and are subject to the armoring definitions and limitations defined above.

4. Qualifying Conditions for the Practice

Existing Qualifying Criteria

The Stream Restoration Expert Panel (2014) outlined a series of qualifying conditions that must be met for a project to be eligible for Chesapeake Bay TMDL reductions. The qualifying conditions were designed to promote a watershed-based approach for screening and prioritizing stream restoration projects to improve stream function and habitat. Qualifying conditions from the original expert panel report will still apply.

In addition, the following new qualifying condition has been added:

- Protocol 1 cannot be combined with Protocol 5 (Outfall Restoration) within the same project reach. Protocol 1 can still be combined with Protocols 2 and 3 in the same project reach, if it meets the conditions for hyporheic exchange and/or floodplain reconnection.

5. Updated Protocol 1

The goal of this revised Protocol is to provide guidance and clarifications to improve the replicability and accuracy of prevented sediment calculations. The protocol will still follow the basic three-step process (CBP, 2014) to compute a mass reduction credit for prevented sediment:

1. Estimate stream sediment erosion rates and annual sediment loadings,
2. Convert erosion rates to nitrogen and phosphorus loadings, and
3. Estimate reduction attributed to restoration.

The more data collection conducted on site, the greater the final reduction efficiency. ***Collecting bulk density samples and soil nutrient concentrations should be considered the bare minimum.*** Monitoring erosion rates pre and post-restoration using cross section surveys, bank pins or an appropriate alternative method (described in Section 7) is the preferred approach. The extrapolation of monitoring data to unmeasured banks should be done with care and the monitored cross sections should be representative of those within the project reach.

Step 1. Estimate the Stream Sediment Erosion Rate

The most common technique to estimate bank erosion rate is the BANCS Method (Rosgen, 2001), where field surveys are used to calculate BEHI and NBS scores, which in turn, are entered into regional bank erosion curves to determine the annual rate of streambank retreat.

The expert panel provided the Hickey Run curve as an example of a regional bank erosion curve, but it should be used with relative caution because limited data was used to construct it. The development of new regional bank erosion rate curves is recommended by the Prevented Sediment Group. However, as outlined in Section 6, curve development could take several years. In the meantime, in order to help provide more consistency among BANCS assessments, practitioners are recommended to use the spreadsheet in Appendix C that was developed specifically for TMDL purposes using data from multiple stream sources including Hickey Run.

Designers also have the option to directly measure the rate of bank retreat in the project reach using bank pins and cross section surveys. Alternative methods that employ LiDAR surveys and hydraulic engineering models can also be used as described in Section 7.

The pre-restoration erosion rate for the project reach is then entered into the following equation to determine its potential prevented sediment load.

Equation 1:

$S = \Sigma(cAR) / 2{,}000$

where: S = sediment load (ton/year) for reach or stream
c = bulk density of soil (lbs/ft3)
R = bank erosion rate (ft/year)
A = eroding bank area (ft2)
2,000 = conversion from pounds to tons

Bulk Density:

Bulk density is the mass of soil for a given volume. It is used to measure compaction. For purposes of Protocol 1, a bulk density soil sample should be taken from each soil horizon present within the restoration reach. The number of samples taken per soil horizon and/or per reach should be proportional to the percentage of the banks consisting of that soil type. The samples should be collected from undisturbed soils using a core and analyzed in the lab using undisturbed sampling methods. Take the average of those bulk density values to input into Equation 1. Locations should be selected using the following guidelines (additional details are provided in Appendix D):

- The number of samples taken along the reach may vary based on best professional judgement. It is recommended that one sample be collected every 200-500 linear feet to get a representative sample.
- If multiple samples are taken, they should alternate cross-sections, left and right bank. Samples should be taken from erosional areas where feasible.
- Samples should be collected from each soil horizon identified within the restoration reach. If one horizon is larger than others, more samples should be taken from that horizon to ensure the reach average is representative of bank conditions.
- Take samples from in-tact bank; (not bank material that has fallen/slumped and is now depositional).

- Where unable to take a sample because of large rocky material, select another location
- If a sample is gravelly, sieve to include materials 2mm or less (as per USDA protocol). If the sample is too gravelly to keep the core intact, the sample may need to be disregarded.

Stream restoration designs that use bank armoring techniques described as “Creditable with Limits” in Table 2 should also be discounted when determining the removal rates. Any armoring that exceeds 30% of the restored bank length should be removed from the prevented sediment load in this step. For example, if 40% of the restored banks are armored with “Creditable with Limits” practices, reduce the prevented sediment load by 10%.

Step 2. Convert Stream Bank Erosion to Nutrient Loading

To estimate nutrient loading rates, the prevented sediment loading rates are multiplied by the average TP and TN concentrations in stream bank sediments. Nutrient concentrations are highly variable from site to site, as demonstrated in Table 4.

Table 4. Summary of streambank nutrient concentration values (lbs/ton of sediment).

Source	TP AVG	TP Range	TN AVG	TN Range	Location
Land Studies 2005*	1.43	0.93-1.87	4.41	2.8-6.8	PA
Baltimore DPW 2006*	0.439	0.19-0.9	--	--	MD
Walter et al 2007*	1.05	0.68-1.92	2.28	0.83-4.32	PA
Stewart 2012*	1.78	--	5.41	--	MD
Merritts et al 2010	1.2	0.9-1.5	2.6	1.7-3.5	PA
Stantec 2013	0.33	0.02-4.24	0.62	0.06-3.12	VA
Tetra Tech 2013	0.46	0.004-2.8	1.78	0.0066-19.6	NC
Doll et al 2018	0.56	0.30-1.57	1.34	1.01-2.64	NC
*Referenced in original Expert Panel Report.					

Because of the high variability, samples from the project reach should be collected and analyzed for TN and TP concentrations. Samples should be taken from the same locations as the bulk density samples and analyzed using the following methods:

Total P concentration: Total-sorbed P – EPA Method 3051 + 6010 (USEPA 1986)
Total N concentration: Total N combustion testing (Bremner 1996)

Step 3. Estimate Stream Restoration Efficiency

Stream bank erosion is estimated in Step 1, but not the efficiency of stream restoration practices in preventing bank erosion. An efficiency factor should be applied to account for the fact that projects will not be 100% effective in preventing streambank erosion and that some sediment transport occurs naturally in a stable stream channel. While the Prevented Sediment Group concluded that a baseline 50% reduction was conservative, they felt it was still an appropriate starting point that would incentivize more site-specific monitoring for prevented sediment. Efficiencies greater than 50% should be allowed for projects that have shown through monitoring that the higher rates can be justified, subject to approval by the states.

For purposes of improving the efficiency factor of stream restoration projects, monitoring is defined as the directly measured difference between pre- and post-restoration sediment lost through streambank erosion. This may include, but is not limited to the following methods:

- Digital Elevation Model (DEM) Differencing
- Bank Pin Monitoring
- Permanent Cross-Sections
- Bank Profile Measurement
- BANCS Assessment
- TSS Monitoring

Post-Restoration monitoring should be conducted for a minimum of 3 years following completion of the project before re-calculating the restoration efficiency. Once the new restoration efficiency is calculated, the stream restoration project may be re-reported, replacing the original record. The re-calculated efficiency will be back-dated to ensure the monitored reductions are credited for all years post-installation.

Whichever monitoring approach is used for pre-restoration assessment should be used in the post-restoration assessment. For example, using the BANCS method prior to restoration to determine initial credit, then comparing the predicted prevented sediment erosion to post-restoration LiDAR differencing assessments would not be an appropriate comparison for determining the efficiency factor. If the BANCS method is used for the post-restoration assessment, it should be based on the same regional erosion rate curve as the pre-restoration assessment. If new curves are available at the time of the post-restoration assessment, these curves should be used and the pre-restoration BANCS assessment should be re-done using the new curves.

Stream Restoration Default Rates

The original expert panel provided default nutrient and sediment removal rates per linear foot of stream restoration. Due to the changes in how sediment delivery is simulated in the new Chesapeake Bay Watershed Model, those default rates will differ for each project, depending on the stream's location in the watershed. Practitioners who previously relied on the default rates for planning purposes should adjust the default rates in Table 5 by the sediment delivery factors calculated using the steps in Appendix B in order to get an estimate based on planned linear feet of restoration.

Table 5. Default Nutrient and Sediment Reductions per Linear Foot of Qualifying Stream Restoration (lb/ft/yr), Applied at Edge-of-Stream.

	TN	TP	TSS
Reduction	0.075	0.068	248

The default rates should never be used for project reporting to the state, and thus should not be accepted as a credit after a new project has been completed. Practitioners should use the recommended new Protocol 1 guidelines above to determine the prevented sediment and nutrient erosion.

Developing Planning-Stage Estimates Project Screening

The Group considers individual site-level data collection critical to improving the accuracy and consistency of Protocol 1 application. Therefore, several default rates are no longer provided to avoid confusion over when and how they should be used. However, there are resources available if planning-stage estimates are needed for project screening.

For example, NRCS soil series values may be used to develop planning level estimates for bulk density, but should not be used to calculate the final nutrient and sediment reductions. Similarly, practitioners may refer to the nutrient concentration default values in the original Expert Panel Report for planning purposes, or develop their own defaults based upon their project experience. These planning-stage defaults should always be replaced with individual site-specific values prior to reporting for nutrient and sediment reduction credit.

6. Recommended Field Data and Quality Control

This section presents short and long-term recommendations to address highest priority data needs and ways to reduce variability during BANCS assessments. The section also discusses time and resource needs to develop new regional curves and stream assessment tools.

Recommendations for Standardizing BANCS Assessment

The BANCS method utilizes two commonly used bank erodibility estimation tools to predict stream bank erosion; the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) methods. Each tool is susceptible to high variability when performed by different practitioners in the field. The following guidance is recommended to reduce the variability in erosion rate estimate.

Calibrating Results:

When several practitioners assess a stream reach, their assessment of different BEHI and NBS characteristics may differ substantially. These differences may lead to the selection of a less-degraded project site, or a significant over or under-estimate of the pollution reduction credit.

BANCS assessments should be performed by teams of two qualified stream restoration practitioners in order to better calibrate their observations and obtain an average of their two assessments. Having more practitioners assess the project reach has been found to improve the accuracy and reduce uncertainty around the most sensitive BEHI and NBS parameters (Bingham et al 2018).

Particular care should be taken to accurately measure the study bank height, root depth, and bank angle, as these have been identified as the most sensitive BEHI parameters. Where possible, best practice is to measure bank height (and sometimes root depth) using survey equipment; bank angle can be measured using an inclinometer or pitch and angle locator.

To help practitioners standardize their assessments, the U.S. Fish and Wildlife Service has developed complete guidance documents on application of the BEHI and NBS Protocols that builds on previous work (Rosgen 2006, Rosgen 2008). The documents can be found in Appendix E and are recommended for use by any BANCS assessors in the field.

In addition to the above guidance, the Prevented Sediment Group recommended forming a technical oversight workgroup to lead future efforts to better standardize BANCS assessments. The following approaches are recommended by the Group:

- Develop a BANCS Manual with Standardized Assessment Protocol
- Evaluate potential QAQC procedures
- Consider other assessment methodologies
- Improve Bank Erosion Rate Curves
- Develop NBS methods that quantify boundary shear stress

BANCS Assessor Training

All BANCS assessments should be conducted by qualified stream restoration professionals. While the group did not categorically define the term "qualified stream professional" – this decision should be made by the project owners/sponsors – it is recommended that they have received some formalized BANCS training by a qualified instructor, such as the Rosgen Level 3 training. It is recommended that a training and certification program for BANCS assessors be developed that can be tailored to the needs of the Chesapeake Bay region.

In general, qualified stream professionals consist of knowledgeable consultants, applicable review agency staff, engineers, ecologists, biologists or other suitable experts. Persons or teams serving in this role are encouraged to identify their qualifications in a simple, straight forward manner and attest they have personally reviewed the site conditions and are trained to conduct BANCS assessments.

Improved Bank Erosion Rate Curves

The original expert panel identified the need for the development of regional stream bank erosion rate curves for the BANCS method using local stream bank erosion estimates throughout the watershed. Improving and localizing stream bank erosion rate data may influence the selection of project sites and lead to better prioritization of restoration activities.

The Prevented Sediment Group recommends the development of two new bank erosion rate curves for the Chesapeake Bay watershed: Coastal Plain Curves and Piedmont Curves. Development of these curves is time and resource intensive, as many data points are needed from multiple stream reaches in order to produce curves that are representative of stream bank conditions within similar geographic and geomorphic settings without being skewed by localized influences.

To date, numerous data points have been collected from both the coastal plain and piedmont. However, more data points are still needed, as is a standardized method for collecting erosion rate data for inclusion in the curves. Statistical analysis of field results to determine outliers is currently subjective and can impact the final curve. In addition, each measurement method has drawbacks (toe pins can get lost or buried, bank pins fall out, remote technology doesn't always penetrate canopy) and decisions still need to be made with regard to which methods will be accepted for curve development.

The following data needs and decisions have been identified:

- Improving NBS relationship to the curves
- Defined drainage area size and stream order for measured reaches
- Defined allowable storm sizes and representative precipitation data
- Threshold for data exclusion based on shift in BEHI/NBS combination (during monitoring)
- Allowable data sources and measurement methods

It is estimated that the development of two regional erosion rate curves will require roughly 2 years and $400k. Funding has not been obtained but scoping efforts are underway.

7. Alternative Monitoring and Modeling Approaches

The Expert Panel allows for the use of monitoring or alternative modeling approaches to estimate sediment loss along the proposed project reach. A charge for this group was to provide additional guidance on appropriate methods and approaches that could be applied in Protocol 1.

Field Monitoring Approaches

There are several traditional methods for conducting streambank erosion monitoring in the field. These approaches generally rely on fixed-station measurements to assess bank retreat over time.

Bank Pin Monitoring

One of the most common methods for measuring sediment erosion is Bank Pin Monitoring. Bank pins are typically 4' smooth iron or steel pins driven horizontally into the bank to measure erosion rates based on the amount of the pin exposed over time. There is little standardized guidance on the use of bank pins, but several general principles should be adhered to (Gatto 1988):

- Pins are pushed perpendicularly into the face of the bank. The pin may be flush with the bank or left with a portion of the end of the pin exposed.
- Pin placement should be determined by the complexity of the bank and the needs of the project. Generally, at least 2 pins should be placed vertically on a bank at a given location to sufficiently capture the erosion rate.
- Measurements should be taken frequently to avoid loss of pins due to vandalism or a rapid erosion event. Following large rainfall events and frost events are recommended.

The number of bank pin monitoring sites along the reach may vary based on best professional judgement. It is recommended that pins be placed roughly every 200-500 linear feet based on the site-specific conditions in order to obtain a representative dataset.

Permanent Cross Sections

Permanent cross sections are cross sections that are repeatedly surveyed at the same location to determine changes in the stream channel. Typically, a permanent monument is fixed on each bank (left and right) and used to mark the starting location for future surveys.

Differential leveling surveys use an iron or steel pin to set the location of the permanent monument in each bank. Once the pins are installed, a Silvey Stake or similar spring clamp is placed on the outside of each pin so that when the tape is attached to the stake, the zero station is directly above the left pin. Once the tape is taut, the bank is surveyed using normal geomorphic survey procedures.

Total station and survey-grade GPS surveys follow a similar procedure where the survey instrument measures a direct line to an established control point.

The number of cross section sites along the reach may vary based on best professional judgement. It is recommended that cross sections be taken roughly every 200-500 linear feet based on the site-specific conditions in order to obtain a representative dataset.

Bank Profiles

Bank profiles are surveyed using a vertical rode and tape. The rod is held vertical on a toe pin and horizontal measurements are made from the edge of the rod to the bank.

Modeling Approaches

There are several new modeling approaches available to stream restoration practitioners to re-construct 3-D images of the stream channel to measure bank retreat. While there are multiple approaches and software packages available, a brief description and general guidance is provided in this section.

Digital Elevation Model (DEM) Differencing

An approach gaining popularity with advances in digital imaging and drone technology is using DEM differencing to estimate bank erosion rates. There are a range of technologies available to obtain DEMs, including GPS, photogrammetry, airborne or terrestrial LiDAR, and structure from motion. Each technology has a range of applications and restrictions in terms of spatial and time scales when employed to obtain 3-D terrain data.

LiDAR is probably the most common of the technologies. It is a surveying method that measures distance to the stream bank by illuminating the bank with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the stream channel. New photogrammetry approaches, like structure from motion, can be used to help refine older LiDAR datasets and are converted to 3-D representations with relatively cost-effective software packages (James et al. 2019).

By taking LiDAR imagery at two different times in the same location, the 3-D images can be compared to measure the bank erosion over time. To calculate the prevented sediment erosion for Protocol 1, you should have at least five DEM datasets: two pre-restoration DEMs to determine the pre-restoration erosion rate; one immediately after restoration; one, one year after project completion; and then the final DEM three years after project completion.

There are several methods available for the use of DEM differencing to measure bank erosion. Software packages are used to complete the change detection, then uncertainty is estimated to help evaluate the results (Wheaten et al 2010). The choice of methodology will depend on the quality of the available data, data size, project accuracy requirements, available hardware and available software.

It should be noted that when relying on aerial imagery, banks can be obscured by a variety of natural and artificial features (i.e. trash, woody debris, vegetation, bank overhang, etc.) that affect the accuracy of the 3-D image. Therefore, some level of manual filtering may be needed to remove large unwanted features and to restrict the data set to the exact areal extent of the study banks. However, removing vegetation from the survey data is difficult because roots, stems, and leaves blend into rougher parts of the bank topography (O'Neal and Pizzuto 2010).

8. Summary of Updated Reporting and Verification Requirements

The basic field verification approach utilizes a two-stage inspection process.

The first stage involves a rapid inspection of the project reach to assess its condition, relying on simple visual indicators. Table 6 presents the visual indicators used to assess projects that rely on the prevented sediment protocol, as defined in Group 1 (2019). The basic approach is to walk the entire project reach to assess the dominant restoration crediting protocol. The rapid initial inspection is intended to look for any potential loss of pollutant reduction function in some or all of the project reach.

Table 6. Defining Loss of Pollutant Reduction Function for Protocol 1

Criteria for Loss	Key Visual Indicators
Evidence of bank or bed instability such that the project delivers more sediment downstream than designed, as defined by exposed soils/fresh rootlets	• Bank erosion (e.g., exposed bare earth or undercutting bank) • Departure of more than 20% from average post-construction design bank height[1] • Incised channel, as indicated by loss of defined pools and riffles and/or presence of an active head cut • Flanking or scour of in-channel structures • Failure or collapse of allowable bank protection practices • Less than 80% ground or canopy cover in the restoration zone[2]
[1] as measured at riffles from the project as-built drawing, preferably from pre-designated control sections established at its most vulnerable locations [2] depending on the long-term vegetative community objectives established for the project, may be expressed as a measure of exposed surface soil (>20%) or canopy cover (<80%)	

The guiding rule is that inspectors are looking for departures from the original design that could possibly compromise pollutant reduction functions. While minor problems are noted for future re-inspection or maintenance, they are not the primary focus of the verification assessment.

The project is analyzed to determine if the degree of change, relative to the original design, is severe enough to warrant management action. The basic idea is that all stream restoration projects fall into one of three possible management categories, as shown in Table 7.

Table 7. Framework for Relating Reach Conditions to Management Decisions

Status	*% Failing*	*Inspections*	*Management Actions*
Functioning or Showing Minor Compromise	0 to 10% of project reach	Re-inspect in 5 years	None Needed Credit Renewed for 5 Years
Showing Major Compromise	20 to 40% of project reach	Conduct immediate forensic investigation to identify cause(s)	Do project repairs and maintenance, as warrented
Project Failure	50% or more of reach	Lose credit and abandon the project or reconstruct a new stable channel	

Based on the reach analysis, some kind of management action is prompted, such as:

(a) Intensive forensic investigations
(b) Project maintenance repairs
(c) Reduction in pollutant crediting
(d) Outright project abandonment (and full loss of credit).

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Appendix A. Computing streambank erosion rates

Tess Thompson, PhD
Associate Professor, Biological Systems Engineering, Virginia Tech

Background

Streambank retreat, frequently called streambank erosion, occurs due to a combination of processes, including subaerial processes (e.g. freeze-thaw cycling), soil piping, fluvial erosion, and mass wasting (i.e. slope failure). The terms "fluvial erosion" and "fluvial entrainment" describe the detachment, entrainment, and removal of individual soil particles or aggregates from the streambank face by hydraulic forces during flood events. The phrases "bank failure" or "mass wasting" denote the physical collapse of all or part of the streambanks as a result of geotechnical instabilities. Bank erosion and bank failure commonly work in concert to produce "bank retreat" or the net recession of the streambank (Figure 1).

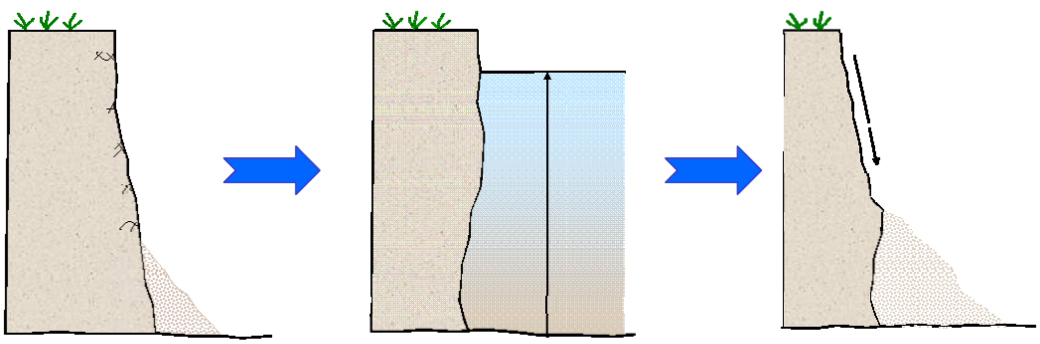

Figure 1: Streambank retreat processes
(Freeze-thaw cycling or desiccation cracking reduce soil strength, streambank soils are eroded during high flows, and the upper bank fails due to slope instability).

Given the temporal and spatial variability of river processes, accurately modeling the rate of streambank retreat is challenging. The most common quantitative model of cohesive streambank erosion (equation 1) predicts the erosion rate as a function of soil erodibility and a measure of flow energy (Moody, 2005):

$$\varepsilon = KX \qquad (1)$$

where ε is the erosion rate; K is a soil coefficient; and X is a measure of flow energy. The soil coefficient is typically called soil erodibility, which is defined as the amount of soil eroded per unit of energy per unit area. As presented, equation 1 is linear, although power functions have also been used with exponents ranging from 1.05 to 6.8 (Knapen et al., 2007).

The flow energy, X, has been quantified many different ways, including kinetic energy per unit area (Poesen and Savant, 1981), the difference between near-bank velocity and average stream velocity (Ikeda et al., 1981; Pizzuto and Meckelnburg, 1989); near-bank velocity (Pizzuto, 2009); near bank water depth (Odgaard, 1989); unit stream power (Hairsine, 1988; Nearing et al., 1997; Rose et al., 1983), boundary shear stress (Elliot et al., 1989; Flanagan and Nearing, 1995), and the "excess shear stress", which is the difference between the applied shear stress (τ_a) and a critical boundary shear stress at which erosion starts, τ_c (DuBoys, 1879; Partheniades, 1965; Ariathurai, 1974; Osman and Thorne, 1988; Hanson and Cook, 1997).

The temporal and spatial average of the excess shear stress has been used for over 70 years and is the most common measure of the applied hydraulic force. Application of this method is limited by the need to determine two soil parameters, namely the soil erodibility and critical shear stress.

The average boundary shear stress (τ_b) can be estimated using the DuBoys equation, which was derived from a fundamental force balance on the channel boundary (equation 2):

$$\tau_b = \rho g R S \tag{2}$$

where ρ is the density of water, g is the acceleration due to gravity, R is the hydraulic radius (A/P, where A is the cross sectional water area and P is the wetted perimeter of the channel) and S is the channel slope, expressed in decimal notation. Equation 2 assumes the flow is constant, predominately in one direction, and uniform (not accelerating or decelerating). In reality, local boundary shear stress varies along the channel and along a given cross section, particularly where topographic steering, due to obstructions or meander bends, creates 3-dimensional flows and may direct flows against streambanks. In these situations, maximum boundary shear stresses may locally exceed the average boundary shear stress (equation 2) by as much as a factor of 13 (Ursic et al., 2012).

From the perspective of quantifying bank retreat rates, it should be recognized that equation 1 models only one bank retreat process, fluvial erosion. However, because bank retreat typically occurs as a series of fluvial erosion and mass wasting events that are ultimately driven by floods, modeling fluvial erosion alone may be sufficient to estimate bank retreat rates. This assumption is commonly made in models such as HEC-6, SWAT, and HSPF, but further research is needed to evaluate the validity of this assumption. Models such as BSTEM, CONCEPTS, and HEC-RAS 5.0 calculate bank retreat rates by modeling both fluvial erosion and mass wasting, but require more site-specific data.

The Bank Assessment for Non-point source Consequences of Sediment (BANCS) model follows a similar form as equation 1 presented above, where K is qualitatively estimated by the bank erosion hazard index (BEHI) and the flow energy is quantified as the near bank stress (NBS). While BEHI qualitatively assesses bank resistance to multiple retreat processes, including soil piping, fluvial erosion, and mass wasting; NBS only estimates the magnitude of the force driving fluvial erosion. Thus, the force balance modeled by BANCS is inconsistent.

BANCS provides seven methods for estimating bankfull NBS in the field:

1. The presence of channel features that may direct flows towards the banks, such as transverse and/or central bars, chute cutoffs, converging flows
2. The ratio of the radius of curvature to the bankfull channel width (R_c/W)
3. The ratio of the pool slope to the average channel slope
4. The ratio of the pool slope to the riffle slope
5. The ratio of the near bank maximum depth to the mean depth
6. Ratio of near-bank shear stress to bankfull shear stress
7. The measured velocity gradient adjacent to the bank

Method 1 assumes that where flows are directed towards streambanks, the hydraulic force will be "extreme." Method 2 is related to studies by Hooke (1975) and Dietrich et al. (1979) that showed boundary shear stress in meander bends is typically a maximum along the outside of the meander bend, just downstream of the bend apex. However, Method 2 neglects observations by Hickin and Nanson (1984) that channel migration rates increase with R_c/W, peak at values of R_c/W of 2-3, and then decrease for tighter bends. The origin of methods 3 and 4 are unknown and do not have a readily apparent foundation in fluid mechanics or fluvial geomorphology. Similar to method 2, method 5 provides an indication of the possible development of 3-dimensional flows and/or flow impingement on the bank. Method 6 calculates non-dimensional estimates of the local boundary shear stress using equation 2. Method 7 is related to the law of the wall, a method for calculating the boundary shear stress; however, to determine τ, the measured velocity data must be statistically fit to the log-law equation (Wilcock, 1996).

Numerical values calculated by methods 2-7 are then converted into qualitative ratings of NBS ranging from "very low" to "extreme" using data provided by Rosgen. The methods used to develop these conversion factors are not available in publicly available literature and have not been tested.

Streambank retreat rates for a given BEHI and NBS value are then determined from regional erosion rating curves that are developed by measuring bank retreat in the field at multiple locations over a range of BEHI and NBS ratings. A significant limitation of the BANCS method is that the data used to develop the sediment rating curve is limited to bankfull flow events (Rosgen, 2019). In stream systems where the hydrology is not driven by snow melt, data collection is limited to one to two data points per year, greatly extending the time necessary to develop a regional sediment rating curve.

Recommendations

Given the need for rapid assessments of bank erosion rates for use in TMDL crediting and the difficulty in directly measuring soil erodibility, soil critical shear stress, and boundary shear stress in the field, use of a qualitative index method, such as BANCS, is recommended. However, given the weak theoretical basis for the NBS calculation methods, use of the DuBoys equation (equation 1) to directly calculate average boundary shear stress is recommended to directly quantify NBS. The DuBoys equation has a strong theoretical foundation, is simple to apply, and is widely used. Additionally, by measuring stream stage simultaneously with bank retreat rates, the boundary shear stress for each erosion event can be calculated, greatly expanding the data available for creating regional sediment rating curves.

The DeBoys equation can be easily applied by conducting a standard stream survey and then using a pressure transducer or a crest gage to record stream depth. A significant limitation of the DeBoys equation is that it assumes 1-dimensional, uniform flow. Both of these assumptions are violated in meander bends, where bank retreat is most commonly observed. However, shear stress multipliers (FHWA, 2005; Ursic et al., 2012) can be used to adapt 1-D calculations of boundary shear stress to meander bends, based on R_c/W.

Future work should include testing of the current and recommended BANCS models in the mid-Atlantic US and the development of sediment rating curves for use in the Chesapeake Bay watershed.

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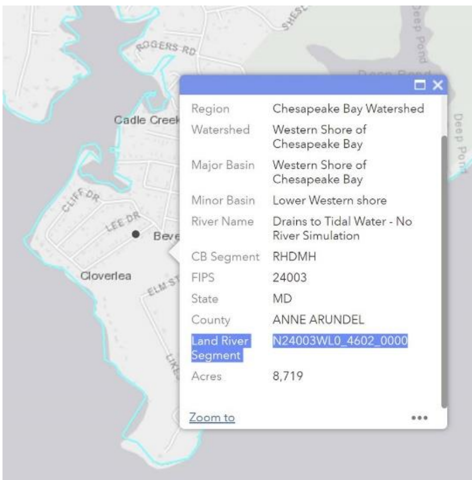
Appendix B: Four Step Method

Step 1: Determine the total load reduction from the protocols.

Step 2: Visit https://gis.chesapeakebay.net/mpa/scenarioviewer/, and enter the nearest physical address or the practice. Once entered, click the identify button on the upper-left-hand corner of the screen, and click on the land surrounding your physical address. This will open a window that contains the land-river segment within which your practice is located. See highlighted land-river segment in screen shot included below.



Step 3: Download CAST Source Data at https://s3.amazonaws.com/cast-reports.chesapeakebay.net/public/SourceData.xlsx, and click on the “Delivery Factors” worksheet. Once there, you can filter the spreadsheet for your land-river segment and you load source. In the case of stream restoration, your load source would be Stream Bed and Bank. See the screen shot below. Here, I have a delivery factor from the stream to the river for sediment of 0.44 and from the river to the Bay of 1. Multiply those two factors together to determine a combined delivery factor from the stream to the Bay of 0.44.

LandRiverSegment	LoadSource	Lan	Lan	L	StreamToRiver_TN_Factor	StreamToRiver_TP_Factor	StreamToRiver_SED_Factor	RiverToBay_TN_Factor	RiverToBay_TP_Factor	RiverToBay_SED_Factor
N24003WL0_4602_0000	Stream Bed and Bank				0.88	0.74	0.44	1.00	1.00	1.00

Step 4: Multiply reduction found in Step 1 by combined delivery factor found in Step 3 to determine pounds of sediment reduced to the Bay from your stream restoration project.

Example:
Step 1: Edge-of-Stream Reduction = 1,000 lbs sediment
Step 2: BMP located within LRSEG N24003WL0_4602_0000
Step 3: Combined Delivery factor = 0.44 X 1.0 = 0.44
Step 4: Edge-of-Tide Reduction = 1,000 lbs sediment X 0.44 = 440 lbs sediment

Appendix C. Spreadsheet Tool for Erosion Rate Estimates

This spreadsheet was developed specifically for TMDL purposes using data from multiple stream sources including Hickey Run. This spreadsheet allows for user defined variables (e.g., bulk density, nutrient concentration) but must be updated to account for the Phase 6.0 model's delivery factors. It will be included once complete.

Click here to view the spreadsheet

Appendix D. Bulk Density and Soil Nutrient Concentration Methods Guidance

4. Bulk Density Test

The bulk density measurement should be performed at the soil surface and/or in a compacted zone (plow pan, etc.) if one is present . Measure bulk density near (between 1 and 2 feet) the site of the respiration and infiltration tests. To get a more representative bulk density measurement of the area, additional samples may be taken.

Materials needed to measure bulk density:

- **3-inch diameter ring**
- **hand sledge**
- **wood block**
- **garden trowel**
- **flat-bladed knife**
- **sealable bags and marker pen**
- **scale (0.1 g precision)**
- **1/8 cup (30 mL) measuring scoop**
- **paper cups**
- **18-inch metal rod**
- **access to a microwave oven**

Did You Know?
Bulk density is the weight of soil for a given volume. It is used to measure compaction. In general, the greater the density, the less pore space for water movement, root growth and penetration, and seedling germination.

Considerations: For rocky or gravelly soils, use the alternate procedure on page 11.

(1) **Drive Ring into Soil**

- Using the hand sledge and block of wood, drive the 3-inch diameter ring, beveled edge down, to a depth of 3 inches **(Figure 4.1)**.

- The exact depth of the ring must be determined for accurate measurement of soil volume. To do this, the height of the ring above the soil should be measured. Take four measurements (evenly spaced) of the height from the soil surface to the top of the ring and calculate the average. Record the average on the Soil Data worksheet.

Figure 4.1

NOTE: Use the metal rod to probe the soil for depth to a compacted zone. If one is found, dig down to the top of this zone and make a level surface. Proceed with Step 1.

(2) **Remove 3-inch Ring**

Dig around the ring and **with the trowel underneath it,** carefully lift it out to prevent any loss of soil.

③ Remove Excess Soil

Remove excess soil from the sample with a flat-bladed knife. The bottom of the sample should be flat and even with the edges of the ring **(see Figure 4.2).**

Figure 4.2

④ Place Sample in Bag and Label

Touch the sample as little as possible. Using the flat-bladed knife, push out the sample into a plastic sealable bag. Make sure the entire sample is placed in the plastic bag. Seal and label the bag.

NOTE: Steps 5-7 can be done in a lab or office if a scale is not available in the field. Step 8 requires access to a microwave.

⑤ Weigh and Record Sample

- Weigh the soil sample in its bag. [If the sample is too heavy for the scale, transfer about half of the sample to another plastic bag. The weights of the two sample bags will need to be added together. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

- Weigh an empty plastic bag to account for the weight of the bag. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

⑥ Extract Subsample to Determine Water Content and Dry Soil Weight

- Mix sample thoroughly in the bag by kneading it with your fingers.

- Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic bag and place it in a paper cup (a glass or ceramic cup may be used).

⑦ Weigh and Record Subsample

- Weigh the soil subsample in its paper cup. Enter the weight on the Soil Data worksheet.

- Weigh an empty paper cup to account for its weight. Enter the weight on the Soil Data worksheet.

⑧ Dry Subsample

Place the paper cup containing the subsample in a microwave and dry for two or more four-minute cycles at full power. Open the microwave door for one minute between cycles to allow venting. Weigh the dry subsample in its paper cup and enter the weight on the Soil Data worksheet.

NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4-minute cycle. When its weight does not change after a drying cycle, then it is dry.

CALCULATIONS (See page 13)

Bulk Density Test for Gravelly and Rocky Soils

This method is to be used when rocks or gravels prevent sampling bulk density by the core method described in the first part of this Chapter. This excavation method will require the user to sieve out the coarse material greater than 2 mm in size.

Materials needed to measure bulk density:

- **Plastic wrap**
- **140-cc syringe**
- **water**
- **garden trowel**
- **sealable bags and marker pen**
- **2-mm sieve**
- **scale (0.1 g precision)**
- **1/8-cup (30 mL) measuring scoop**
- **paper cup or bowl**
- **access to a microwave oven**

Considerations: Choose a spot that is as level as possible to allow water to fill the hole evenly. If the soil is too wet to sieve, ignore the part in Step 2 about replacing rocks, and proceed to Step 3. Soil will have to be dried and sieved later. The volume of gravel will need to be determined and subtracted from the total volume of the soil sample taken in the field.

(1) Dig Hole

- Dig a bowl shaped hole three inches deep and approximately five inches in diameter using the trowel (**Figure 4.3**). Avoid compacting the soil in the hole while digging. Place **all** of the soil and gravel removed from the hole in a plastic bag.

- Using the 2-mm sieve, sieve the soil in the plastic bag to separate the gravel. Collect the soil in a plastic sealable bag. Put the gravel aside to be used in Step 2. Seal and label the plastic bag. **[Note: See Considerations above if soil is wet.]**

Figure 4.3

(2) **Line the Hole**

Line the hole with plastic wrap as shown in **Figure 4.4**. Leave some excess plastic wrap around the edge of the hole. Place the sieved rocks and gravel carefully in the center of the hole on top of the plastic wrap. Assure that the pile of rocks **do not** protrude above the level of the soil surface.

Figure 4.4

(3) **Add Water to Hole**

- Use the 140 cc syringe to keep track of how much water is needed to fill the lined hole. The level of the water should be even with the soil surface.

- The amount of water represents the volume of soil removed. Record the total amount of water in cubic centimeters (1 cc = 1 cm^3) on the Soil Data worksheet.

NOTE: Steps 4-6 can be done in a lab or office if a scale is not available in the field. Step 7 requires access to a microwave.

(4) **Weigh and Record Sample**

- Weigh the soil sample in its bag. [If the sample is too heavy for the scale, transfer about half of the sample to another plastic bag. The weights of the two sample bags will need to be added together. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

- Weigh an empty plastic bag to account for the weight of the bag. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

(5) **Extract Subsample to Determine Water Content and Dry Soil Weight**

- Mix sample thoroughly in the bag by kneading it with your fingers.

- Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic bag and place it in a paper cup (a glass or ceramic cup may be used).

(6) **Weigh and Record Subsample**

- Weigh the soil subsample in its paper cup. Enter the weight on the Soil Data worksheet.

- Weigh an empty paper cup to account for its weight. Enter the weight on the Soil Data worksheet.

7 Dry Subsample

Place the paper cup containing the subsample in a microwave and dry for two or more four-minute cycles at full power. Open the microwave door for one minute between cycles to allow venting. Weigh the dry subsample in its paper cup and enter the weight on the Soil Data worksheet.

NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4-minute cycle. When its weight does not change after a drying cycle, then it is dry.

CALCULATIONS (for both bulk density methods):

Soil water content (g/g) = $\dfrac{\text{(weight of moist soil - weight of oven dry soil)}}{\text{weight of oven dry soil}}$

Soil bulk density (g/cm^3) = $\dfrac{\text{oven dry weight of soil}}{\text{volume of soil}}$

Soil water-filled pore space (%) = $\dfrac{\text{volumetric water content x 100}}{\text{soil porosity}}$

Volumetric water content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)

Soil porosity (%) = 1 - $\left(\dfrac{\text{soil bulk density}}{2.65}\right)$

Volume of Rocks (cm^3) = Fill 1/3 of a graduated cylinder with water, and record the amount. Add the rocks to the cylinder and record the change in the water level. The difference is the volume of rocks (1 mL = 1 cm^3).

Volume of Soil (cm^3) = Total soil volume - volume of rocks

Appendix E. BEHI Protocol Guidance

Standards for Rosgen Bank Erosion Hazard Index

1. PURPOSE

The Bank Erosion Hazard Index (BEHI) is a field method to evaluate bank erodibility potential at a typical study bank or a study bank length. Several bank characteristics are measured including top of bank and bankfull height, rooting depth, root density, bank angle, percent bank protection, bank composition, and bank material stratification. This information, used in conjunction with field estimated near bank shear stress (NBS) ratings, allows one to predict bank erosion quantities and rate of erosion using existing bank erodibility curves developed by Rosgen for Yellowstone and Colorado (Rosgen 2001). A bank erodibility curve is a graph that relates combinations of BEHI and NBS ratings with actual erosion rates. Repeated measurements at monumented cross sections for representative conditions allow for validations of quantities and rates.

Surveyors should also read and understand the Near Bank Shear Stress (NBS) Standards prior to using these standards in the field as the BEHI and NBS are generally conducted at the same time.

The purpose of this standard is to document methods for collecting and recording field data.

2. METHODS

The methods, procedures, and definitions presented within this protocol are drawn from several sources, including:

- Brady, N.C. 1990. The nature and properties of soils. Tenth edition. Macmillan Publishing Co., NY.

- Rosgen, D. L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

- Rosgen, D.L. 2001. A practical method to predict stream bank erosion. In: U.S. Subcommittee on Sedimentation. Proceedings of the federal interagency sedimentation conferences, 1947 – 2001.

- Rosgen, D.L. 2003. Wildland Hydrology. 2003. River Assessment and Monitoring Field Guide.

3. DEFINTIONS

- Duripan: mineral soils, in the form of a hard pan, and strongly cemented by silica.
- Fragipan: mineral soils in the form of a brittle pan, usually loamy textured, and weakly cemented.
- Hemic soil materials: organic soils with an intermediate degree of organic material decay.

4. FIELD EQUIPMENT

- Field Forms: (1) Rosgen Reach BEHI and NBS Field Form and (2) Rosgen - XS BEHI Bank Profile Field Form.
- Completed geomorphic map, sketch, or aerial photograph with mylar overlay.
- Survey rod, pocket rod, and clinometer.
- Digital camera.

5. BEHI CALIBRATION, MEASUREMENTS, AND REVIEW

When several workers are assessing a watershed, they should initially work together to familiarize themselves with the existing bank conditions and calibrate their observations. The BEHI requires and examination of the amount of bank material susceptible to erosion processes, such as, freeze/thaw, rotational failure, mass wasting, water piping, etc. Take measurements in feet and tenths-of-feet, degrees, and percentages. Prior to completing the BEHI for the reach or cross section, the observer(s) should review the BEHI data and consider if the results are representative of the bank conditions.

6. BEHI FIELD PROCEDURES

Surveyors will conduct two types of BEHI assessments: 1. Reach BEHIs to predict sediment contributions from bank erosion, and 2. Cross section BEHIs to validate bank erosion rates. The field methods for selection are discussed separately below. In some situations, such as an entrenched stream, it may be necessary to assess bank conditions on each side of the stream.

1. Reach BEHI Assessment

   a. Assess all stream banks prone to erosion, excluding banks with significant deposition or stable concrete revetment (*i.e.*, no indications of erosion along the revetment).

   b. Partition the study banks based on different combinations of BEHI and NBS conditions (*e.g.*, study bank with one BEHI rating but two NBS conditions should be assessed as two separate study banks).

   c. Note the study bank locations on an aerial photograph with mylar overlay, site sketch, or a geomorphic map.

   d. Evaluate BEHI conditions for the entire length of study bank

   e. Draw a typical bank profile in the space provided in the field form, with illustrations of rooting depth, bank protection, bank composition, and bank stratification.

   f. Photograph the study bank with a surveyor or survey rod in the foreground as reference.

   g. Identify reach BEHI location and length on the geomorphic map.

   h. If a repeat survey, use the same reach BEHI bank map labels, if BEHI and NBS conditions are the same.

   i. Use the same reach BEHI bank map labels and add a sequential letter if additional bank labels are required (*e.g.*, Bank 9, Bank 9A, and Bank 9B).

2. Cross Section BEHI Assessment

   a. Surveyors should conduct the cross section BEHI assessment following the completion of each cross section survey.

   b. BEHIs at monumented cross sections should represent the various BEHI and NBS combinations found in the study reach in order to validate bank erosion predictions.

   c. Assess the study bank directly in line with the cross section.

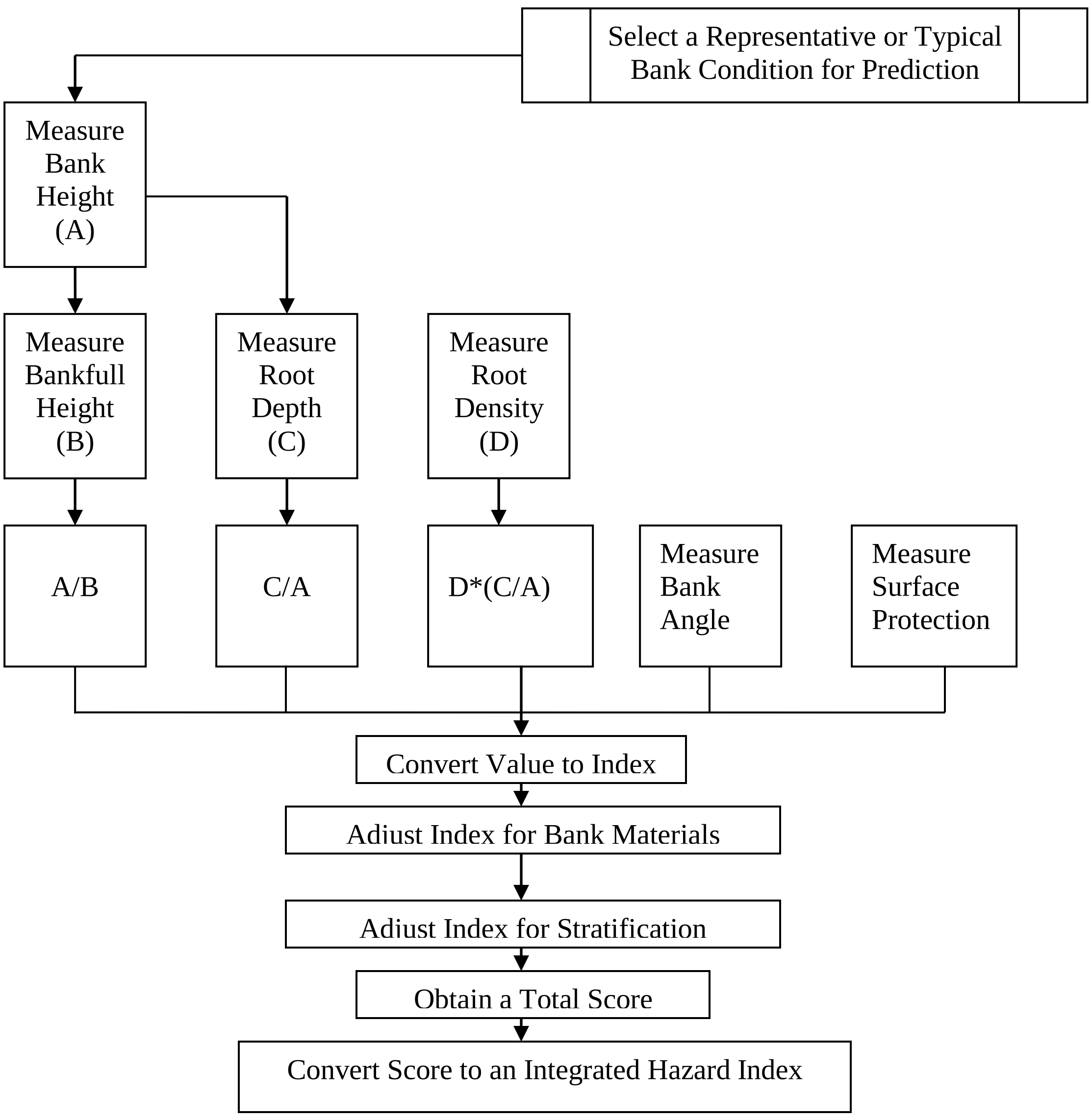
d. Avoid evaluating upstream and downstream influences, such as boulder diversions or protection, when assessing the study bank.

e. Photograph the study bank with surveyor or survey rod in the foreground as reference.

For study bank BEHIs, the assessment location and BEHI characteristics (*e.g.*, top of bank to bankfull height ratio, rooting depth-bank height ratio, *etc.*) should represent average bank conditions in the study reach. For example, if the bank angles within a study reach ranged from 50^o to 60^o the average bank angle would be 55^o for the study reach.

BEHI CRITERIA AND PROCEDURES

The flow diagram below (from Rosgen 2003) outlines the general BEHI procedure and relationship between variables. Figure 1 provides a graphic display for general measurement and Figure 2 is the BEHI Index and Value chart. Outlined below are the seven BEHI criteria and procedures for measurement. In some cases, specific examples from the mid-Atlantic region are provided for explanatory purposes.



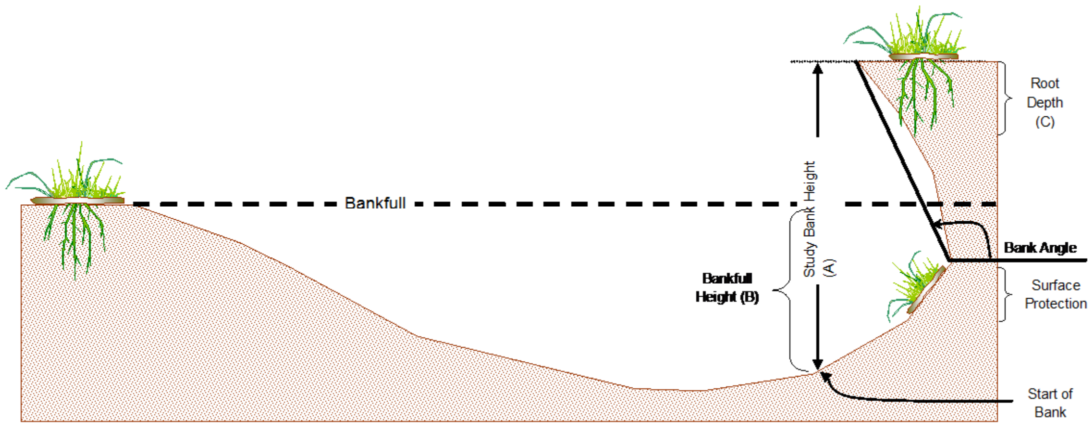


Figure 1. BEHI Variables (Rosgen 2003).

Bank Erosion Hazard Index

Erodibility Variable		Bank Erosion Potential: Very Low	Low	Moderate	High	Very High	Extreme
Bank Height/ Bankfull Height	Value	1.0 - 1.1	1.11 - 1.19	1.2 - 1.5	1.6 - 2.0	2.1 - 2.8	>2.8
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Root Depth/ Bank Height	Value	1.0 - 0.9	0.89 - 0.5	0.49 - 0.3	0.29 - 0.15	0.14 - 0.05	<0.05
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Weighted Root Density	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 5.0	<5.0
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Bank Angle	Value	0 - 20	21 - 60	61 - 80	81 - 90	91 - 119	>119
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Surface Protection	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 10	<10
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10

Bank Materials

Bedrock (Bedrock banks have very low bank erosion potential)
Boulders (Banks composed of boulders have low bank erosion potential)
Cobble (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, do not adjust)
Gravel (Add 5-10 points depending on percentage of bank material that is composed of sand)
Sand/Silt/Clay loam (Add 5 points, where sand is 50-75% or the composition)
Sand (Add 10 points if sand comprises > 75 % and is exposed to erosional processes)
Silt/Clay (+ 0: no adjustment)
Clay (Subtract up to 20 points depending on percentage of bank material composed of clay)

Stratification

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

Total Score

Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

Figure 2. BEHI Value and Index table (Rosgen 1996).

<u>Top of Bank Height to Bankfull Height Ratio</u>

a. Measure the top of bank and bankfull heights from the bank toe (Figures 1 and 3).

b. For BEHIs at a cross section survey, determine the top of bank and bankfull heights from the survey data.

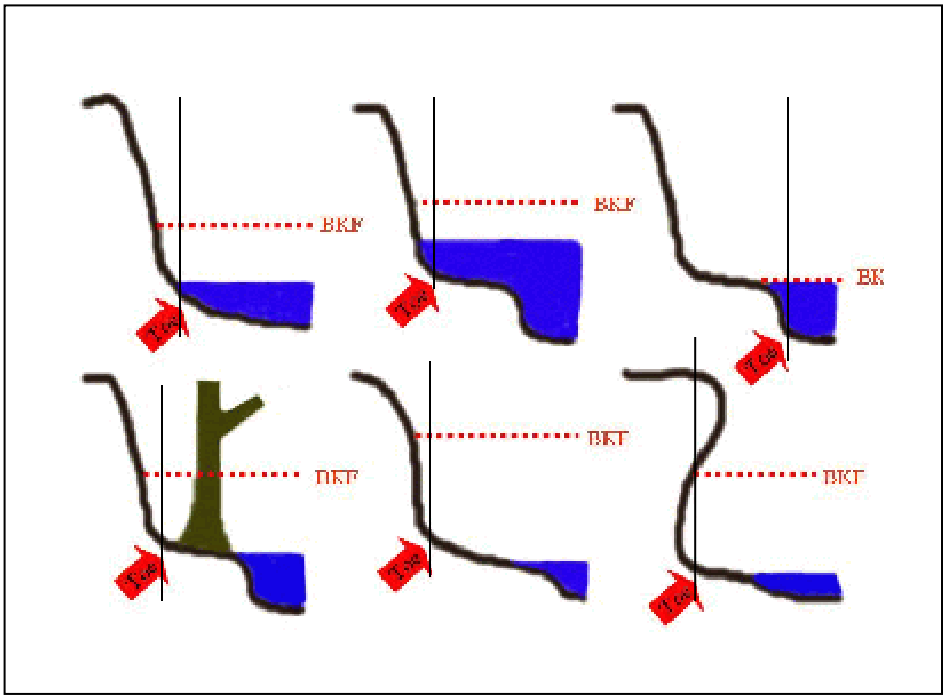


Figure 3. Bank toe location examples.

1. <u>Rooting Depth to Top of Bank Height Ratio</u>

   Rooting depth to bank height ratio is a measure of rooting depth in relation to the top of bank height (Figure 4). Rooting depth is highly variable and depends on vegetation type and soil conditions. Familiarity with annual and perennial growth for a particular region and an understanding of how conditions may change seasonally is essential. Rooting depth is often species and location dependent. Table 1 provides average root depths for various vegetation types; however, one should look for evidence in the field of rooting depths for the particular vegetation growing at the study sites.

Table 1. Average Root Depths (adapted from Colorado State University cooperative extension newsletter).			
Vegetation Type	Root Depth (ft)	Vegetation Type	Root Depth (ft)
Annuals	0.16 - 0.25	Shrubs	0.67 - 1.00
Perennials	0.33 - 0.83	Trees	0.83 – 1.5
Turf grass	0.50 - 0.67		

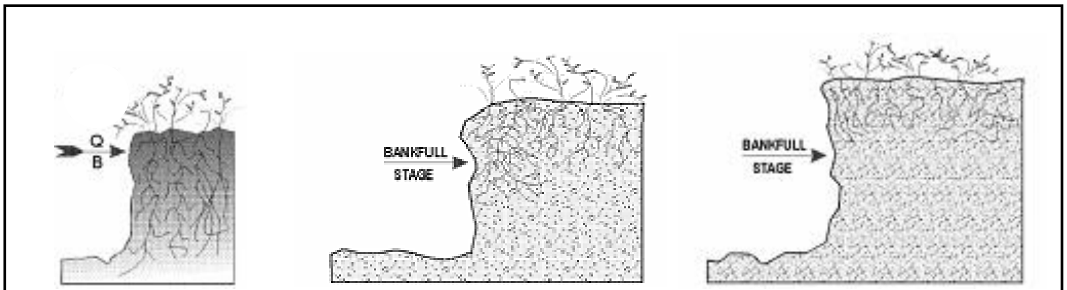


Figure 4. Examples of low, medium, and high BEHIs for rooting depth (Rosgen 1996).

Along with vegetation type and soil conditions, the location of vegetation influences root depth measurements. Figure 5 through 8 show two different vegetation location scenarios as well as two different types of vegetation. The vegetation locations include vegetation at the top of the bank and near the toe of the bank and vegetation covering the entire bank. Vegetation types include grass vegetation and woody vegetation (e.g., woody vegetation can be shrubs or trees).

If the bank vegetation is grass, than the root depth is based on the depth of roots associated with the grass vegetation regardless of its location on the bank, even if it covers the entire bank (Figures 5 and 6). This is because there is higher probability of internal tension cracks and bank mass wasting or rotational failures since grass root depths are typically shallow and have low density. However, all vegetation on a bank is applied to the surface protection measurement category.

If the bank vegetation is woody and not covering the entire bank, then the root depth is a cumulative measurement. The individual roots depths are added together to obtain the root depth measurement. In Figure 7, there are two woody vegetation locations. Each vegetation locations have an individual root depth of 3 feet. Therefore, the total root depth is 6 feet for this scenario. This is because the root depths and densities are high enough to protect against internal tension cracks and bank mass wasting or rotational failures. In Figure 8, the woody vegetation covers the entire bank. In this scenario, the root depth is the height of the bank, which is 9 feet. A root depth measurement can never be greater than the height of bank regardless of what the vegetation coverage is on a bank.

a. Where the upper bank is accessible (but not at the cross section location), clear the soil to expose the roots and assess the root depth. If the upper bank is not accessible, look for areas with exposed roots or use Table 1 to determine rooting depths.

b. Where the tree and/or tree roots extend down the bank, the extent of the roots down the bank (*i.e.*, the height of the root ball) is the rooting depth (Figure 9).

c. It is important to consider soil conditions (*e.g.*, duripan, fragipans, and hemic soil materials) that will affect rooting depths. Duripans and fragipans tend to retard rooting depths. Hemic soil materials tend to promote rooting depth because of its high organic matter.

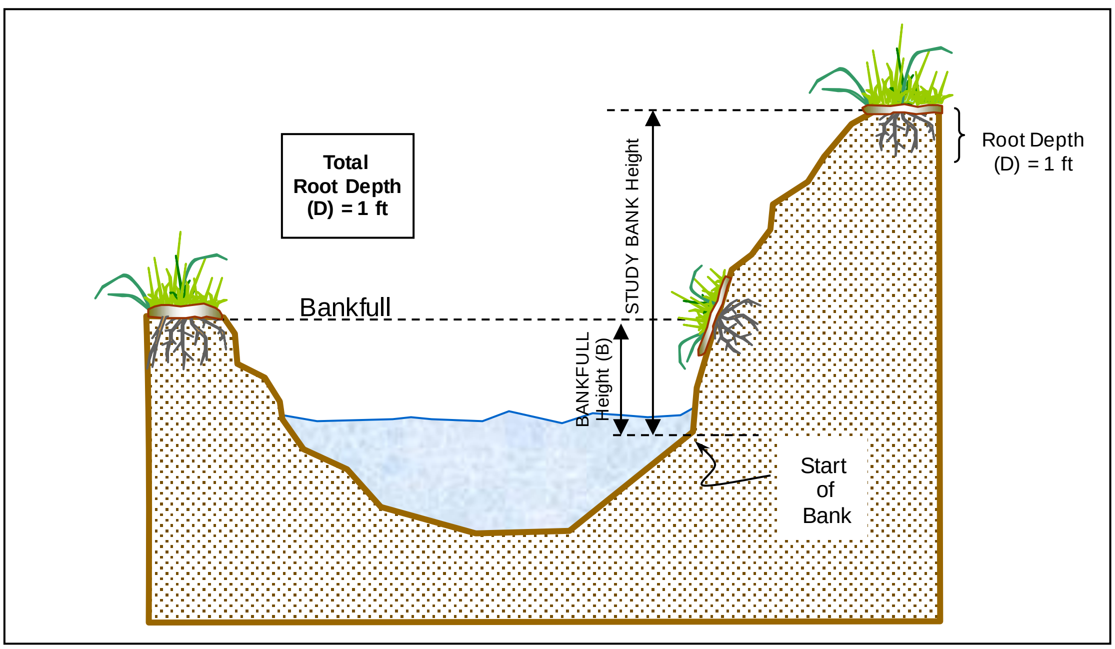


Figure 5. Root depth for partial grass vegetation bank coverage

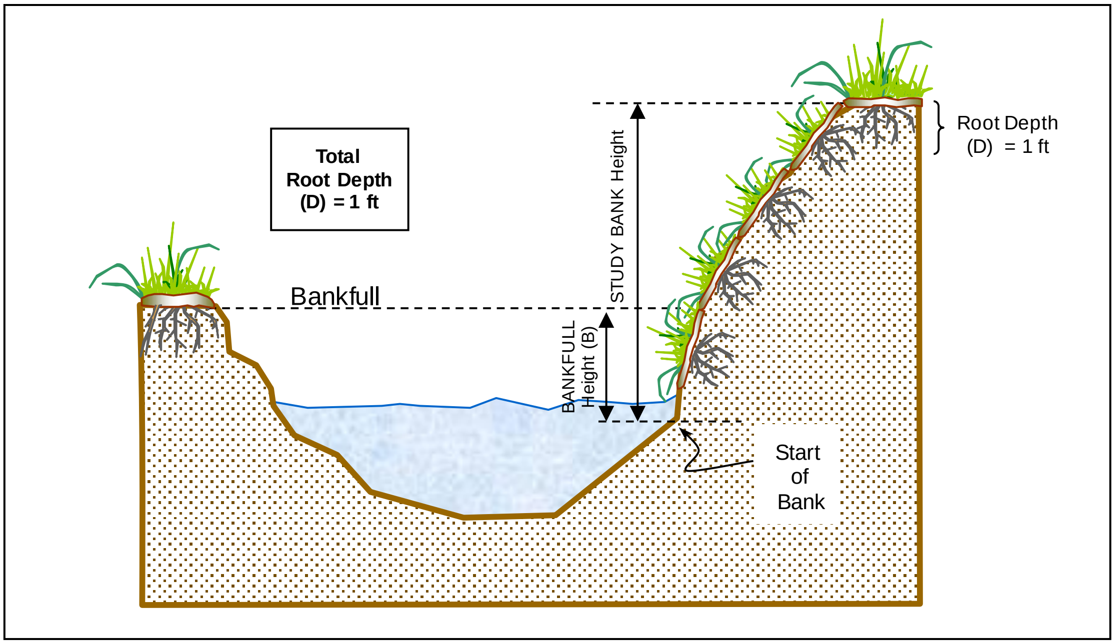


Figure 6. Root depth for entire grass vegetation bank coverage

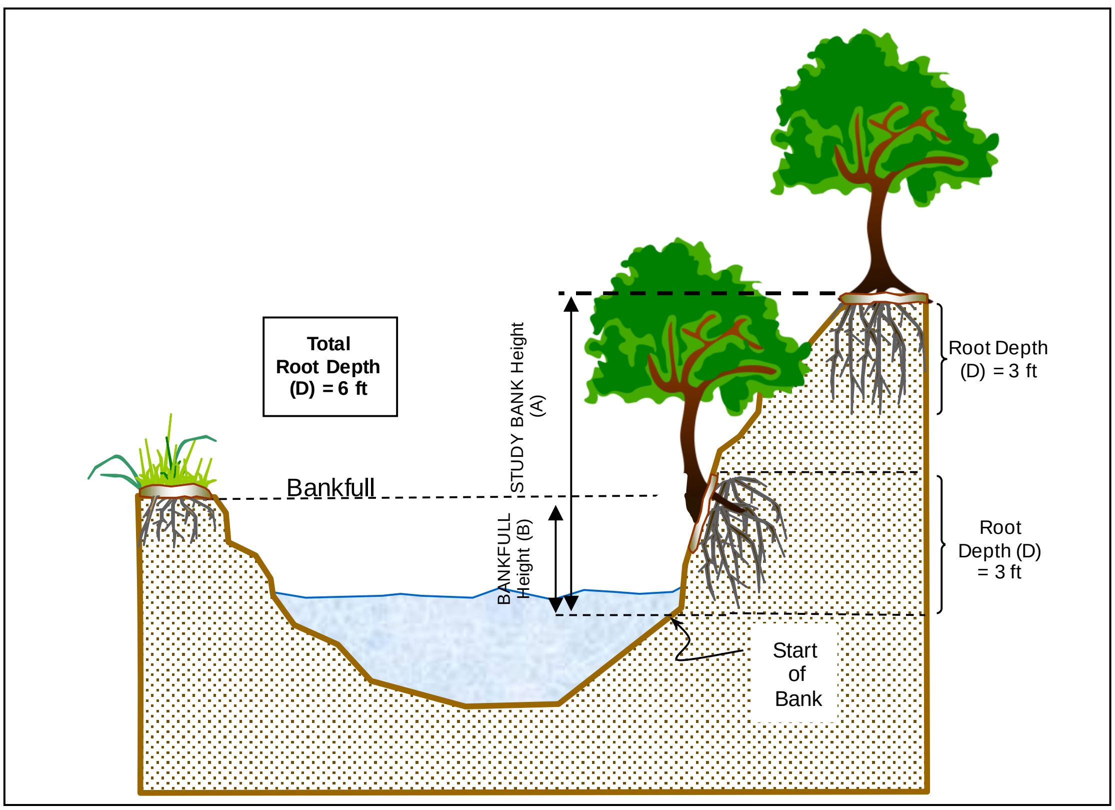


Figure 7. Root depth for partial woody vegetation bank coverage

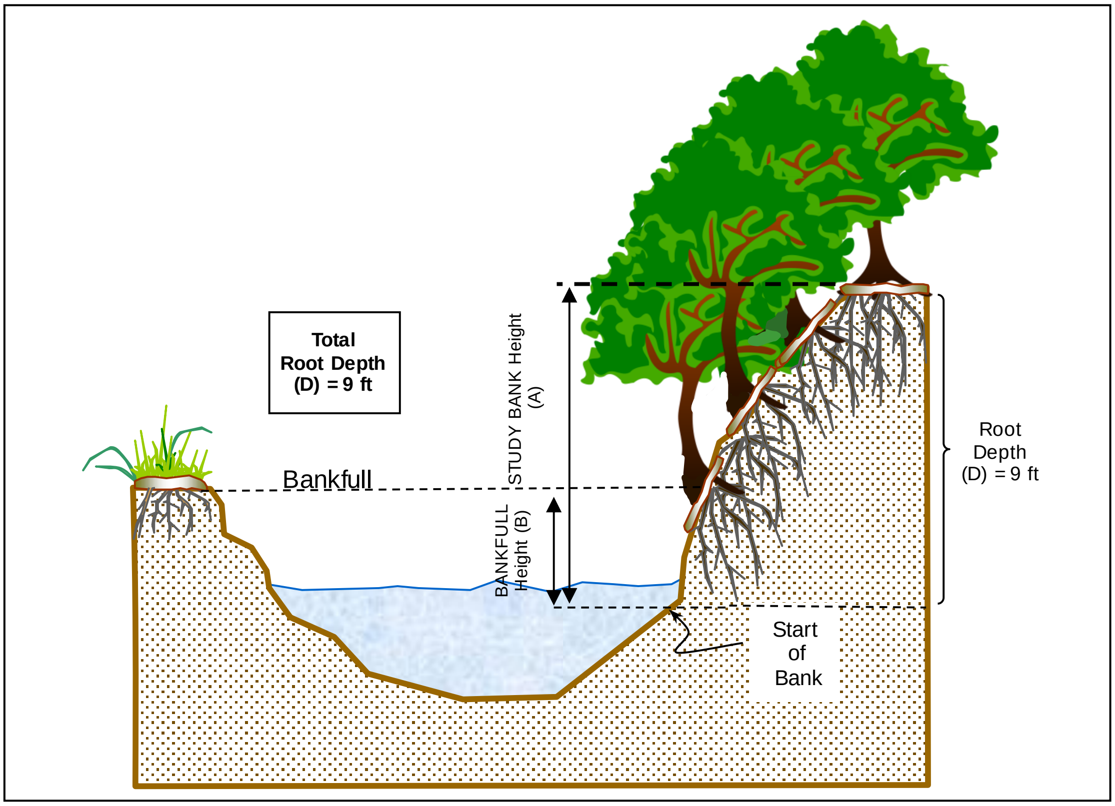


Figure 8. Root depth for entire woody vegetation bank coverage

Rooting depth =
Bank Height

Figure 9. Tree roots extending down the stream bank.

3. Weighted Root Density

Weighted root density is a percentage of root density within the rooting depth. This is an ocular estimate, (*e.g.*, if the bank as a 60 percent density but only on 1 percent of the bank, then root density is less than 5 percent (extreme category)). Similar to rooting depth, root density is highly variable and depends on vegetation type and soil conditions.

a. Where the upper bank is accessible, clear the soil (except at the cross section) to expose the roots and assess the root density.

b. When estimating root density, it maybe helpful to compress the surface area of the root and visualize what percent that area comprises of the total rooting depth area (Figure 10).

c. If the upper bank is not accessible, look for areas with exposed roots to determine root density.

d. It is important to note soil conditions (see 2.d. above).

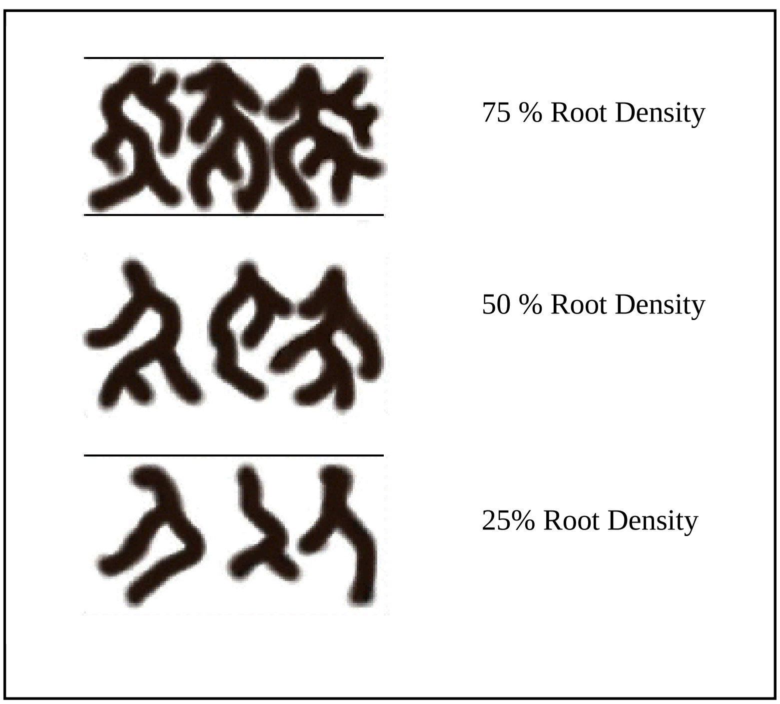


Figure 10. Root density examples.

4. Bank Angle

Bank angle is a measure of the angle-of-repose of the bank. Figure 11 provides five common bank angle scenarios.

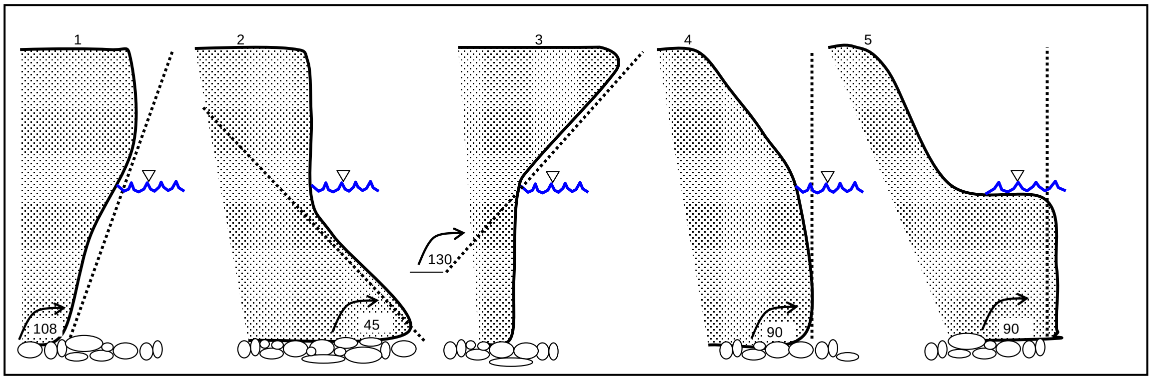


Figure 11. Bank angle scenarios (perspective: cross-section view)(Rosgen 2003).

a. In general, measure the angle of steepest slope or slope most prone to failure, at bankfull.

b. If possible, place a survey rod on the slope face.

c. Using a clinometer, place the base of the clinometer on the survey rod and measure the angle. If using a compass with a clinometer, remember to set the bezel so that the clinometer reads 0° when the compass base is flat and 90° when it is vertical.

d. The measure of bank angle for a bank angle that is overhanging/cantilevered (Figure 11 – Bank Angle Scenario 3) is depended upon the potential for the bank to fail causing mass wasting. The potential for mass wasting is depended upon the bank height ratio and the root characteristics of the vegetation on the bank. The undercut should be substantial enough to create the cantilevered failure. If the cantilevered banks represents a small part of the bank is not very significant as a potential failure mechanism, there angle associated with the cantilevered banks is **NOT** measured. However, the likelihood of mass wasting is higher for banks that have a bank height ratio greater than 1.5. Therefore, the cantilevered bank angle **SHOULD** be measured. Furthermore, rooting depth and density ratios should also be considered when determine what bank angle to measure. If rooting depth and density ratios are high and appear, *based on professional judgment*, to be preventing the cantilevered bank from mass wasting, do **NOT** measure the cantilevered banks angle. A rule of thumb to follow is if the rooting depth is only 1/3 of bank height and the bank height ratio is greater than 1.5, the cantilevered bank angle **SHOULD** be measured.

5. Surface Protection

Surface protection characterizes bank conditions (*e.g.*, boulders, vegetation) that attenuate erosional forces along the bank. Surface protection is a percentage measurement of the surface area of the bank protected from erosion. The surface protection can be vegetation, debris, rootwads, etc.

a. Determine areas along the bank that have surface protection.

b. Determine the protected percent of the total bank height.

c. For banks vegetated with vines, brambles annuals, and/or moss, determine the vegetated percent of the bank. It may be easier to determine the percent of exposed soil, and calculate the remaining vegetated percentage (Figure 12).

Figure 12. Herbaceous bank vegetation.

d. To determine bank protection for banks vegetated with shrubs and trees, determine the percent of the bank influenced by the root fan (Figure 13). Soil exposed within the area of the root fan is less a consideration with woody vegetation.

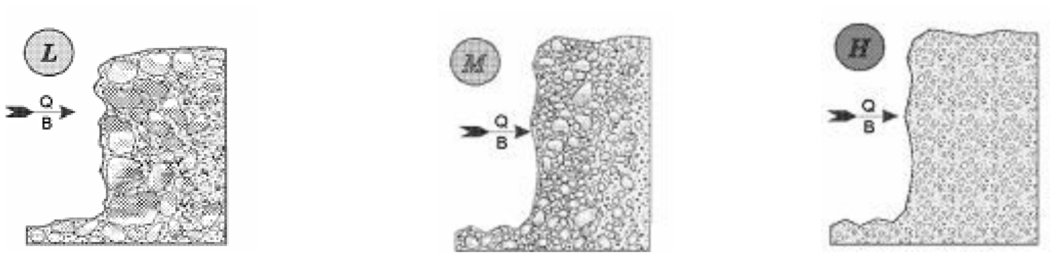
Figure 13. Woody bank vegetation.

e. When evaluating suspended logs, and trees and boulders in the channel, determine the percent of the bank protected at the near bank (Figure 14).

Figure14.Suspended log bank protection.

6. Bank Material Adjustment

Bank material adjustment characterizes the composition and consolidation of the bank (Figure 15).



(0 points) (5 points) (10 points)

Figure 15. Examples of low, medium, and high erodibility bank material composition (Rosgen 1996).

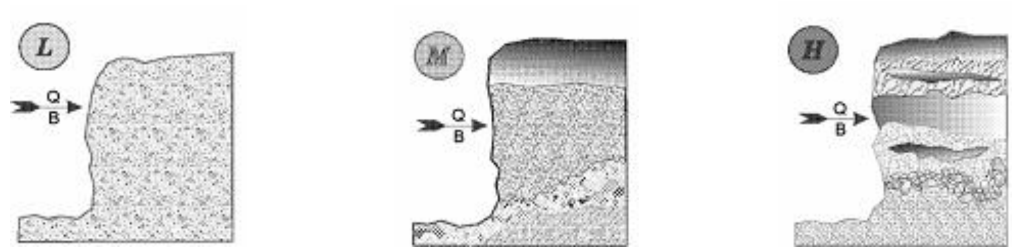
a. Determine the general bank composition. Stream flow may influence surface appearance, if necessary, remove the surface layer of soil.

b. Adjust the overall BEHI score using values from Table 2.

Table 2. Bank Material Adjustment	
Bank Material	BEHI Rating Adjustment
Bedrock	BEHI for bedrock banks are "very low erosion potential".
Boulders	BEHI for boulder banks are "low erosion potential".
Cobble	Subtract 10 points. No adjustment if sand/gravel composes greater than 50 percent of bank.
Sand/Silt/Clay Loam	Add 5 points, if composition is 50 – 75 percent sand.
Gravel	Add 5-10 points depending on percentage of bank material composed of sand.
Sand	Add 10 points if sand comprises greater than 75 percent and is exposed to erosional processes.
Silt/Clay	0 – No adjustment
Clay	Subtract up to 20 points depending on percentage of bank material composed of clay. *Note: this is a new adjustment

7. Bank Stratification Adjustment

Bank stratification adjustment characterizes unstable soil horizons that are prone to erosion in relation to the bankfull stage (Figure 16). There are several processes of bank erosion to consider when evaluating bank stratification adjustments: fluvial entrainment, rotational failure, soil piping, and freeze/thaw.



(0 points) (5 points) (10 points)

Figure 16. Examples of low, medium, and high erodibility soil stratification (Rosgen 1996).

a. Observe the bank profile and soil horizons along the bank.

b. Identify any zone(s) where water concentrates, and area(s) of rotational failures and soil piping.

c. Evaluate the horizon's consolidation by attempting to dislodge the bank materials. Stream flow may influence surface appearance, if necessary, remove the surface layer of soil.

d. Adjustment values depend on the location of horizons prone to erosion, for example, if the bank has a gravel lens in the lower third of the bank add 10 points. Add 5-10 points depending on position of unstable layers in relation to bankfull stage.

8. PHOTOGRAPHIC DOCUMENTATION

Photographic documentation is required for each BEHI assessment. The photograph should represent bank conditions assessed for the BEHI. Reach BEHIs may require multiple photographs, while site BEHIs may require only one photograph.

1. If possible, incorporate a reference (*e.g.*, survey rod) into the photograph.

2. If necessary, take the photograph at an oblique angle to accentuate bank conditions.

3. Record the camera number, photograph number, and photograph description on the BEHI data sheet.

Appendix F. NBS Protocol Guidance

Standards for Estimating Near-Bank Stress

1. PURPOSE

Estimation of Near-Bank Stress (NBS) rating is a field method, developed by Dave Rosgen, to estimate bank stress associated with bankfull flows. The use of stream pattern, shape, and depositional areas provides a rapid method to estimate NBS for a study reach for general assessment and initial predications. When used with Bank Erodibility Hazard Index (BEHI) scores, the NBS ratings allow one to predict bank erosion rates. If the objective is to quantify bank erosion rate, a more intensive level of assessment is required (*i.e.*, validation).

Rosgen (2003) provides seven levels of estimating and/or quantify near-bank stress (Figure 1). The method selected must incorporate an understanding of stream processes. For example, if a tight radius in a bend is having greater influence than the local stream slope, the radius of curvature/bankfull width is a better predictor.

The purpose of this standard is to document field methods for estimating NBS.

2. METHODS

The methods and procedures presented within this protocol are drawn from:

- Rosgen, D.L. 2001. A practical method to predict stream bank erosion. In: U.S. Subcommittee on Sedimentation. Proceedings of the federal interagency sedimentation conferences, 1947 – 2001.
- Rosgen, D.L. 2003. Wildland Hydrology. 2003. River Assessment and Monitoring Field Guide.

3. FIELD PROCEDURE

1. Use the Estimating near-bank stress Field Form (Figure 1).
2. For reach-level assessment, use near-bank stress estimation based on channel pattern, depositional feature, and cross section shape (Level I Reconnaissance) (Figures 2 - 4).
3. Select, from Figures 2 and 4, the plan form and cross section that best represents the study reach cross section.

4. Consider the following factors when determining the NBS rating:

   - Always consider the direction of flow in relation to the study bank (e.g., parallel versus perpendicular) and the near bank depth of the study bank in relation to the overall channel depth (Figure 4).

   - The maximum depth location will influence the NBS rating. For example, a cross section with the maximum depth located in the middle has a lower NBS rating than a cross section with the maximum depth located in the outer one third of the stream.

   - Chute cutoff return flows and split channels converging against study banks (Figure 3) will cause a disproportionate energy distribution in the near bank region and NBS ratings will be extreme.

   - Depositional features such as transverse bars and/or central bars (Figure 3) will also create a disproportionate distribution of energy in the near bank region and NBS estimate ratings should be adjusted upward due to high velocity gradients. For central bars, estimate both outside banks.

   - Evaluate the individual channels of a braided reach separately based on the distribution of energy in the near bank region.

   - If the stream slope directly upstream of a study bank is steeper than the average reach slope, adjust the NBS rating upward.

Figure 1. Estimating near-bank stress Field Form

Stream: Location: Date: Crew:

Level	Method				
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 (Figure X). NBS = Extreme			
Level II	2	Radius of Curvature Rc (feet)	Bankfull Width W_{bkf} (feet)	Ratio Rc/W	Near-Bank Stress
	3	Pool Slope S_p	Average Slope S	Ratio S_p/S	Near-Bank Stress
	4	Pool Slope S_p	Riffle Slope S_{rif}	Ratio S_p/S_{rif}	Near-Bank Stress

Dominant Near-Bank Stress

Level	Method								
Level III	5	Near-Bank Max Depth d_{nb} (feet)	Mean Depth d (feet)	Ratio d_{nb}/d	Near-Bank Stress				
	6	Near-Bank Max Depth d_{nb} (feet)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d (feet)	Average Slope S	Shear Stress τ (lb/ft^2)	Ratio τ_{nb}/τ	Near-Bank Stress
Level IV	7	Velocity Gradient (ft/s/ft)		Near-Bank Stress					

Converting Values to a Near-Bank Stress Rating

Near-Bank Stress	Method Number						
	1	2	3	4	5	6	7
Very Low		>3.0	< 0.20	< 0.4	<1.0	<0.8	<1.0
Low	N/A	2.21 - 3.0	0.20 - 0.40	0.41 - 0.60	1.0 - 1.5	0.8 - 1.05	1.0 - 1.2
Moderate		2.01 - 2.2	0.41 - 0.60	0.61 - 0.80	1.51 - 1.8	1.06 - 1.14	1.21 - 1.6
High		1.81 - 2.0	0.61 - 0.80	0.81 - 1.0	1.81 - 2.5	1.15 - 1.19	1.61 - 2.0
Very High	N/A	1.5 - 1.8	0.81 - 1.0	1.01 - 1.2	2.51 - 3.0	1.20 - 1.60	2.01 - 2.3
Extreme		< 1.5	> 1.0	> 1.2	> 3.0	> 1.6	> 2.3

Methods for Estimating Near-Bank Stress

1. Transverse bar or split channel/central bar creating NBS/high velocity gradient: **Level I - Reconnaissance.**
2. Channel pattern (Rc/W): **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 (t_{nb}/t_{bkf}): **Level III - Detailed Prediction.**
7. Velocity profiles/Isovels/Velocity gradient: **Level IV - Validation.**

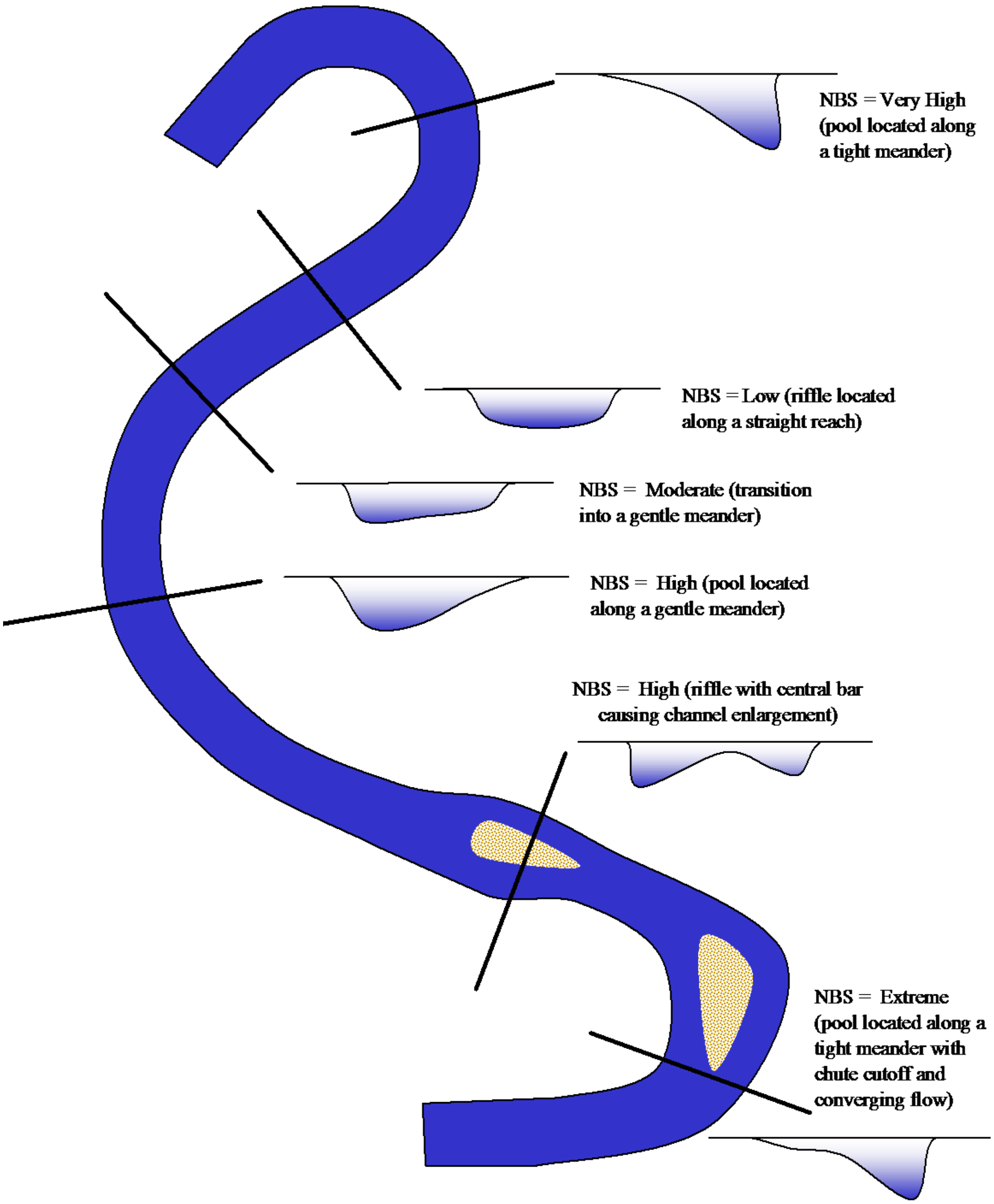


Figure 2. Near-bank stress estimation based on channel pattern, depositional features, and cross-section shape (Level I Reconnaissance) (Rosgen 2003).

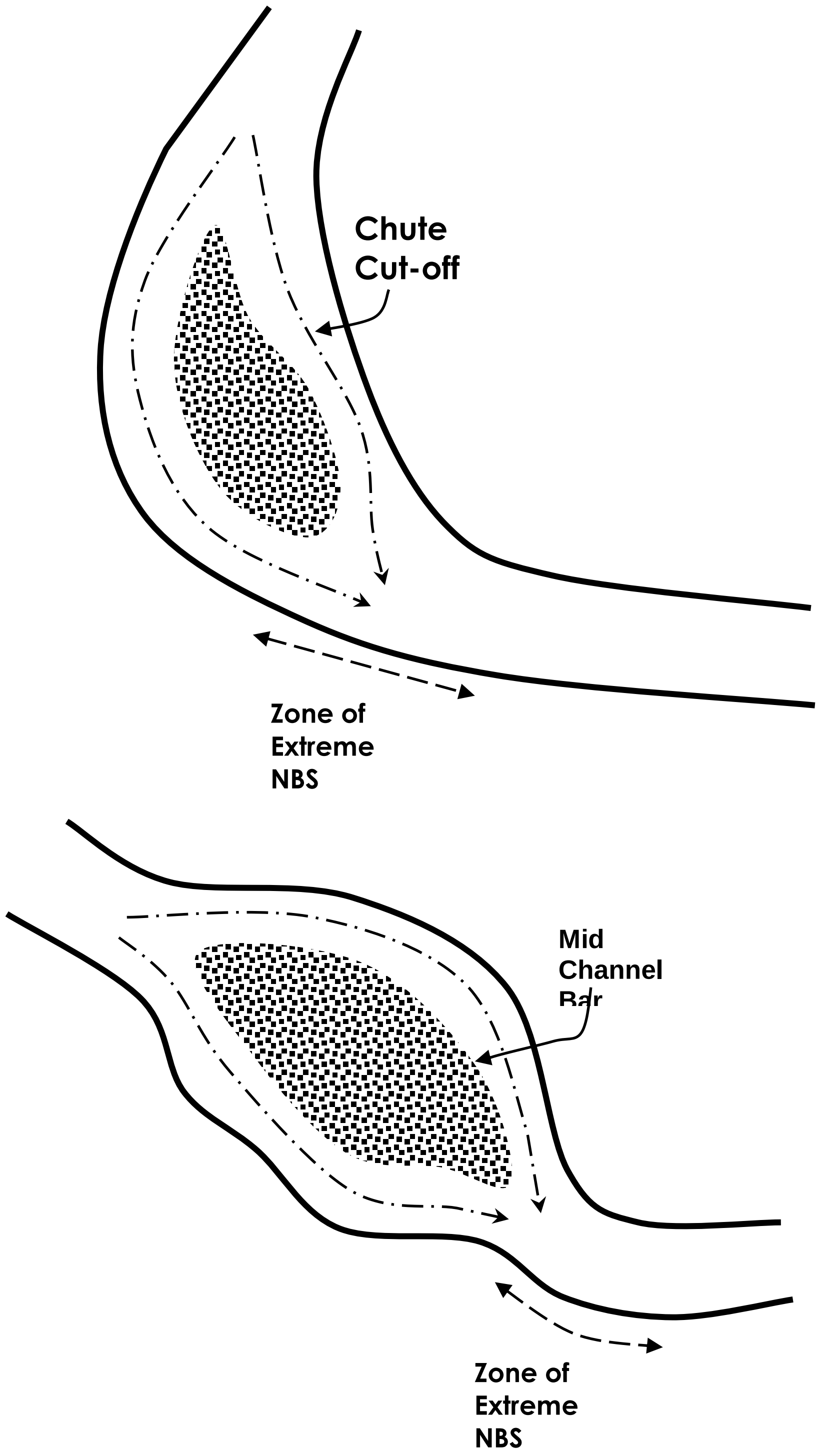


Figure 3. Examples of converging flows from chute cutoffs and central bars (Rosgen 2003).

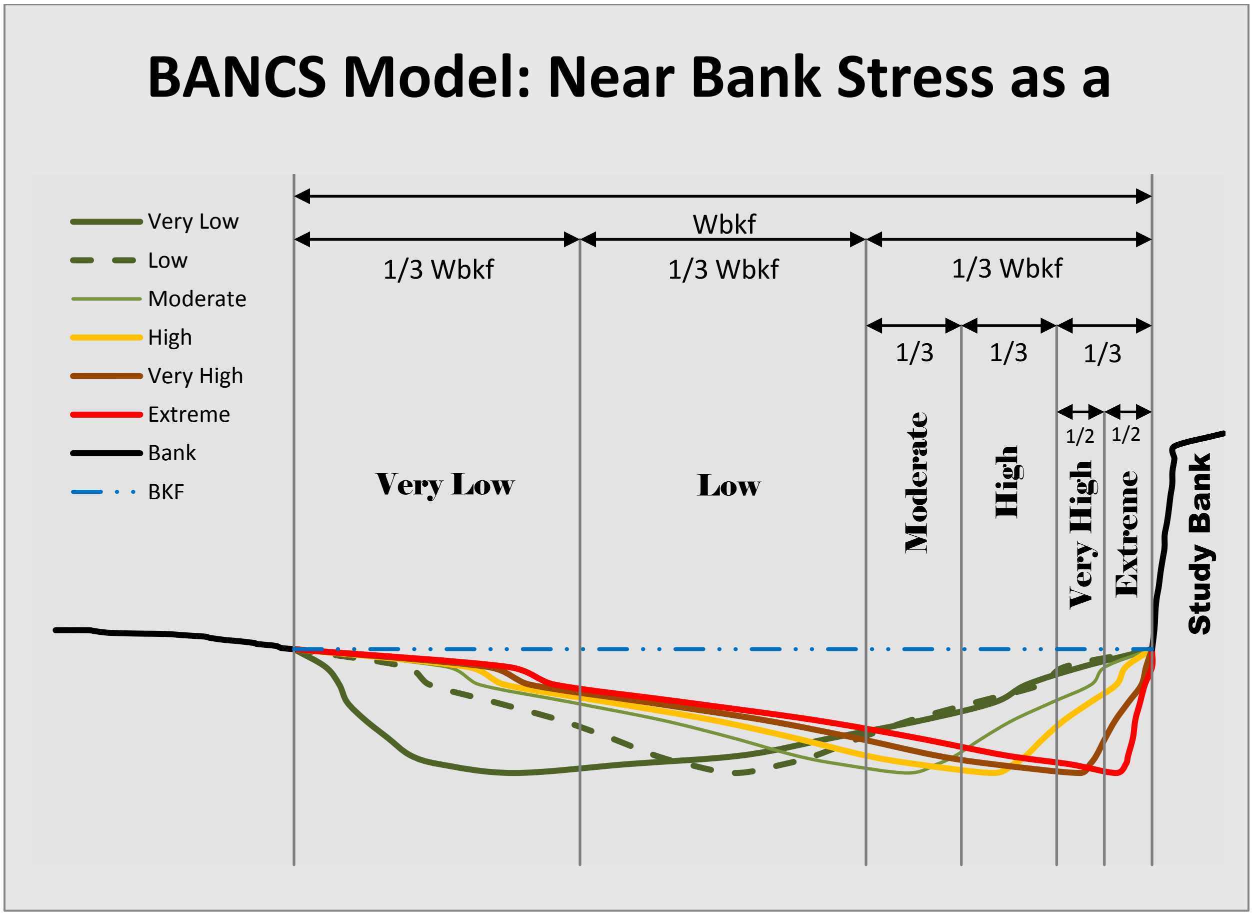


Figure . Examples NBS conditions based on study near bank depth in relation to overall channel depth (Stantec 2015).