Stream Stability Assessment Guidelines for NPS Grant Applicants

All applications for 319 NPS grants or Clean Michigan Initiative NPS grants addressing stream engineering projects (bank stabilization, channel relocation, etc.) should consider assessing stream channel stability, to improve both the quality of their project and the competitiveness of their application. Recommended assessment procedures are described below.

1.0 Introduction. This document describes five tools for assessing stream channel stability; one set of qualitative, picture-based indicators and four more quantitative tools. It is directed primarily at (a) grant applicants who are applying for monies to execute a channel restoration or bank stabilization project, to help in assessing whether the cause of the problem to be fixed is local or large-scale in nature, and (b) grantees who are writing watershed management plans and need to assess the scope of channel stability problems.

Stream channel stability refers to the capacity of a stream channel to transport its water and sediment inputs without changing its dimensions (width, depth, cross-sectional area, and slope). This simple definition obscures a couple of complicating factors:

- Stream bank and bed mobility is a natural phenomenon, and stable streams differ from unstable streams primarily in the rate of bank and bed mobility.
- Unnaturally high rates of bank and bed mobility can have multiple causes, ranging from small-scale, local causes like unrestricted livestock access or all-terrain vehicle traffic, to large-scale, regional causes like a watershed-wide increase in impervious pavement.

Assessing the scale of a stream stability problem is important for choosing whether, and what, corrective best management practice (BMP) should be installed. Stream channel stability problems with small-scale causes can be addressed by removing the cause; fencing out the livestock or blocking ATV trails, for example; followed by an appropriate local BMP such as bank stabilization. Conversely, permanently fixing large-scale stream stability problems requires large-scale solutions; increasing regional storm water retention or infiltration, for example.

Further, choosing the proper BMP to match the scale of the stream stability problem has ecological and economic implications. Applying small-scale BMPs such as bank stabilization to stream reaches impacted by large-scale degradations is at best a “band-aid” approach in which the BMP is likely to fail in a few years. Worse, inappropriate BMPs can actually exacerbate stream channel problems; for example, “hard” bank stabilization BMPs such as sheet

pile or extensive rip rap installed in a stream reach impacted by a large-scale watershed development can deflect stream energy downstream, increasing erosion at the next unprotected stream meander bend.

Since a mismatch between the scale of the cause of a stream channel problem and a proposed solution is at best ineffective and could even make the problem worse, applicants proposing major stream treatments such as bank stabilization, meander restoration, or installation of instream structural BMPs like sand traps or cross-vanes, should assess the scale of the cause(s) of the problem to be solved.

Documenting local causes like livestock access is usually straightforward, while identifying large-scale causes is more challenging. By far the most common large-scale cause of stream channel instability in Michigan is changing land use practices, which alters the hydrologic regime of the stream, primarily by increasing the frequency and magnitude of post-storm peak flows and/or lowering base flows. Hydrologic alteration often results in changes in channel geomorphology; for example, increased width and/or depth, or decreased sinuosity. Hydrologic alteration can be assessed directly with a suitable hydrologic study (guidance is being developed), and indirectly using measures of bank condition and channel morphology. The rest of this document describes five recommended hydrologic and geomorphic tools for assessing stream stability. MDEQ's recommended interpretation of the results of these tools is also described. The five stability assessment tools are discussed in order of increasing complexity.

2.0 Tool 1 – Qualitative Indicators of Channel Stability. Qualitative observations of channel stability can provide supporting evidence for conclusions drawn from the more quantitative assessment techniques described below. Several examples of useful qualitative observations of channel instability or stability are described in Figure 1 and Figure 2, respectively.

In practice, qualitative observations of channel stability should be made at the project site and at multiple locations in the vicinity of the project site. The data will be interpreted as per Figure 3.

<u>Reporting requirements:</u> If qualitative indicators are used to assess stream stability for an NPS grant application, a checklist documenting their presence or absence at the project site and at multiple locations in the vicinity of the project site should be included with the application.

Figure 1. Examples of Qualitative Indicators of Channel Instability.

Unvegetated mid-channel bars or **side bars,** or **braided channels** often indicate excessive sedimentation (aggradation), although they can also be caused by local flow restrictions, like undersized or blocked culverts. Mid-channel bars due to excessive sediment loads are often accompanied by locally over-wide channels. Natural mid-channel bars can occur where channel slope declines abruptly, as in some Upper Peninsula streams.	
Leaning trees on <u>both</u> sides of the channel in straight reaches can indicate channel widening or incision. Observations of arching vs. straight tree trunks can provide insight into the speed of channel widening; trees can compensate for slow channel widening by arching back towards the bank. Note that leaning trees on only the outside of channel meanders may be due to natural bank erosion and mobility.	
Tree trunks in the middle of the channel can be caused by excessive sedimentation, or other causes of channel widening.	

Figure 1. Examples of Qualitative Indicators of Channel Instability (continued).

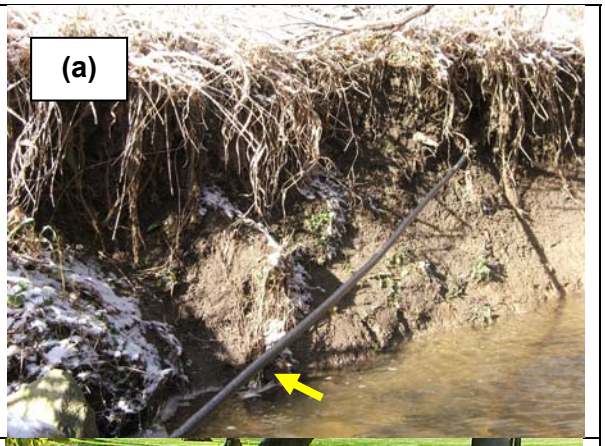
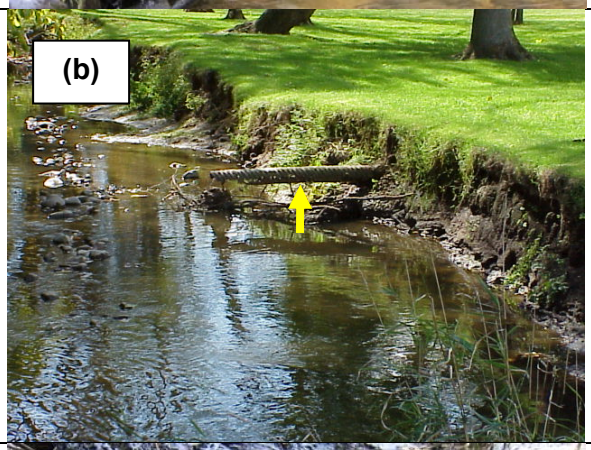
Exposed infrastructure (for example, sewer pipes, buried electrical wires [a], or street drains [b]) is a sign of widening and/or incising channels.	 
Headcuts, or **nickpoints**, are points of channel incision where the channel bed elevation rapidly adjusts to a natural or human-induced disturbance. Headcuts range from over-steep riffles to small waterfalls, and can rapidly migrate upstream, destabilizing channels far from the original disturbance. If observed at or near the mouth of a small tributary, another headcut has already migrated upstream in the larger stream.	

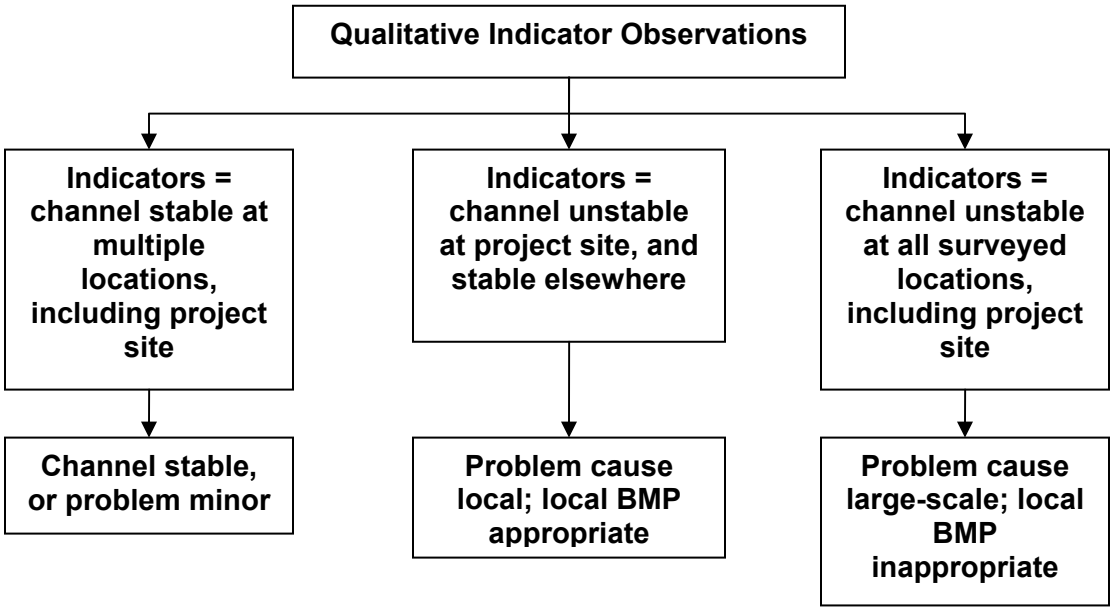
Figure 1. Examples of Qualitative Indicators of Channel Instability (concluded).

Exposed tree roots on both sides of the bank indicate channel widening.	
Slumping banks (mass-wasting erosion) indicate erosion at the bank toe, often due to channel widening. (This stream near Ann Arbor is so over-wide that the low flow wetted channel, which is to the left, is not even visible in the picture.)	
Failed bank stabilization BMPs. Arrows show bank toe rip rap from a previous, unsuccessful stabilization project. This site is downstream from a small dam, which produced sediment-starved, highly erosive "hungry water."	
Proximity to dam. "Hungry water" downstream of dams can cause channel incision and/or widening.	

Figure 2. Examples of Qualitative Indicators of Channel Stability.

Herbaceous vegetation (grasses, sedges, wildflowers, emergent aquatic macrophytes, mosses) **at the low-flow water line.**	
Self-sustaining populations of **sensitive fish species**, including sculpins, certain darters, and non-migrating salmonids. (Migrating salmonids can be temporarily found in highly unstable streams, during spawning season.)	
Aquatic moss growing on submerged rocks indicates minimal sedimentation and mobilization of the stream bottom materials. This is not necessarily true for attached filamentous algae like *Cladophora*, which grow more quickly than aquatic mosses and can therefore cope with limited channel bed mobility.	

Figure 3. Interpretation of Qualitative Bank Stability Observations.



3.0 Tool 2 – Bank Erosion Hazard Index and Ribbon Test. A quantitative assessment of stream bank stability can be rapidly performed using the Bank Erosion Hazard Index (BEHI; Rosgen, 2001). The BEHI assigns scores to several aspects of bank condition and provides an overall score that can be used to inventory stream bank condition over large areas, prioritize eroding banks for remedial actions, etc. The original BEHI procedure (Rosgen, 2001) consists of five metrics; four observational and one requiring some field measurements (Figure 4):

1. Ratio of bank height to bankfull height
2. Ratio of riparian plant root depth to bank height
3. Root density, in percent
4. Bank angle, in degrees
5. Surface protection, in percent

BEHI assessments can be made conveniently at or near road crossings (taking care to consider impacts of the road crossing structure itself), and can usually be performed in well less than a half hour per station. Results of the BEHI calculations are divided into 6 categories of bank erosion potential: very low, low, moderate, high, very high, and extreme. A Standard Operating Procedure (SOP) for BEHI, which explains the metrics and how to calculate an erosion hazard score, is available on the MDEQ NPS Unit website (____). This SOP includes an abbreviated version of the BEHI procedure that uses only four of the five metrics (2 – 5, above), and is suitable for use by volunteers.

Figure 4. Examples of BEHI Results.

<u>Rural Stream</u> **Plant root depth ≈ 100 %** **Root density ≈ 90 %** **Bank angle ≈ 30º** **Surface protection ≈ 90 %** **BEHI = 7.3 = Low**	
<u>Urban Stream</u> **Plant root depth ≈ 20 %** **Root density ≈ 15 %** **Bank angle ≈ 80º** **Surface protection ≈ 20 %** **BEHI = 25.80 = High**	

Stream bank appearance is not the only factor in assessing bank erosion hazard, however; bank soil cohesiveness is also important. For example, a high, steep, bare bank of sandy soil is much more erodible than an identical bank composed of clayey soil. A later BEHI protocol (Rosgen, 2006) includes two additional metrics; bank material and bank material stratification; and the bank material metric attempts to account for the lower erodibility of cohesive soils. A more quantitative assessment of bank material cohesiveness is the <u>ribbon test</u> (Figure 5). The ribbon test is very simple and can be performed in a few seconds, as described below:

1. Put a ping-pong-sized ball of moist streambank soil in palm of hand.
2. Roll soil into cigar-shape between palms, then roll out between thumb and forefinger into ribbon ⅛" to ¼" thick and as long as possible.
3. Compare to Table 1.

Figure 5. Example of a Stream Bank Soil Ribbon.

Table 1. Interpretation of Ribbon Test Results

Ribbon Length (cm)	Approx. % Clay	Soil Type/Texture	Qualitative Erosion Potential
None	≥ 50 % *sand*	Sand	High
Flakes, not ribbon	0-20	Sandy silt/silt loam	High
< 5 cm	20-40	Clayey sand/sand clay loam	Moderate
5-7.5	40-50	Silty clay	Low
> 7.5	> 50	Clay	Low

In practice, BEHI measurements and the ribbon test should be performed at the project site and at multiple locations in the vicinity of the project site. The data will be interpreted as per Figure 6.

The BEHI procedure does have pros and cons (Table 2).

Reporting requirements: If BEHI evaluations are used to assess stream stability for an NPS grant application, the scores from the project site and multiple locations in the vicinity of the project site should be included with the application.

Figure 6. Interpretation of BEHI and Ribbon Test Scores.

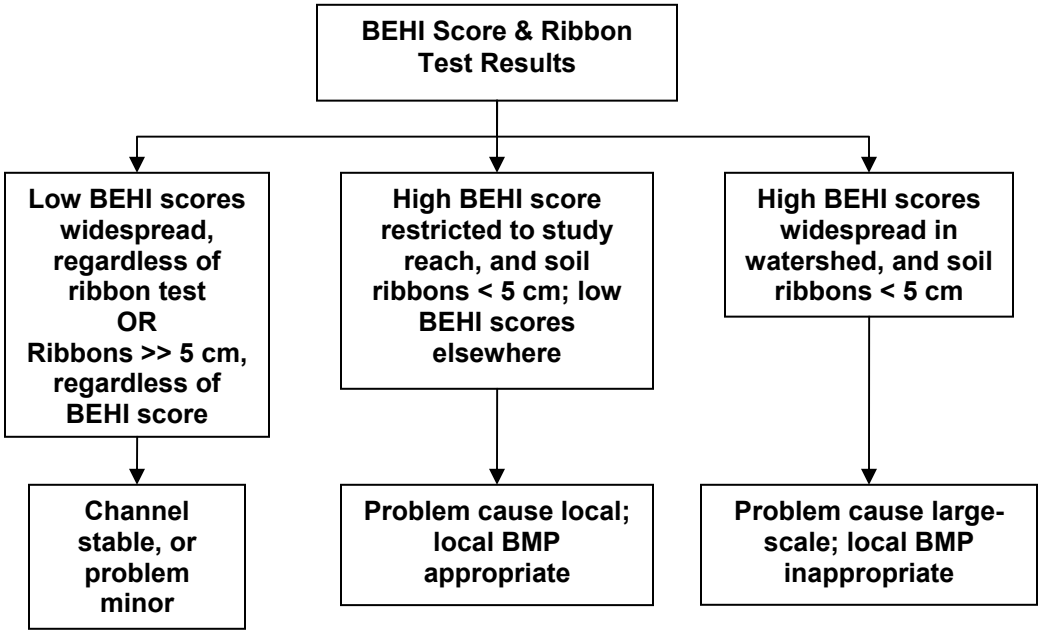


Table 2. Pros and Cons of the Bank Erosion Hazard Index (BEHI) Procedure.

Pros	Cons
Minimal training required Low level of effort; 1 day = multiple locations	Natural bank erosion in an active floodplain can be mistaken for unnatural, excessive erosion Does not account for soil cohesiveness, unless ribbon test is performed Does not provide an estimate of erosion rate Can be difficult to select a "representative" reach

4.0 Tool 3 – Hydrologic Flashiness Index. The Richards-Baker Flashiness Index (R-B Index; Baker, et al., 2004) is an expression of stream discharge variability, or hydrologic flashiness. Significantly increasing values of the R-B Index over time correspond to increasing variability in stream flashiness, which is interpreted as a strong indication of hydrologic instability (refer to Baker et. al. 2004, for details of this calculation). USGS discharge data are required to

calculate the R-B Index; consequently, its results can only be applied to stream reaches within a reasonable distance of a USGS gage station. (Note that "reasonable distance" will be project-specific, and should be discussed with the appropriate NPS engineer.) MDEQ has calculated and graphed the R-B Index trends for almost 280 locations throughout the Michigan, and this report (which includes a map of the gages used) may be found at the "Nonpoint Source Hydrologic Assessment" link on the MDEQ's Nonpoint Source Pollution website. Figure 7 illustrates some results for the Au Sable River.

Figure 7. Example R-B Index Graphs. (Au Sable River)

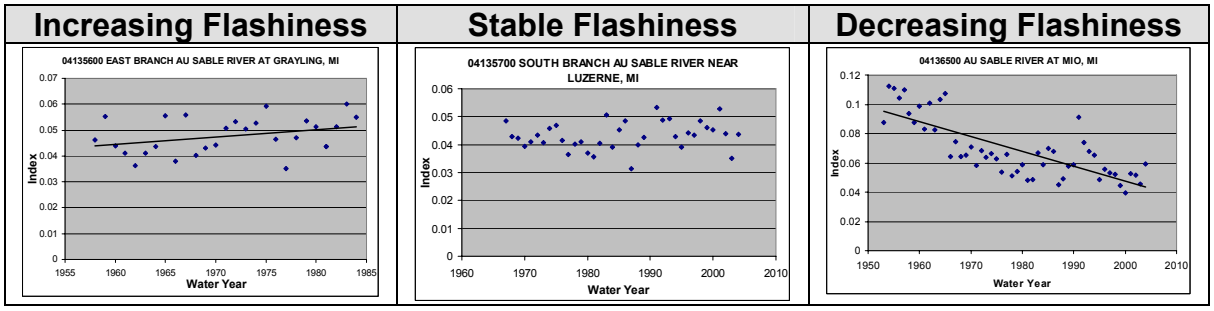


Figure 8 illustrates how stream flashiness data could influence BMP selection and siting in a watershed with multiple USGS gages. Stream flashiness is increasing at the two gages in Grayling, in the headwaters of the Au Sable River (upward red arrows), and steady or decreasing at the other four gages in the rest of the watershed (downward yellow or horizontal green arrows). Consequently, channel stability problems in the Grayling area may be due to large-scale hydrologic alteration and would be best addressed by BMPs like regional storm water retention or infiltration. In the rest of the watershed, channel stability problems are more likely to have a local cause, and if so could be addressed with a small-scale BMP like stream bank stabilization.

There are pros and cons to the hydrologic flashiness index (Table 3). In practice, hydrologic flashiness information will be interpreted as per Figure 9.

Table 3. Pros and Cons of the R-B Flashiness Index.

Pros	Cons
All calculation already performed by MDEQ, and available on website	Limited number of gages Interpretation complicated by dams, water withdrawals, land uses, etc.

Figure 8. Example of Stream Flashiness Results: Au Sable River, Michigan.
(Upward arrows = increasing flashiness; downward arrows = decreasing flashiness; level arrows = no trend)

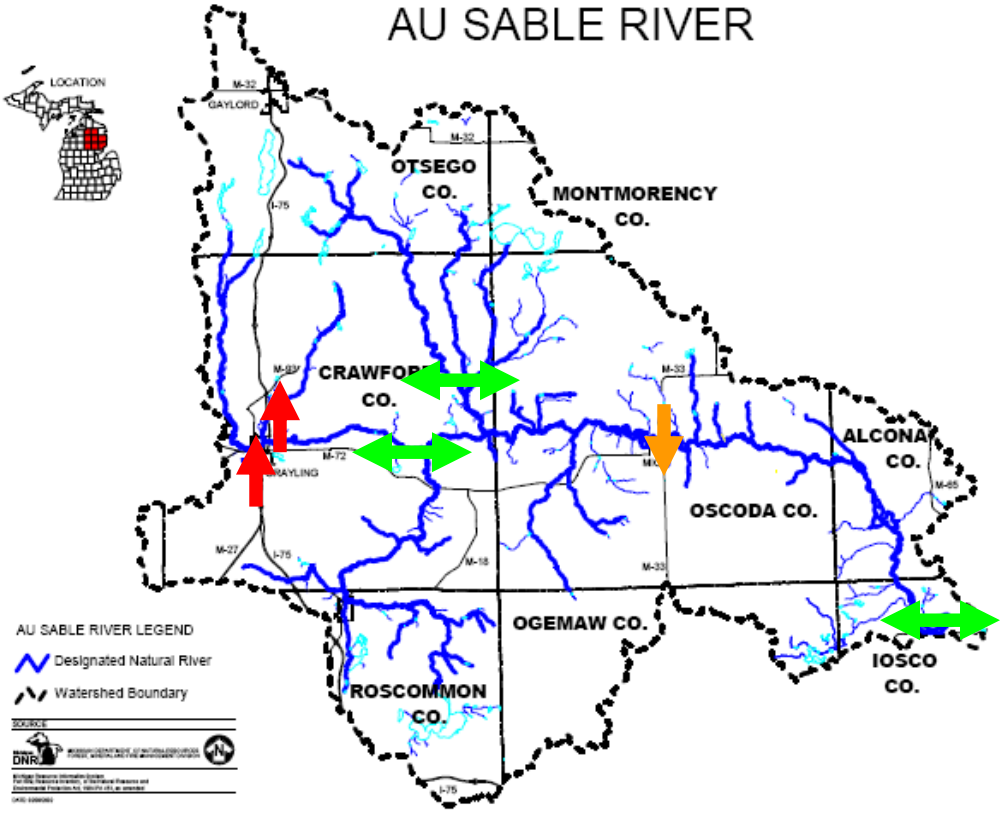
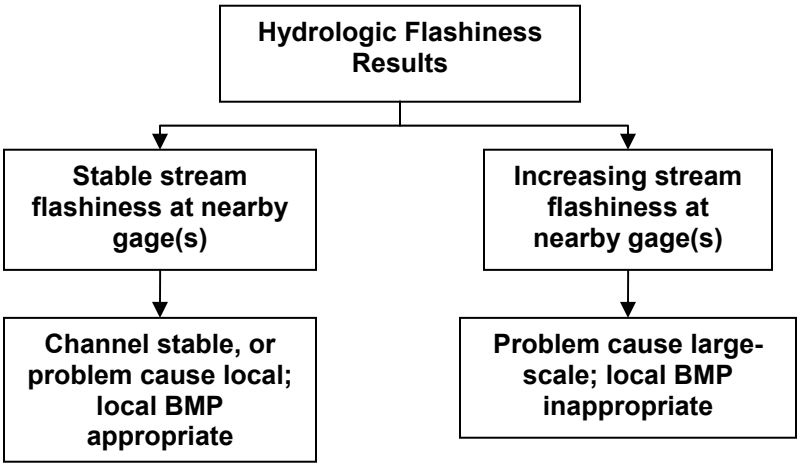


Figure 9. Interpretation of Stream Flashiness Data.



Reporting requirements: If flashiness trends are used to assess stream stability for an NPS grant application, the identification number of the gage(s) used and a short summary of their results should be included with the application.

5.0 Tool 4 – Tractive Force Calculations. The tractive force equation is one of several ways to calculate the stress exerted by the water flowing in the stream channel on the stream bed ("shear stress" or τ). Shear stress increases with both increasing water depth and increasing channel slope, and higher shear stresses are capable of mobilizing larger stream bed particles. For this purpose, channel stability is assessed by (a) calculating the shear stress produced by bankfull discharges and expressing it as the particle size mobile at that discharge, (b) performing a "pebble count" to measure the size of bedded sediment particles available to be moved at the bankfull discharge, and (c) calculating the ratio of (a) and (b) to assess if the shear stress produced by bankfull discharges is likely to cause channel erosion and instability.

The tractive force equation is:

$$T = D_{BF} \times S$$

where D_{BF} is the maximum bankfull depth and S is the channel slope. When D_{BF} is expressed in millimeters and S is dimensionless (feet/feet or meter/meter), τ is approximately equal to the particle size (in centimeters) that is mobile at bankfull discharges. A particle of this size is the calculated incipient particle diameter, or IPDc. See Box 1 for an example of the calculation.

Harrelson et al. (1994) describes procedures for measuring bankfull depth and channel slope. It must be noted that it can be very difficult to identify bankfull dimensions in unstable, incised streams. In these situations, channel depth from the top of the bank to the thalweg is substituted for bankfull depth (Figure 10).

Box 1. Calculated Incipient Particle Diameter (IPDc) Example.

- Bankfull depth = D_{BF} = 1.97 ft = 60 cm = 600 mm
- Channel slope = S = 0.002 ft/ft

- IPDc = D_{BF} x S = 600 x 0.002 = 1.2 cm (= small gravel)

Figure 10. Top of Bank (dashed lines) in an Incised Channel (Rouge River, Wayne Co., Michigan; the banks are actually the same elevation, but the angle of the photo makes the bank on the right look lower)

Another way to establish the particle size mobile at bankfull discharge is to perform a pebble count (see chapter 11 in Harrelson et al., 1994), wherein the intermediate diameter of at least 100 "pebbles" (bedded particles which can range from silt to boulders) are measured, and the 84th percentile diameter of the particle distribution (D_{84}; Figure 11) is calculated. A number of empirical studies have indicated that the D_{84} is the maximum particle size mobile at bankfull discharges. The particle size corresponding to the D_{84} is the measured incipient particle diameter, or IPDm.

Stream stability is assessed by calculating the ratio of the IPDc to the IPDm and interpreting the results as shown in Table 4.

There are pros and cons to tractive force measurements (Table 5). The cons of this stream stability assessment tool in particular emphasize the need for a weight-of-evidence approach (Section 7.0)

Figure 11. Example of Pebble Count Data. (dashed red line = D_{84})

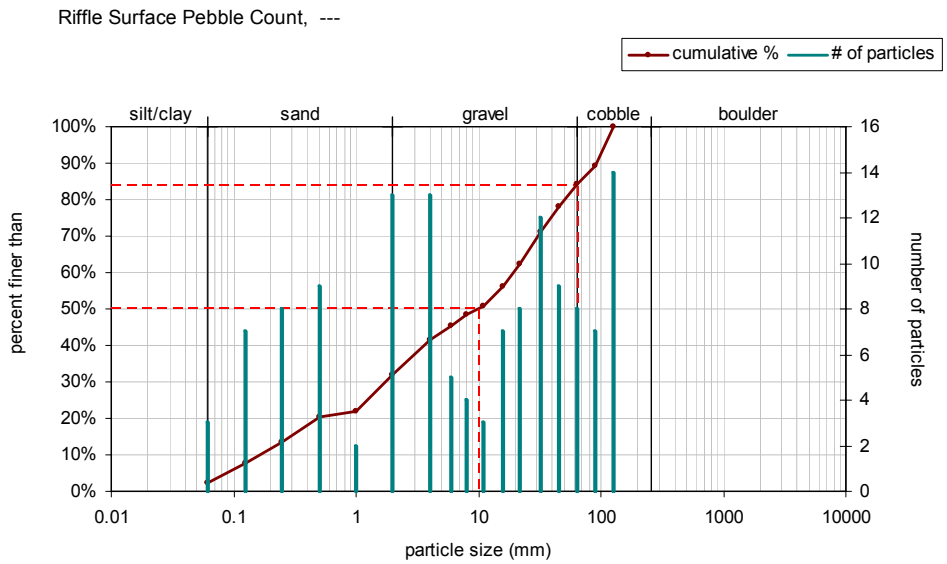


Table 4. Interpretation of the Tractive Force Calculation Results.

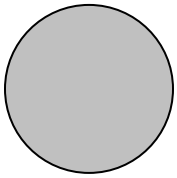
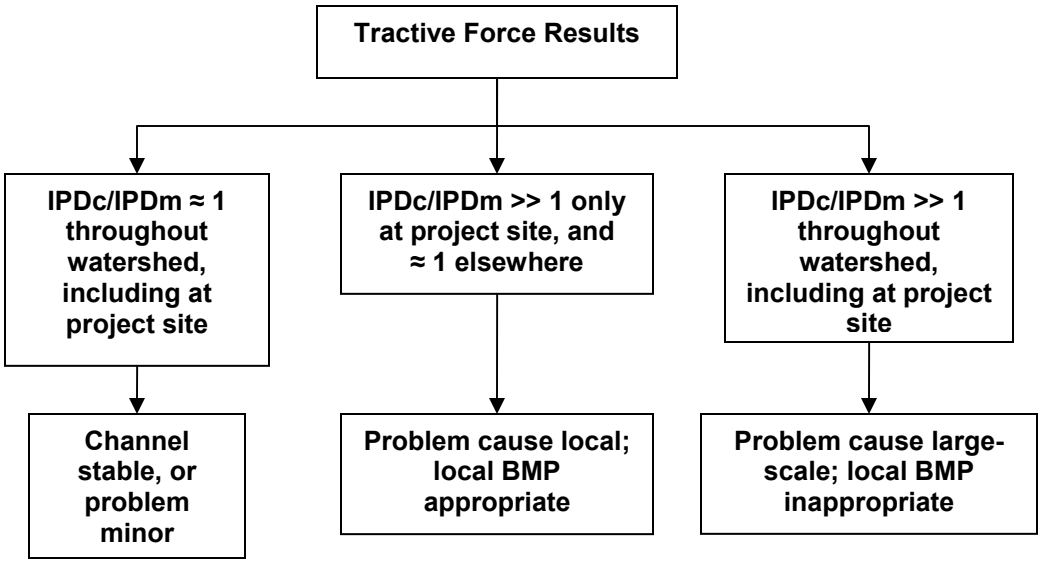
Calculated IPD (IPDc)	Measured D_{84} (IPDm)	Ratio IPD / D_{84}	Conclusion
		IPDc / IPDm ≈ 1	Stable stream
		IPDc / IPDm >> 1	Unstable stream

Table 5. Pros and Cons of the Tractive Force Calculation.

Pros	Cons
Moderate level of effort; experienced crew of 2 can survey 2 or 3 sites per day Tractive force assesses the likely stability of the stream bed, unlike BEHI and the qualitative stability indicators which focus on the stream banks	Correctly determining bankfull elevation in stable streams requires training and experience Substituting top of bank for bankfull elevation in incised streams can result in inappropriately high IPDc, especially in over-wide but otherwise generally stable ditches

In practice, tractive force measurements should be made at the project site and at several locations in the vicinity of the project site, and their data interpreted as per Figure 12.

Figure 12. Interpretation of Tractive Force Data.



Field work needed for collecting data for the tractive force calculations (channel depth and slope, and pebble counts) requires more training than the qualitative indicators or the BEHI. An experienced field crew of two could complete the field measurements in a couple of hours to half a day per location, depending on stream size.

Reporting requirements: If tractive force data are used to assess stream stability for an NPS grant application, ratio values from the project site and from several locations in the vicinity of the project site should be included with the application.

6.0 Tool 5 – Regional Geomorphic Reference Curves. Regional reference curves (RRCs) are plots of drainage area vs. one of several channel dimensions or hydrologic attributes; most commonly, bankfull width, depth, cross-sectional area and discharge (Figure 13). Data for RRCs must be collected from stable stream reaches, but the curves can then be used to assess whether the dimensions of other streams are comparable, and therefore, whether the other streams are stable. The Michigan Stream Team is currently collecting channel dimension data at stable USGS gage locations around the state, to create RRCs for as much of the state as possible. These RRCs will be available in 2009.

Using RRCs to assess stream stability involves collecting channel dimension data (width, depth and cross-sectional area) at the proposed project site and at

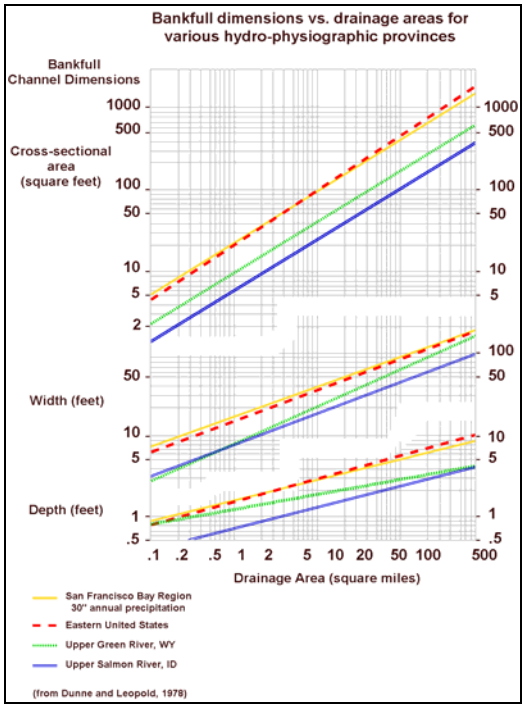
several locations upstream, and then comparing the measured dimensions to the appropriate curves. Field techniques for collecting channel morphology data are described in Harrelson et al. (1994) and the Michigan Stream Team's field protocol (Michigan Stream Team, 2008). An important aspect of collecting field data from other streams for comparison to RRCs is recognizing bankfull elevations. Various field indicators of bankfull elevation are discussed in the literature, and these are reviewed in the Stream Team's protocol. In most stable Michigan streams, a floodplain break or an inflection point are the most reliable bankfull field indicators (Figure 14). In unstable streams the channel is often incised, and in these cases it is necessary to use the top of the stream bank as an indicator of the channel-forming discharge (Figure 10).

In practice, RRCs are used as follows:

1. Select the RRC appropriate to the project location (the coming report will identify which parts of the state are covered by RRCs).
2. Collect the field data described above, and identify the drainage area upstream of the proposed project location.
3. Plotting the project location's drainage area on the appropriate RRCs, identify the expected bankfull dimensions.
4. Compare the expected bankfull dimensions to the bankfull dimensions measured at the project location. The RRCs will be plotted with confidence intervals around the drainage area:dimension regression line (as opposed to Figure 13, which does not show confidence intervals, just the regression intervals). If the measured dimensions fall inside the confidence intervals, that location is considered stable; otherwise, the channel may be unstable.

It should be noted that developing RRCs for the entire state is an ongoing process, and some regions will not have curves for some years (e.g., the Lake Erie shoreline in southeastern Michigan).

Figure 13. Example Regional Reference Curve.



Regional reference curves have pros and cons, including a major limitation; the curves won't be available until 2009, and even then probably won't cover the entire state (Table 6).

Figure 14. Examples of Field Indicators of Bankfull Height in Stable Streams. (Dashed white line = floodplain break)

Natural stream channel	Stable two-stage ditch

Table 6. Pros and Cons of Regional Reference Curves.

Pros	Cons
Moderate level of effort; usually ≤ 1 day in the field for a crew of 2 If channel dimensions are abnormal, curves will identify approximate stable dimensions	Curves will not be available until 2009, and even then probably won't cover the entire State Training required for field measurements, especially for correctly identifying bankfull indicators Only appropriate for alluvial channels (channels whose boundaries and dimensions are maintained by the sediment carried by the current), not for bedrock channels

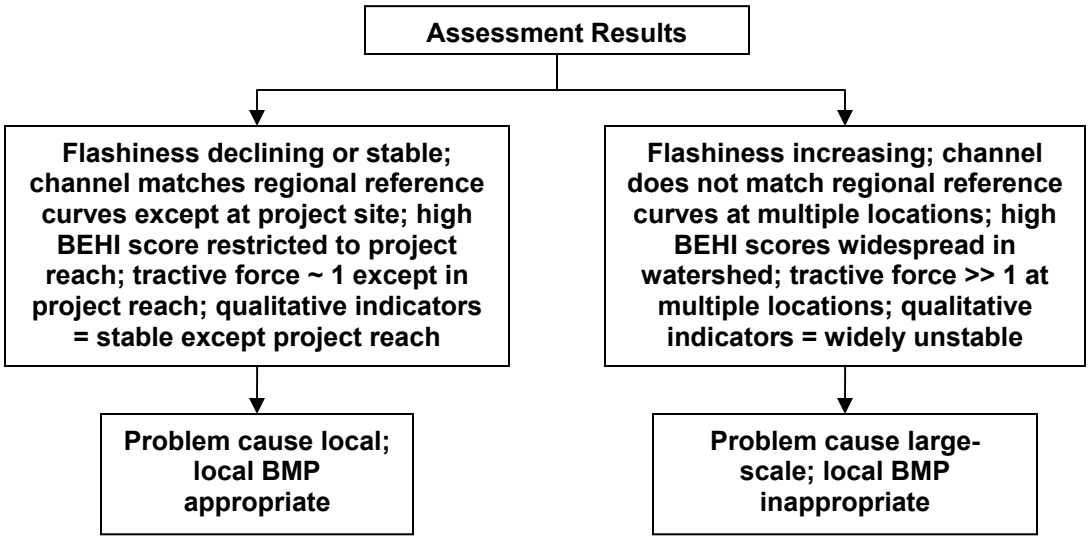
Reporting requirements: If regional reference curves are used to assess stream stability for an NPS grant application, 3 graphs illustrating the channel dimensions (bankfull width, depth and cross-sectional area) at the project site and several locations in the vicinity of the project site, plotted on the appropriate reference curve graphs, should be included with the application.

7.0 Combining the Tools – the Weight-of-Evidence Approach: Since the stability assessment tools described in this document separately address different aspects of the stream channel condition (stream hydrology, stream banks, stream bed, and overall channel dimensions), and since channel stability problems can affect one or more of these aspects in a single stream, it is highly recommended that NPS grant applicants utilize as many of these stream stability assessment tools as possible when applying for an NPS grant. This is referred to as a weight-of-evidence approach. For example, for a proposed project in a particular watershed:

- Flashiness trends at nearby USGS gages, if available, can be assessed. This is free and quick given that the data are available from MDEQ.
- Qualitative indicator observations and the BEHI observations can be made at the proposed project site and at multiple locations in the vicinity of the project site. An experienced crew of 2 could perform this work at many locations in a single day.
- Field measurements for the tractive force calculations and for comparison to the regional reference curves (when available), can be made at the proposed project site and at multiple locations in the vicinity of the project site. An experienced crew of 2 could perform this work at at least 1 or 2 locations per day.

In practice, information from multiple locations collected using a weight-of-evidence approach would be interpreted as per Figure 15.

Figure 15. Weight-of-Evidence Approach to Stream Stability Assessment.



8.0 Other Stream Stability Assessment Tools: There are multiple other approaches to assessing stream channel stability, including channel evolution models (e.g., Simon, 1989), channel stability indices (e.g., Simon and Downs, 1995; Center for Watershed Protection, 2003; Center for Watershed Protection, 2005), steam bank stability indices (Pfankuch, 1975; Vermont Agency of Natural Resources, 2004), and sediment budget-based approaches to channel stability (Rosgen, 2006).

Most of these alternative approaches are more complicated than the five assessment tools described in this document, and some are more appropriate for more rocky, mountainous watersheds than are common in Michigan. Several, however, also provide more detailed and quantitative information. MDEQ will consider the application of these alternative analyses on a case by case basis. Contact Joe Rathbun (rathbunj@michigan.gov; 517-373-8868) for more details.

9.0 References Cited

Baker, D., P. Richards, T. Loftus, and J. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. *J. American Water Resources Association* 40(2):503-522.

Center for Watershed Protection. 2003. *New York State Stormwater Management Design Manual. Appendix J: Geomorphic Assessment*. CWP, Ellicott City, MD.

Center for Watershed Protection. 2005. *Urban Subwatershed Restoration Manual 10: Unified Stream Assessment: A User's Manual*. CWP, Ellicott City, MD. 142 pp.

Harrelson, C, C. Rawlins, and J. Potyondy. 1994. *Stream channel reference sites: an illustrated guide to field technique*. USDA Forest Service GTR RM-245. 61 pp. Available at: http://www.treesearch.fs.fed.us/pubs/20753

Michigan Stream Team. 2008. *Protocol for Field Surveys of Stream Morphology at Gaging Stations in Michigan.* Available at the Michigan Stream Team website: www.michigan.gov/streamteam.

Pfankuch, D. J. 1975. Stream Reach Inventory and Channel Stability Evaluation. United States Department of Agriculture Forest Service. Government Printing Office #696-260/200, Washington, D. C., RI-75-002.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D. 2001. *A Practical Method of Computing Streambank Erosion Rate*. Pages II 9-15 in the Proceedings of the Seventh Federal Interagency Sedimentation Conference, Reno, NV. Available on the Wildland Hydrology, Inc. website – http://www.wildlandhydrology.com/html/references_.html

Rosgen, D. 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSSS)*. Wildland Hydrology, Pagosa Springs, CO.

Simon, A. 1989. A Model of Channel Response in Disturbed Alluvial Channels. *Earth Surface Processes and Landforms* 14:11-26.

Simon, A., and P. Downs. 1995. An Interdisciplinary Approach to Evaluation of Potential Instability in Alluvial Channels. *Geomorphology* 12:215-232.

Vermont Agency of Natural Resources. 2003. *Stream Geomorphic Assessment Protocol Handbooks: Remote Sensing and Field Survey Techniques for Conducting Watershed and Reach Level Assessments. Phase 2 Handbook – Rapid Stream Assessment – Field Protocols.*