Video Article

Modifying the Bank Erosion Hazard Index (BEHI) Protocol for Rapid Assessment of Streambank Erosion in Northeastern Ohio

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URL: http://www.jove.com/video/52330
DOI: doi:10.3791/52330

Keywords: Environmental Sciences, Issue 96, Streambank erosion, bankfull, alluvial boundaries, sediment, geomorphic assessment, non-point source pollution, Bank Erosion Hazard Index

Date Published: 2/13/2015

Citation: Newton, S.E., Drenten, D.M. Modifying the Bank Erosion Hazard Index (BEHI) Protocol for Rapid Assessment of Streambank Erosion in Northeastern Ohio. *J. Vis. Exp.* (96), e52330, doi:10.3791/52330 (2015).

Abstract

Understanding the source of pollution in a stream is vital to preserving, restoring, and maintaining the stream's function and habitat it provides. Sediments from highly eroding streambanks are a major source of pollution in a stream system and have the potential to jeopardize habitat, infrastructure, and stream function. Watershed management practices throughout the Cleveland Metroparks attempt to locate and inventory the source and rate the risk of potential streambank erosion to assist in formulating effect stream, riparian, and habitat management recommendations. The Bank Erosion Hazard Index (BEHI), developed by David Rosgen of Wildland Hydrology is a fluvial geomorphic assessment procedure used to evaluate the susceptibility of potential streambank erosion based on a combination of several variables that are sensitive to various processes of erosion. This protocol can be time consuming, difficult for non-professionals, and confined to specific geomorphic regions. To address these constraints and assist in maintaining consistency and reducing user bias, modifications to this protocol include a "Pre-Screening Questionnaire", elimination of the Study Bank-Height Ratio metric including the bankfull determination, and an adjusted scoring system. This modified protocol was used to assess several high priority streams within the Cleveland Metroparks. The original BEHI protocol was also used to confirm the results of the modified BEHI protocol. After using the modified assessment in the field, and comparing it to the original BEHI method, the two were found to produce comparable BEHI ratings of the streambanks, while significantly reducing the amount of time and resources needed to complete the modified protocol.

Video Link

The video component of this article can be found at http://www.jove.com/video/52330/

Introduction

Streambank erosion is a natural process; however excessive erosion can contribute a significant amount of non-point source pollution in the form of suspended sediment[2]. Increased suspended sediment affects water quality, physical, and biological functions of a stream[3]. Human influences can greatly affect streambank erosion, and significantly increase sediment loads[4], particularly in urban systems where there is an increase in storm water runoff and impervious surfaces[5]. Higher sediment loads can negatively affect water quality and the ecosystems of streams[6]. Watershed management practices throughout the Cleveland Metroparks attempt to locate and inventory the source and rate the risk of potential streambank erosion to assist in effective management strategies, as well as in stream, riparian, and habitat restoration.

David Rosgen, with Wildland Hydrology, developed the Bank Erosion Hazard Index (BEHI), which evaluates the susceptibility of streambank erosion on a stream reach based on a combination of several erodibility variables[7]. BEHI uses a variety of indicators to rank the severity and probability of streambank erosion, including the bank material, stratification, root depth and density, bank angle, the bankfull height to bank height ratio, and the amount of surface protection present. The BEHI assessment assigns a numerical value which corresponds to an overall BEHI rating (very low, low, moderate, high, very high, or extreme), for a particular streambank. This protocol has been effective in assessing potential streambank erosion[8-10] and can be used in conjunction with other water quality and habitat assessments. Streambanks exhibiting a high BEHI rating have been shown to correspond to less diverse and less stable macroinvertebrate communities, consisting mainly of opportunistic species[11]. Though the original BEHI method is useful, it can be extremely time consuming, difficult for non-professionals, and confined to specific geomorphic regions, specifically tailored for alluvial stream conditions[12].

Modifications to this protocol were necessary in order to address these constraints. A "Pre-Screening Questionnaire" (**Figure 1**) was developed to identify and eliminate streambanks that are likely to rank very low or low, thus focusing the assessment on higher erosion areas, and decreasing the amount of time and resources required to perform a BEHI assessment on an entire stream. The questionnaire also addresses geologic differences between alluvial and non-alluvial stream conditions seen in Northeastern Ohio, such as extremely erodible shale bedrock[13], which would not be assessed as an erodible material based on the original BEHI protocol. Elimination of the Study Bank-Height Ratio metric including the bankfull stage, which can be very difficult to determine, allowed for a faster streambank assessment and for non-professionals to complete the assessment with introductory training. This elimination of the Study Bank-Height Ratio was based on a modified BEHI procedure

developed by Joe Rathbun at the Michigan Department of Environmental Quality[14]. To eliminate the necessity for additional calculations in the field, all other metrics are expressed as percentages except for bank angle, and stratification and bank material adjustments. Root density was initially expressed as the percent of soil composed of roots where the roots are extended. This was multiplied by the root depth to account for the entire bank height; however we replaced this with a simple estimate of the density of roots in the entire bank. Score adjustments were made to the original BEHI scoring system in order to account for the elimination of the Study Bank-Height Ratio metric and estimated percentages. As described in the original BEHI protocol the measured metrics were converted to a risk rating of 1-10 (10 being the highest level of risk). The risk ratings from 1 to 10 correspond to risk ratings of very low, low, moderate, high, very high, and extreme potential erosion. These relationships were established based on a catalog of field observations[10]. In the modified BEHI protocol, scores for the Study Bank-Height Ratio metric were subtracted from the original BEHI scoring system to reflect new total scores and risk ratings (**Figure 2**). These modifications address the limitations of the original BEHI protocol in Northeastern Ohio and assisted in maintaining consistency and reducing user bias.

The modified BEHI protocol was used to assess several high priority streams within the Cleveland Metroparks. The original BEHI assessment was performed by trained Cleveland Metropark personnel, on a length of stream to confirm the effectiveness of the modifications in identifying streambanks with higher rates of erosion. The modified BEHI protocol is used by professionals, volunteers, staff, and students to evaluate streambank erosion throughout the Cleveland Metroparks.

Protocol

1. Streambank Identification

1. Identify a uniform section of bank on one side of the stream. Differentiate this section by a drastically different slope of the bank, different bank material, or a break in vegetation. This section of streambank should be visibly different from the sections on either side. There is not a minimum or maximum length of bank. Separation of extremely long sections into smaller segments will simplify the assessment.

2. Pre-Screening BEHI Questionnaire (Figure 1)

1. Answer the following questions about the uniform streambank section with yes/no responses from **Figure 1**.
    1. Answer the question “does the uniform section of bank exhibit less than or equal to 50% protection at the toe of the bank?” The toe is located at the base of the bank where it meets the water during base flow conditions; on average the bottom six to eight inches of the bank. Protection includes embedded boulders, embedded large woody debris, and rooted vegetation. Bedrock counts as toe protection; however, easily breakable bedrock is not toe protection.
    2. Answer the question “does 50% or more of the bank exhibit an undercut of 0.5 feet or more?” An undercut bank is a streambank that has undergone erosion beneath the ground surface.
    3. Answer the question “does 50% or more of the bank exhibit stratification?” Stratification is a clearly defined horizontal break in geology. One layer of the stratification must be composed of an erodible material (sand, gravel, or matrix).
    4. Answer the question “does 50% or more of the bank have a bank height of ten feet or more with 50% or more soil exposure?”
    5. Answer the question “does 50% or more of the bank exhibit roots lacking bank material (soil)?”
    6. Answer the question “is 50% or more of the bank void of rooted vegetation?”
2. If there are two or more “YES” answers in the **Figure 1** questionnaire, perform a BEHI evaluation of the bank as there is a significant chance that streambank erosion is occurring or will occur.
3. If there are less than two “YES” answers in the **Figure 1** questionnaire, do not proceed with the BEHI evaluation because the bank is experiencing little to no erosion (*i.e.*, very low to low BEHI rating).

3. BEHI Evaluation Data Sheet (Figure 3)

1. Record the date, the weather, and the personnel in the spaces provided on the BEHI Evaluation Data Sheet.
2. Record the number of the bank being evaluated. For example, 1 is the first bank being assessing that day, 2 is the second bank being assessing, 3, 4, 5…and so on.
3. Take GPS coordinates at the most upstream (where the water is flowing from) and most downstream (where the water is flowing to) points of the bank. Stand as close to the bank as possible to ensure accuracy.
4. Take pictures at both the upstream and downstream points on the bank. Capture the main features of the bank in the pictures. Take additional pictures to capture features on the bank or in the channel (*i.e.*, stratification, large woody debris jams, etc.). Record the picture numbers for reference.
5. Record the side of the stream being assessed (left bank or right bank). Determine the left bank and right bank when facing downstream; left and right respectively.
6. Measure the bank height, in feet, from the toe of the bank to the top of the bank. Determine the top of the bank by the first definable break in slope, generally lying parallel to water flow.
7. Measure the bank length at the toe, in feet, between the most upstream and most downstream points on the bank.
8. Write the number of the questions that were answered with a “yes” in the initial “Pre-Screening BEHI Questionnaire” in Step 2.
9. Note the distance to infrastructure and the type of infrastructure (*i.e.*, bridges, culverts, roads, utilities, houses etc.).
10. Circle any of the following qualitative indicators that are present: Unvegetated mid-channel bar/braided channel, exposed tree roots on both sides, leaning trees on both sides, exposed infrastructure, downstream of a dam, slumping streambanks, headcuts, perched tributaries, failed “Best Management Practices” (BMP’s) such as revetment walls, gabion baskets or culverts.
11. Note the composition of the bank material. Record the predominant materials found along the bank section that is under evaluation.
    NOTE: Streambanks can be a mix of materials. For example, a bank may have “shale at the toe, and silty sand with trace gravel above”. “Silty sand” indicates more sand than silt and “trace gravel” indicates a small amount of gravel. “Sandy silt” indicates more silt than sand.

12. Make bank material adjustments based on the erodibility of the material.
    1. Subtract up to 10 points for material that does not have a high rate of erodibility (*i.e.*, cobble). Add up to 10 points for extremely erodible materials (*i.e.*, sand). A mixture of material (*i.e.*, sand with some gravel or silty sand with trace gravel) is more often found in stream systems so an average score would be more appropriate (**Figure 4**). This is not a mandatory adjustment. See **Figure 4** In Results Section.

13. Determine the ratio of the average root depth of plants to the study bank height, expressed as a percentage, to estimate the adherence of bank material by vegetation (**Figure 5**).
    1. Visually estimate the root depth vertically from top of the bank to the toe of the bank. For example, if roots are growing in the top half of the bank, the root depth would be 50%. If there are roots growing from the top of the bank to the toe, the root depth would be 100%.
    2. Take an average percentage of the root depth along the entire section under evaluation. Do not consider roots that are void of bank material (*i.e.*, hanging roots).
    3. Estimate a percentage based on the entire bank, then use the "BEHI Score Chart" to record the score for that percentage on the data sheet. See **Figure 5** in Results Section.

14. Determine the root density by making a visual assessment of the amount of bank composed of root material, expressed as a percentage.
    1. Do not consider roots that are void of bank material. Small, fibrous roots can be very dense and provide greater soil retention compared to the larger root systems of trees (**Figure 6A and 6B**). Estimate a percentage based on the entire bank, then use the "BEHI Score Chart" to record the score for that percentage on the data sheet. See **Figure 6** in Results Section.

15. Measure the angle from the lower bank at the waterline during base flow to the top of the bank (**Figure 7**). An extremely undercut bank can have an angle up to 120 degrees.
    1. Place a measuring stick at a 90 degree angle to the waterline in order to estimate the bank angle or use an inclinometer if available. Take an average of the bank angle along the entire section under evaluation. For example, if the section is mostly 90 degrees with a small section that has 110 degree undercut, the recorded degree would be approximately 100 degrees.
    2. Estimate a percentage based on the entire bank, then use the "BEHI Score Chart" to record the score for that percentage on the data sheet. See **Figure 7** in Results Section.

16. Determine the surface protection present, the amount of streambank covered and protected by woody debris, rooted vegetation, embedded boulders, revetment, bedrock, or other embedded materials that protect the streambank from erosion (**Figure 8**).
    1. Visually estimate the percentage of streambank not exposed to erosive forces. Estimate a percentage based on the entire bank, then use the "BEHI Score Chart" to record the score for that percentage on the data sheet. See **Figure 8** in Results Section.

17. Visually determine the number of stratified layers. Stratification refers to a clearly defined horizontal break in geology which has the potential to cause and enhance zones of preferential erosion (**Figure 9**).
    1. Record how many layers of stratification are present. See **Figure 9** in Results Section.

18. Make stratification adjustments if increased erosion is occurring due to the stratified layers.
    1. Add up to 5 points for a single layer of stratification (two different geologic layers). Add up to 10 points for multiple layers of stratification (three different geologic layers). Only adjust for stratification if at least one layer of material is erodible (sand, gravel, or matrix).
    2. Consider where the stratified layers are in relation to the water, *i.e.*, stratified layers that are 50 feet above the base flow may not have an erosive effect. A stratified layer near the toe of the bank may have an extremely erosive effect. An average score may be necessary, especially when considering how erodible the materials are and where the stratified layer is in relation to the water. This is not a mandatory adjustment.

19. Add all scores together to determine the overall modified BEHI rating (very low/low: 4 – 15.5, moderate: 15.75 – 23.5, high: 23.75 – 31.5, very high: 31.75 – 36.5, or extreme: >36.5) for the streambank assessed. Record the total score and the rating in the spaces provided on the data sheet.
20. Take note of the streambank specifics. For example, streambank is on the outside of a meander bend, a large woody debris jam, an out of place culvert, or strong petroleum odor. Note any failing infrastructure here.

Representative Results

Streambanks that did not pass the Pre-Screening Questionnaire and were not assessed with the modified BEHI protocol, ranked low or very low when assessed with the original BEHI protocol (**Figure 10**). This supports the use of the Pre-Screening Questionnaire as a way to quickly identify streambanks that are experiencing moderate to extreme rates of erosion. See **Figure 10** below.

In general, streambanks assessed were placed in the same final BEHI rating using both the original and the modified BEHI protocol. Sixteen out of the eighteen, or 89% of the streambanks assessed with both BEHI protocols received the same final BEHI rating (**Figure 10**). Streambank 5 scored a 23.0 using the modified BEHI protocol, which is 0.5 points below the cutoff between a moderate and a high BEHI rating (Table 1). Using the original BEHI protocol, the bank scored a 31.25, a high BEHI rating; however, the score was within 1.25 points of the cutoff between a moderate and a high BEHI rating (Table 2). This slight difference in the final BEHI rating can be attributed to the cutoff margins within the BEHI ratings. It is recommended that the final numerical scores are considered, when assessing the overall health of the stream to observe slight variations in the margins of the BEHI ratings (*i.e.*, a high, moderate versus a low, high). See **Tables 1 & 2** below.

Streambank 18 (**Figure 11**), a weathered shale wall, had a differing BEHI rating between the two protocols because it was unable to be assessed with the original BEHI protocol as bedrock automatically receives a very low BEHI score; however, this streambank failed the Pre-Screening Questionnaire due to the lack of toe protection present (erodible shale does not count as toe protection in our modification of BEHI), a bank height of ten feet or more with 50% or more soil exposure, and more than 50% of the bank was void of rooted vegetation (**Figure 11**); therefore, an assessment using the modified BEHI protocol was necessary. The final BEHI rating, using the modified BEHI protocol was extreme,

due to the steep bank angle, erodible material, lack of a riparian root system extending to the toe, and small amount of surface protection present. See **Figure 11** below.

Pre-Screening BEHI Questionnaire

If the bank in question is exhibiting 2 or more of the following then proceed with the BEHI protocol. If the bank is not exhibiting 2 or more do not proceed with the BEHI protocol because the bank is exhibiting little to no erosion (i.e very low to low BEHI rating).

1. Does the bank exhibit less than or equal to 50% protection at the toe?
    - The toe is located at the base of the bank where it meets the water; on average the bottom 6-8 inches.
    - Protection includes: boulders, rocks the stream can not move (has to be larger than the largest size of rock on depositional bars), large woody debris embedded in bank, rooted vegetation.
    - Bedrock counts as toe protection however, if you are able to break/pull pieces this does not count as toe protection. For example, in this area you will often find weathered shale which does not function the same way as bedrock.
2. Does 50% or more of the bank exhibit an undercut of 0.5 feet or more?
3. Does 50% or more of the bank exhibit stratification?
    - Stratification is a clearly defined break in geology (i.e. change in material type).
    - One layer of the stratification must be of erodible material: sand, gravel, matrix (combination of sand, gravel), weathered shale.
4. Does 50% or more of the bank have a bank height of 10 feet or more with 50% or more soil exposure?
    - Often times this is indicative of an incised channel (i.e. large shale walls).
5. Does 50% or more of the bank exhibit roots lacking bank material (soil)?
6. Is 50% or more of the bank void of rooted vegetation?

Figure 1. Pre-Screening Questionnaire.

BEHI SCORES							
Root Depth	Score	Root Density	Score	Bank Angle	Score	Surface Protection	Score
100	0	100	0	120	10	100	0
95	1.5	95	0.5	115	9.75	95	0.5
90	2	90	1	110	9	90	1
85	2.25	85	1.5	105	8.75	85	1.5
80	2.5	80	2	100	8.5	80	2
75	2.75	75	2.5	95	8.25	75	2.5
70	3	70	2.75	90	8	70	3
65	3.25	65	3.25	85	7	65	3.25
60	3.5	60	3.5	80	6	60	3.5
55	3.75	55	4	75	5.5	55	4
50	4	50	4.25	70	5	50	4.25
45	4.25	45	4.5	65	4.5	45	4.5
40	4.75	40	5	60	4	40	5
35	5.25	35	5.5	55	3.75	35	5.5
30	6	30	5.75	50	3.5	30	6
25	6.5	25	6	45	3.25	25	6.5
20	7	20	7	40	3	20	7
15	7.75	15	8	35	2.75	15	8
10	8.5	10	8.5	30	2.5	10	9
5	9	5	9	25	2.25	5	9.5
0	10	0	10	20	2	0	10
				15	1.75		
				10	1.5		
				5	1		
				0	0		

Figure 2. Score Chart.

Date:		**Weather:**			
Personnel:				**Bank Number:**	
GPS up:			**GPS down:**		
Picture Numbers:				**Bank:**	
Bank Height:			**Bank Length (ft):**		
Questions answered yes to:					
Distance to Infrastructure (ft):			**Type (bridge, culvert, utility etc.):**		
Qualitative Indicators: Circle all that apply					
unvegetated mid channel bar/braided channel			exposed infrastructure		failed BMP's
exposed tree roots on both sides			downstream of dam		headcuts
leaning trees on both sides			slumping stream bank		perched tributaries

BEHI Metrics and Scoring

Material Description:

Root Depth/Bank Height	**Score**	**Root Density**	**Score**	**Material Adjustment***		**Score**
				Yes	**No**	
Bank Angle	**Score**	**Surface Protection**	**Score**	**Number of Stratified Layers****		**Score**

Total Score:	**Ranking (ex:high, mod, low, etc.):**

Very Low: 4-7.5 Low: 7.75-15.5 Mod: 15.75-23.5 High: 23.75-31.5 Very High: 31.75-36.5 Extreme: >36.5

Notes:

* Material adjustments can be made based on the erodibility of the material. Up to 10 points can be subtracted for nonerosive material (i.e. cobble). Up to 10 points can be added for extremely erodible materials (i.e. sand). A mixture of material (i.e. sand with some gravel or silty, sand with trace gravel) is more often found in stream systems so an average score would be more appropriate (i.e. add 6 points instead of 10). Typically there are no adjustments made for clay, silt, or bedrock. This is not a mandatory adjustment.

** Stratification adjustments can be made if erosion is enhanced due to the stratified layers. Adjust only if one of the layers is an erodible material (sand/gravel; not bedrock/clay). Up to 10 points can e added for multiple layers of stratification. Up to 5 points can be added for a sigle layer of stratifiction. Consider where the layers are in relation to water when making adjustments. This is not a mandatory adjustment.

Figure 3. BEHI evaluation Data Sheet.

Figure 4. Bank Material Metric. Adjustments can be made based on the erodibility of the material. A mixture of material, as shown in the figure is often found in stream systems so an average score would be more appropriate.

Figure 5. Riparian Root Depth Metric. The ratio of the average root depth of plants to the study bank height, expressed as a percentage. For this bank, roots grow to a depth of approximately 30% of the entire bank.

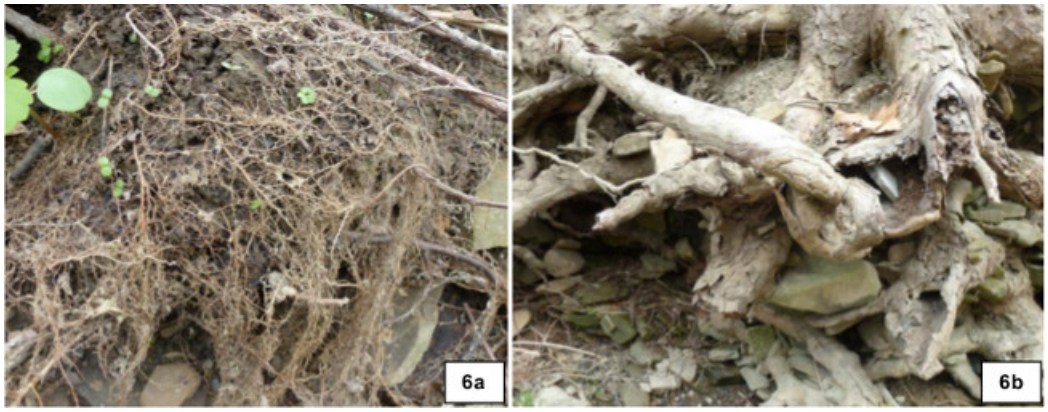

Figure 6. Root Density Metric. Small, fibrous roots, as shown in **(A)** can be very dense and provide greater soil retention compared to large, tap root systems shown in **(B)**. Please click here to view a larger version of this figure.

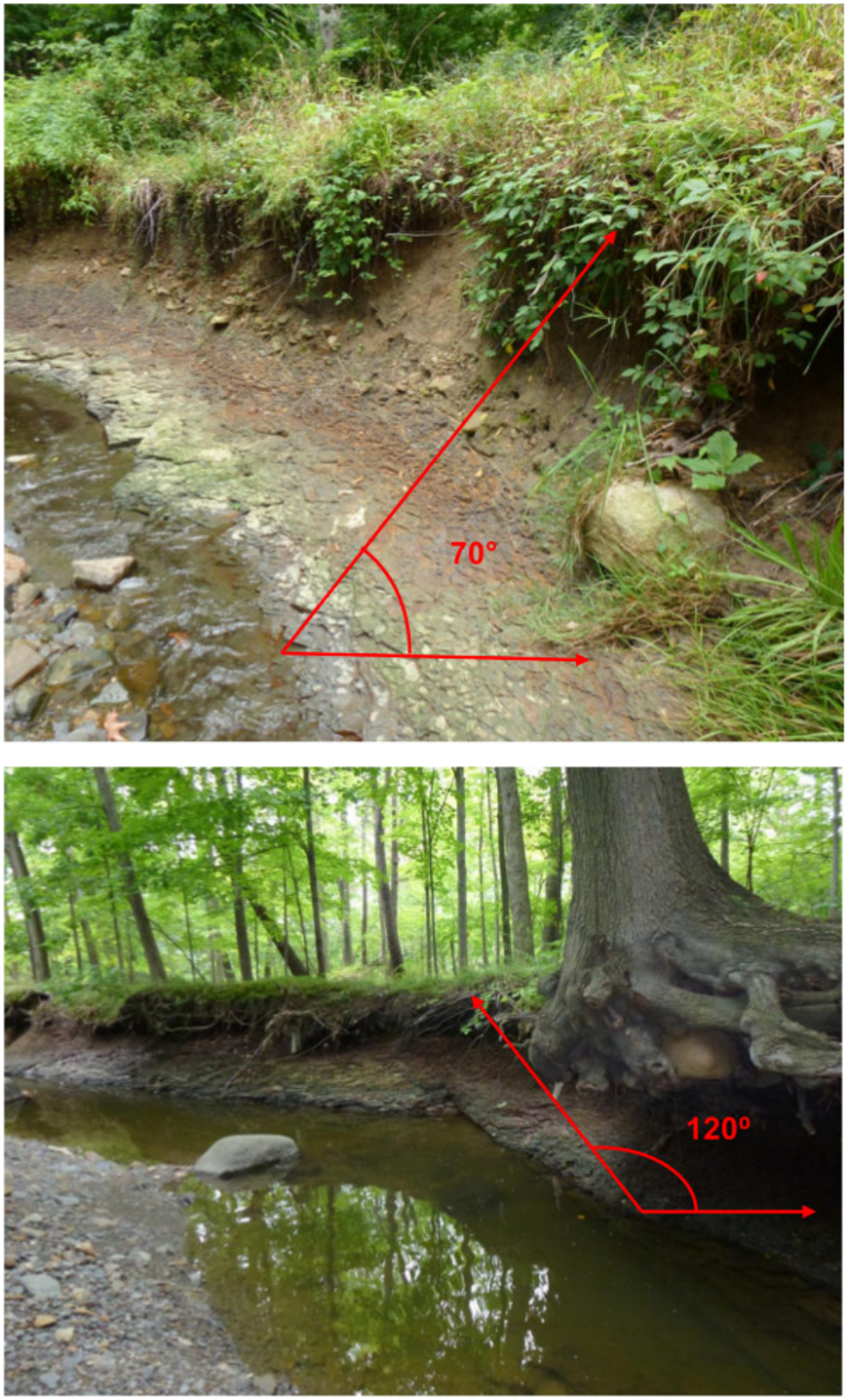

Figure 7. Bank Angle Metric. The bank angle is the angle from the lower bank at the waterline during base flow to the top of the bank. An extremely undercut bank, as shown in the figure can have an angle of 120 degrees or more.

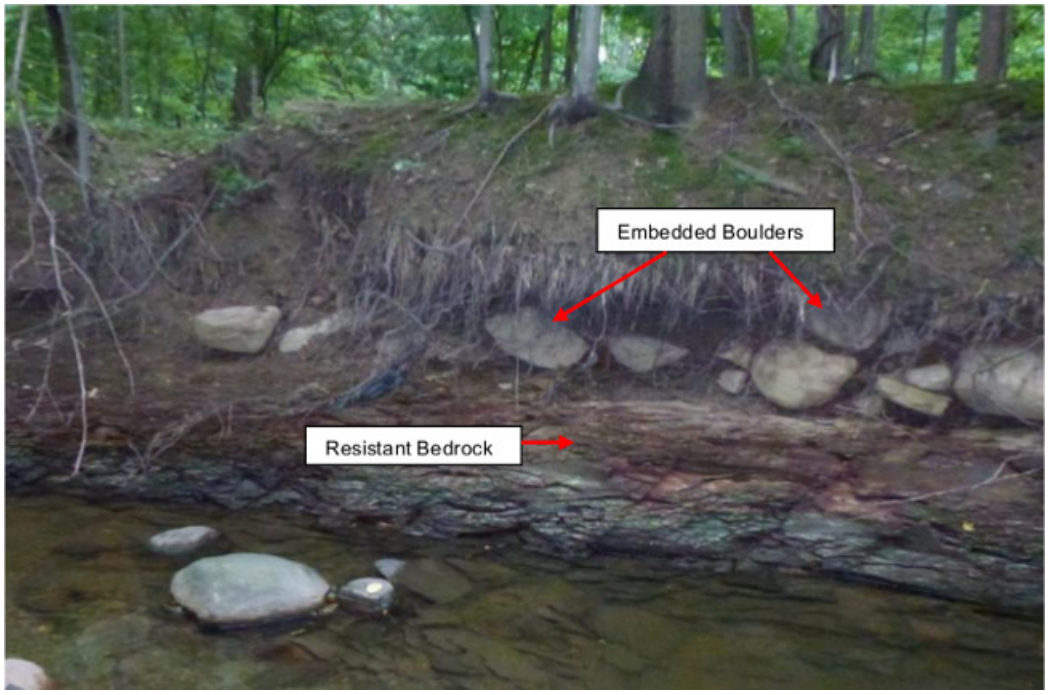

Figure 8. Surface Protection Metric. Surface protection is the amount of stream bank covered and protected by woody debris, rooted vegetation, embedded boulders, revetment, bedrock, etc. The figure shows a bank with resistant bedrock and embedded boulders acting as surface protection.

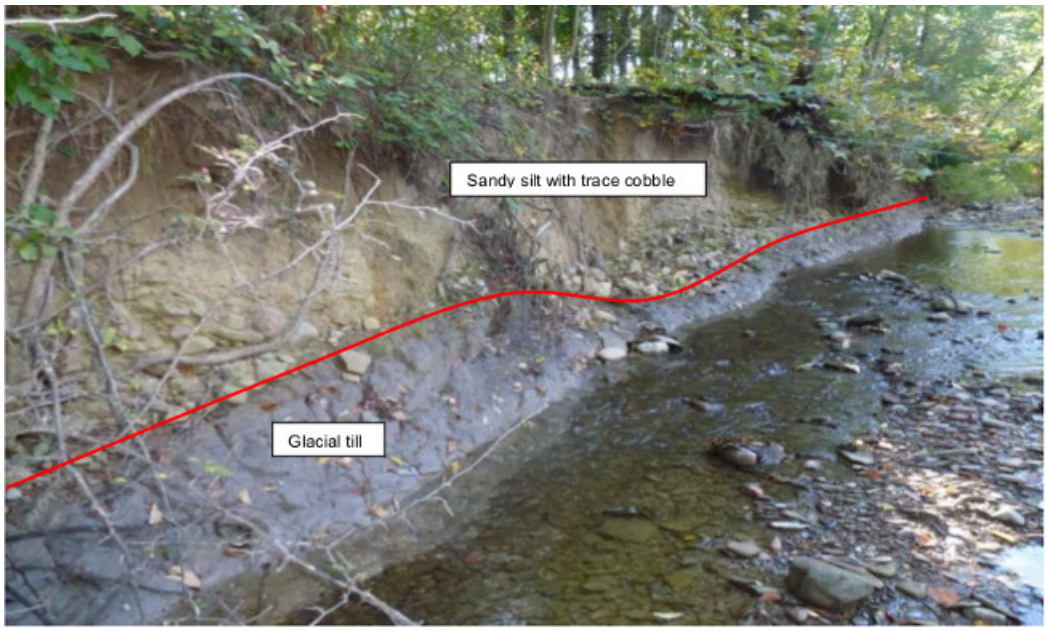

Figure 9. Stratification Metric. A clearly defined layer of stratification with glacial till at the toe and a gravelly sand layer above.

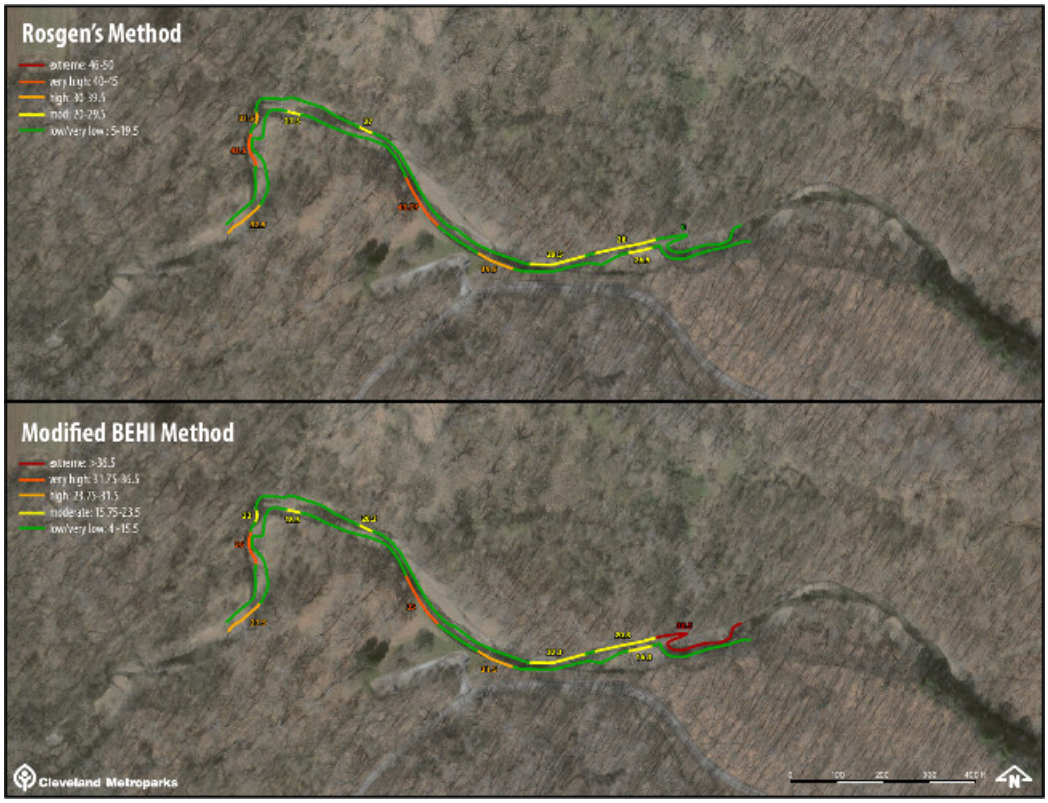

Figure 10. Map comparison. Sagamore Creek map of BEHI ratings, comparing the modified and original protocol. Streambanks that did not pass the Pre-Screening Questionnaire and were not assessed with the modified BEHI protocol, ranked low or very low when assessed with the original BEHI protocol as shown in green above. Sixteen out of the eighteen streambanks assessed with the original BEHI protocol had the same final BEHI rating when assessed with the modified BEHI protocol.

Figure 11. Shale Wall. The weathered shale wall that was unable to be assessed with the original BEHI protocol because bedrock automatically receives a very low BEHI score; however, after completing the modified BEHI protocol, this streambank ranked extreme.

Bank Number	Questions answered yes to	Material Adjustment Score	Stratification	Stratification Score	Rooth Depth/ Bank Height	Score	Root Density	Score	Bank Angle	Score	Surface Protection	Score	Total Score	Final Rank
1	2, 5	0	No layer	0	55	4	30	6	110	9	10	9	28	High
2	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
3	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
4	1, 5,6	5	No layer	0	20	7	10	9	100	8.5	20	7	36	Very High
5	1,5,6	0	No layer	0	30	6	10	9	60	4	45	5	23	Moderate
6	1, 6	-7	No layer	0	100	0	10	9	90	8	10	9	19	Moderate
7	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
8	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
9	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
10	2,5	0	No layer	0	80	3	50	4	100	8.5	40	5	20	Moderate
11	1,6	7	No layer	0	50	4	5	9	80	6	10	9	35	Very High
12	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
13	Did Not Pass the Pre-Screening Questionnaire													V. Low/Low
14	1,6	5	No layer	0	80	3	5	9	80	6	10	9	32	High
15	1,5,6	0	No layer	0	80	3	30	6	90	8	30	6	22	Moderate
16	1, 5	0	No layer	0	75	3	40	5	85	7	30	6	21	Moderate
17	1, 5	0	No layer	0	80	3	50	4	80	6	60	4	16	Moderate
18	4, 1,6	5	No layer	0	10	9	5	9	85	7	10	9	39	Extreme

Table 1. Modified BEHI Protocol Dataset. Dataset from the Sagamore Creek BEHI assessment, using the modified protocol.

Bank Number	Study Bank height	Bankfull Height	Study Bank Ht/ Bankfull Ht	Score	Material Adjustment Score	Stratification	Strat Score	Rooth Depth	Root Depth/ Study Bank Height	Score	Weighted Root Density	Weighted Root Density* (Root Depth/Study Bank Height)	Score	Bank Angle	Score	Surface Protection	Score	Total Score	Final Rank
1	2.5	1.8	1.4	5	0	No	0	1.4	0.6	3.5	50	28.0	6.0	110	9	10	9	32.5	High
2	1.8	1.8	1.0	0	0	No	0	1.8	1.0	0	95	95.0	0.5	35	3	95	0.5	4	V. Low
3	2.0	1.2	1.7	6	-5	No	0	2	1.0	0	40	40.0	5.0	35	3	70	3.0	12	Low
4	6.0	1.3	4.6	10	5	No	0	1.2	0.2	7	80	16.0	6.0	100	8.5	20	7.0	43.5	V. High
5	7.5	1.3	5.8	10	0	No	0	2.5	0.3	5.75	85	28.3	6.5	60	4.5	45	4.5	31.25	High
6	2.5	1.3	1.9	7.5	-7	No	0	2.5	1.0	0	10	10.0	10.0	90	8	10	9.0	27.5	Mod
7	10.0	1.3	7.7	10	0	No	0	9.5	1.0	1	70	66.5	3.0	55	3.5	90	1.0	18.5	Low
8	2.0	2.0	1.0	1	0	No	0	2	1.0	0	70	70.0	3.0	60	4	90	1.0	9	V. Low
9	2.0	2.0	1.0	1	0	No	0	1.95	1.0	0	50	50.0	4.0	30	2.5	80	2.0	9.5	V. Low
10	3.5	2.0	1.8	7	0	No	0	2.8	0.8	2.5	60	48.0	4.0	100	8.5	40	5.0	27	Mod
11	4.0	2.0	2.1	8	7	No	0	2	0.5	3.75	10	5.0	10.0	80	6	10	9.0	43.75	V. High
12	2.0	2.0	1.0	1	0	No	0	2	1.0	0	50	50.0	4.0	30	2.5	70	2.5	10	Low
13	4.0	2.0	2.1	8	0	No	0	3.8	1.0	1	45	42.8	4.8	60	4	85	1.8	19.5	Low
14	4.0	2.0	2.1	8	5	No	0	3.2	0.8	2.5	15	12.0	8.8	80	6	10	9.0	39.25	High
15	3.5	2.0	1.8	6.5	0	No	0	2.8	0.8	2.5	40	32.0	5.8	90	8	30	5.5	28.25	Mod
16	4.0	1.6	2.5	8.5	0	No	0	3	0.8	2.75	50	37.5	5.0	85	6.3	30	5.5	28	Mod
17	7.0	1.6	4.4	10	0	No	0	5.6	0.8	2.5	60	48.0	4.3	80	6	60	3.5	26.25	Mod
18	Bedrock- Not Assessed with Original Protocol																		

Table 2. Original BEHI Protocol Dataset. Dataset from the Sagamore Creek BEHI assessment, using the original protocol.

Discussion

The most critical steps for accurate completion of the modified BEHI protocol are to: correctly identify a uniform section of streambank to assess, if the streambank length has too much variability it is best to separate and assess smaller segments to accurately capture the erodibility of the streambank; complete the Pre-Screening Questionnaire to confirm that a BEHI assessment should be completed on that streambank, if there is uncertainty in whether a bank passes the Pre-Screening Questionnaire, a BEHI assessment should be conducted; accurately assess the BEHI metrics avoiding observer bias and maintain consistency, which can be achieved by conducting the assessment with 2-4 people; and fill out the BEHI Evaluation Data Sheet completely.

This modified BEHI protocol significantly reduces the time needed for streambank evaluations, and greatly improves the ease of the assessment, making it possible to conduct BEHI assessments with nonprofessionals. It also accounts for non-alluvial conditions, specifically the erodible shale found in Northeastern Ohio; however, further modifications to the protocol can be made to fit an area's needs. Specific changes may be needed to account for the inconsistent alluvial boundaries and the underlying geology of an area.

The modified BEHI protocol is effective for ranking and prioritizing streambank erosion to assist in formulating effective stream management strategies; however, limitations exist with the modified BEHI protocol, such as the inability to predict annual streambank erosion rates without determining the bankfull discharge stage, completion of a Near Bank Stress (NBS) analysis, and completion of the Bank Assessment for Non-point Consequences of Sediment (BANCS) model developed by David Rosgen at Wildland Hydrology[10].

Another limitation arises with the application of the modified and the original BEHI protocol to urban settings. Many locations throughout the Cleveland Metroparks lie within such settings; therefore, these locations have been treated by mitigation and restoration efforts, often in the form of rock revetment, with the intention of decreasing flood and erosion hazards on private and public infrastructure. Once the streambanks have been armored with rock revetment, the erosive potential of the bank cannot be assessed accurately; however, it is recommended that the condition of the revetment is noted, in order to address any functional issues that may be occurring.

The modified BEHI protocol has practical applications in identifying sections of streambank where BMP's would be most beneficial. Inventories of streambank conditions can be obtained using the quantitative variables in the modified BEHI protocol, allowing for the prioritization of streambank management efforts. Completion of this procedure does not require extensive experience or training, allowing for various groups, organizations, and individuals to perform this assessment accurately and effectively. By completing extensive monitoring and assessment of streambank erosion using the modified BEHI protocol effective stream management strategies can be formulated.

Disclosures

The authors have nothing to disclose.

Acknowledgements

The authors would like to acknowledge the Cleveland Metroparks, including J. Grieser, J. Markowitz, B. Garman, and supporting staff; Case Western Reserve University, Dr. J. Burns; and GLISTEN, the Great Lakes Innovative Stewardship through Education Network.

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