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.

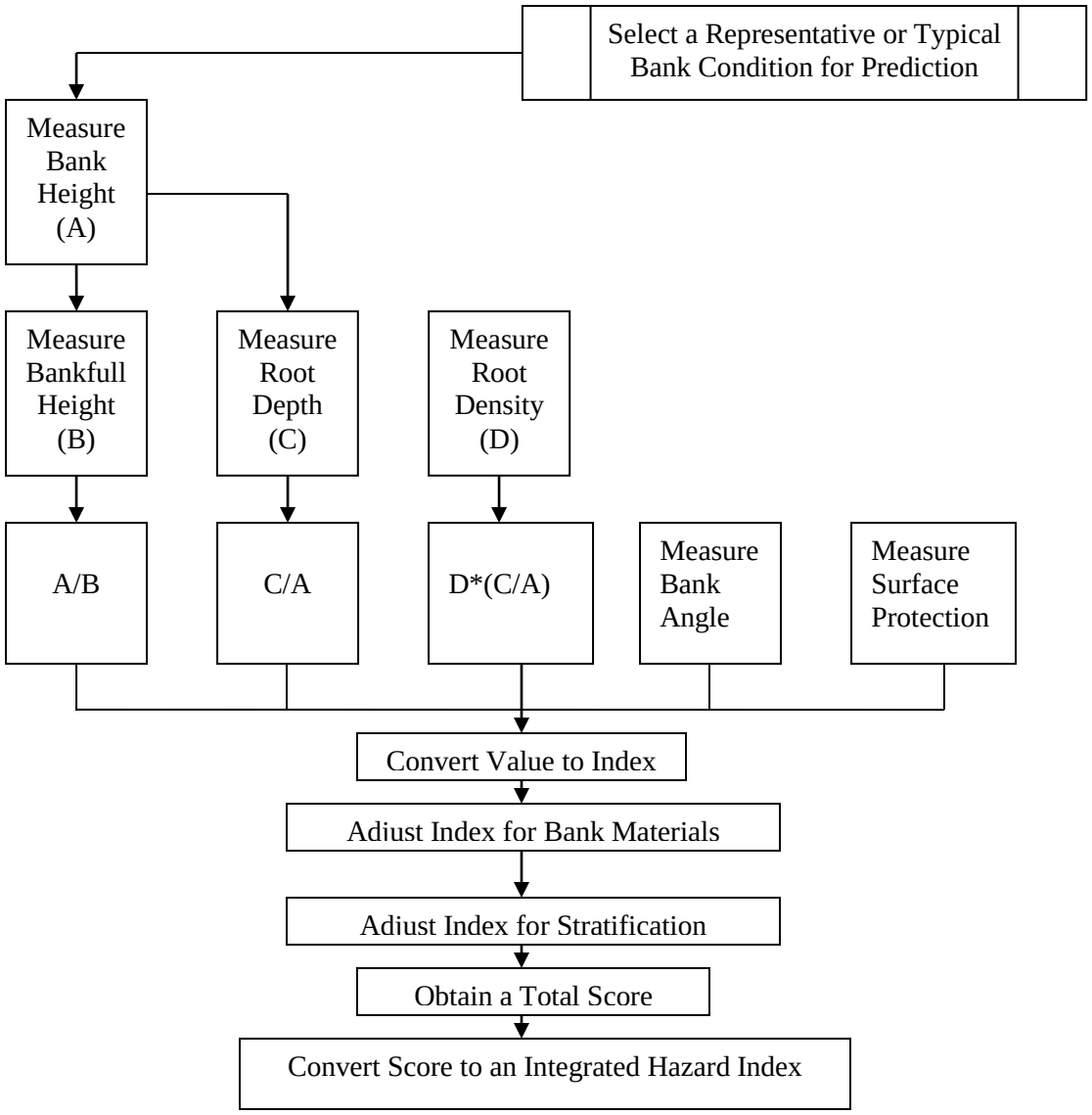
d. Avoid evaluating upstream and downstream influences, such as boulder diversions or protection, when assessing the study bank.

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.



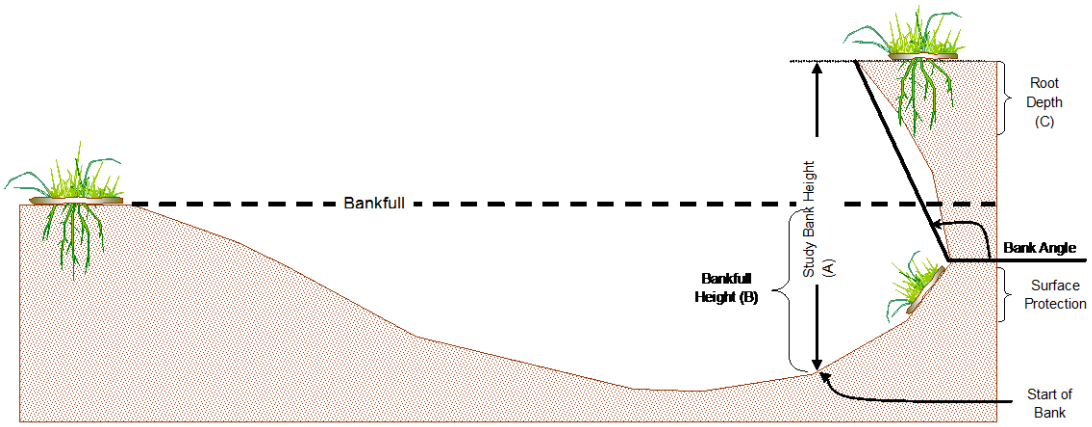


Figure 1. BEHI Variables (Rosgen 2003).

Bank Erosion Hazard Index								
			Bank Erosion Potential					
			Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
Erodibility Variable	*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).

Top of Bank Height to Bankfull Height Ratio

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.

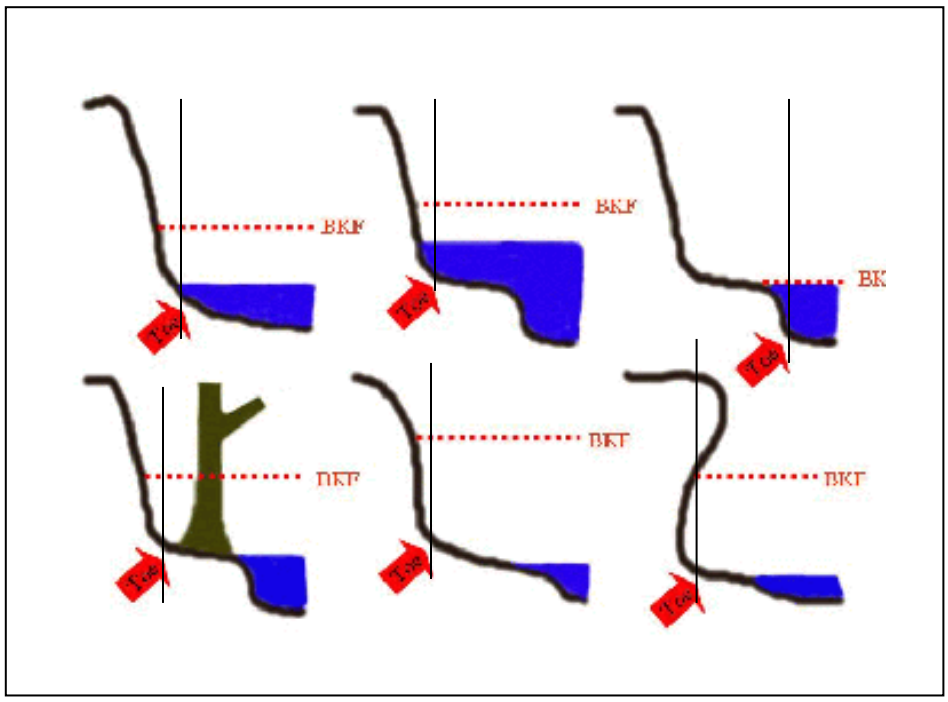


Figure 3. Bank toe location examples.

1. Rooting Depth to Top of Bank Height Ratio

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		

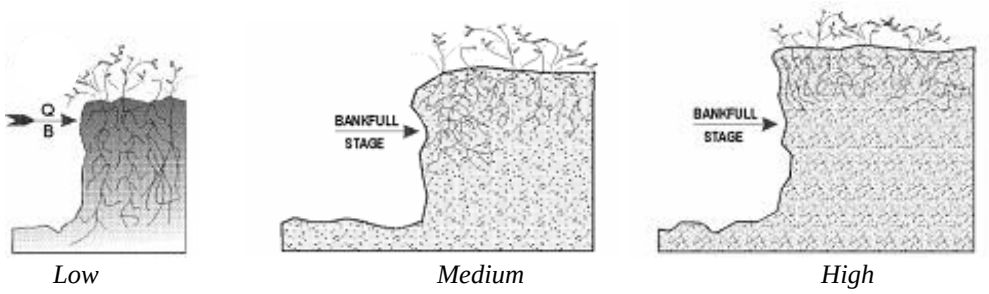


Figure 4. Examples of low, medium, and high BEHIs for rooting depth (Rosgen 1996).

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.

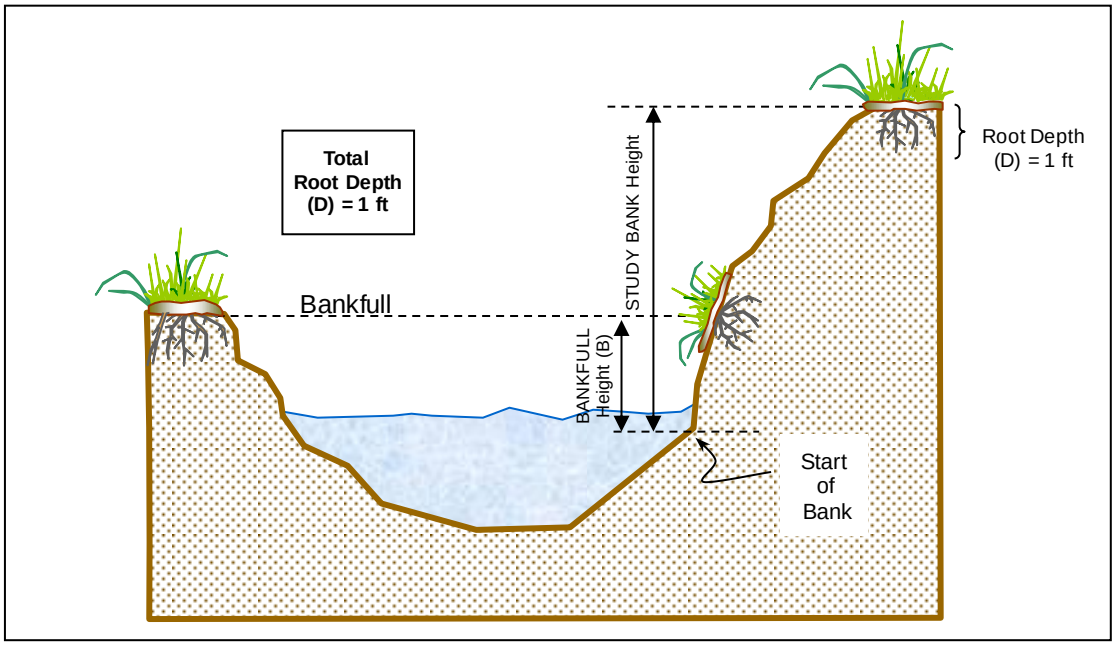


Figure 5. Root depth for partial grass vegetation bank coverage

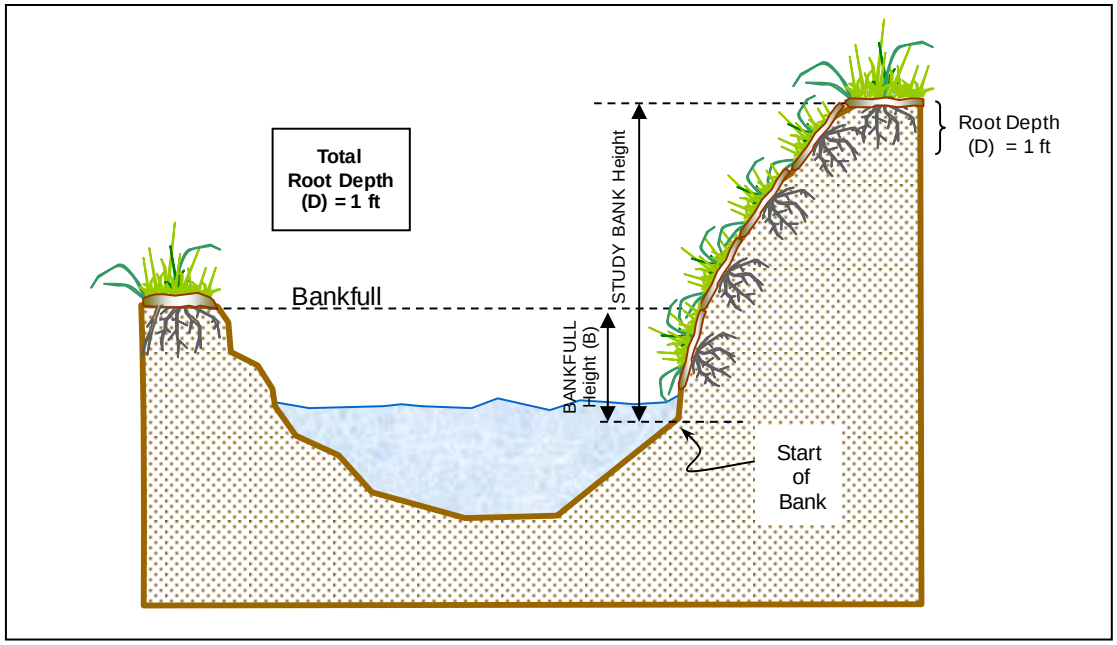


Figure 6. Root depth for entire grass vegetation bank coverage

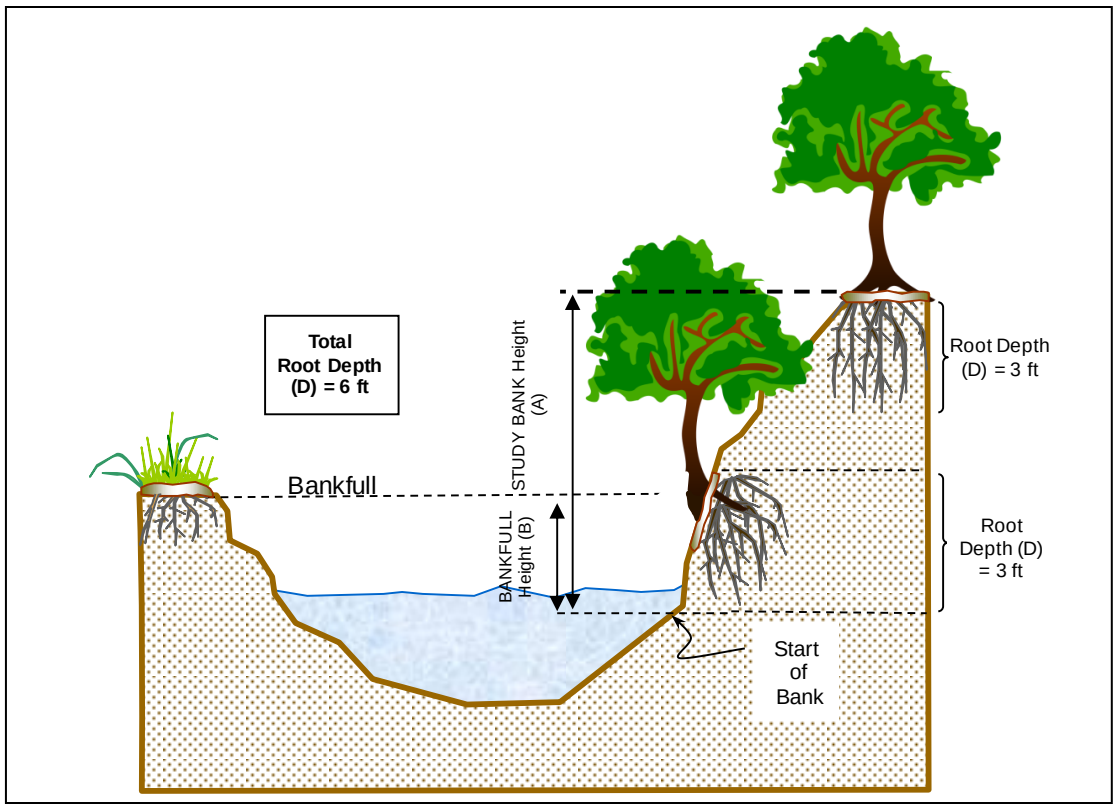


Figure 7. Root depth for partial woody vegetation bank coverage

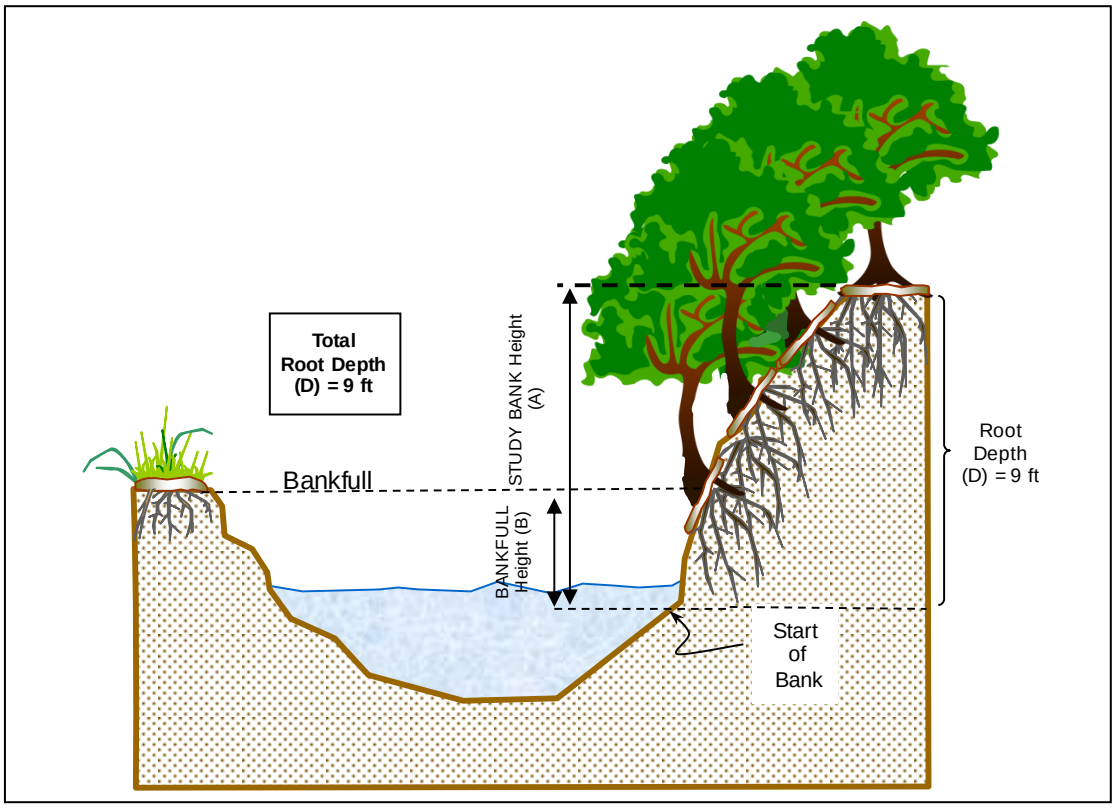


Figure 8. Root depth for entire woody vegetation bank coverage

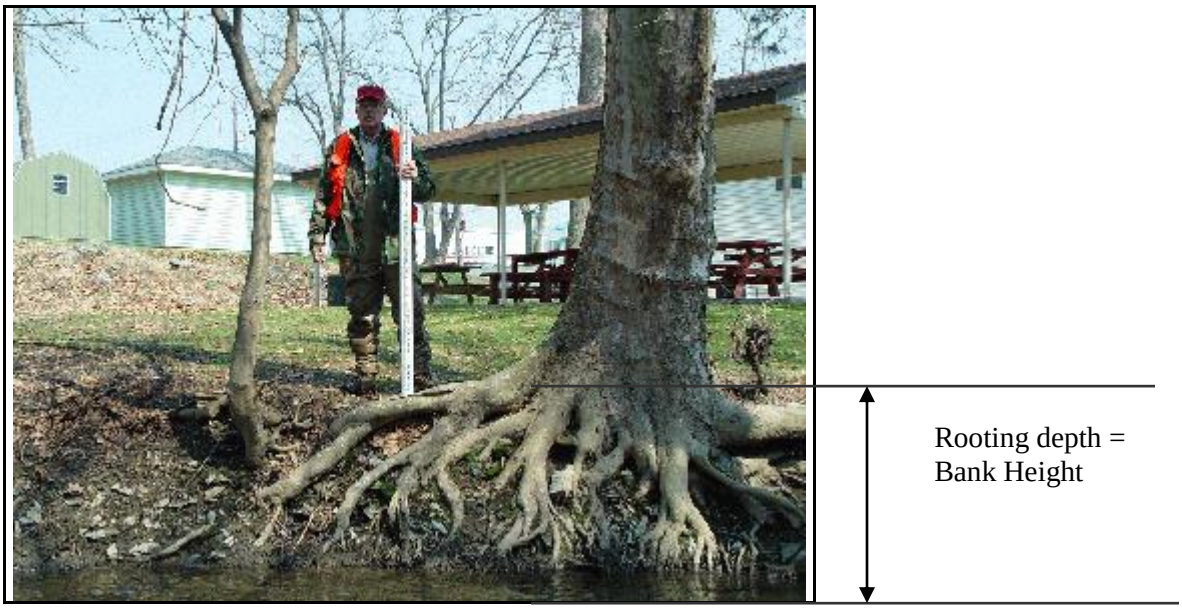


Figure 9. Tree roots extending down the stream bank.

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).

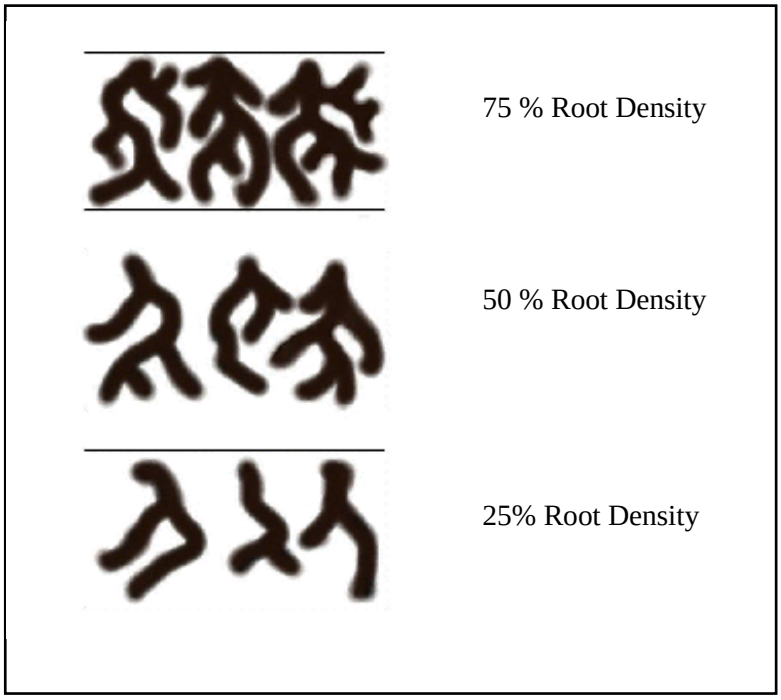


Figure 10. Root density examples.

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

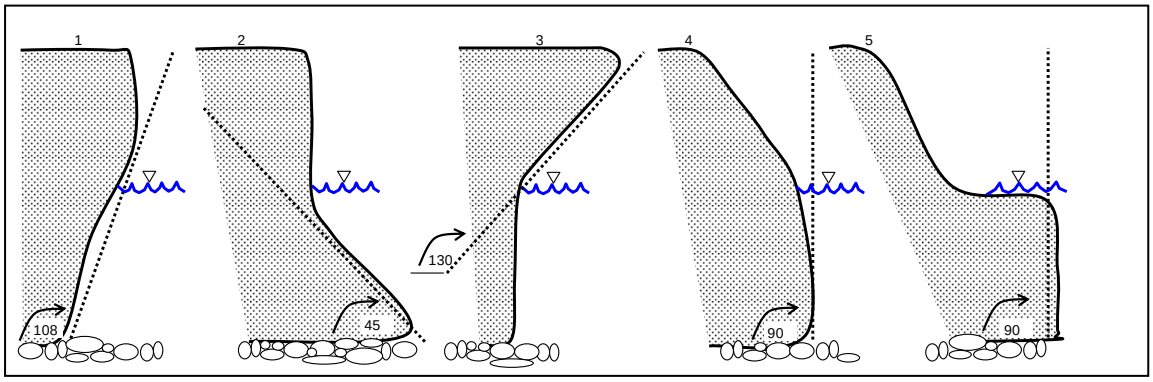


Figure 11. Bank angle scenarios (perspective: cross-section view)(Rosgen 2003).

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^{o} when the compass base is flat and 90^{o} 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.

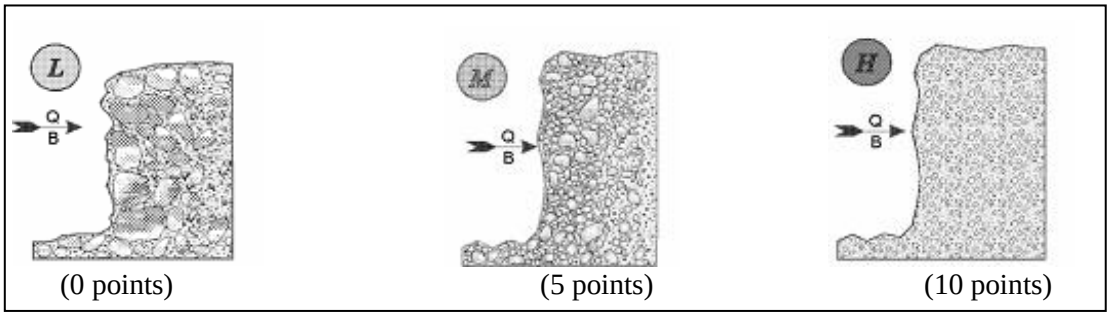
Figure 13. Woody bank vegetation.

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.

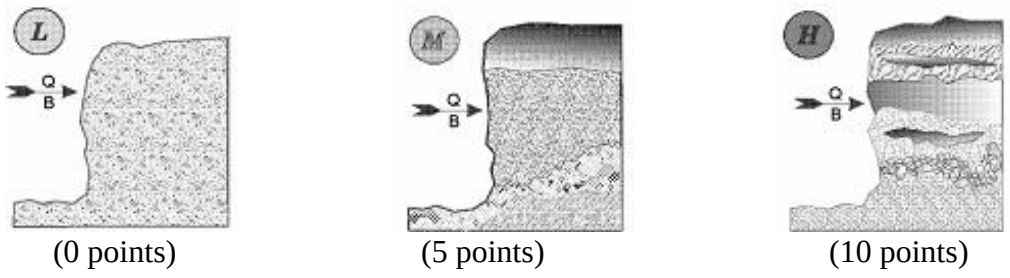


Figure 16. Examples of low, medium, and high erodibility soil stratification (Rosgen 1996).

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.