A Methodology for Assessing Erosion Control Best Management Practice (BMP) Effectiveness

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1. Introduction

In northwest Michigan streams, sediment is a pollutant of concern. Many coldwater streams in this region support trout and salmon populations that require gravel riffles for spawning. Sediment clogging of this critical habitat threatens important ecological and economic resources. In addition, excess sediment alters stream morphology by filling pools and causing the channel to become shallower and wider. Shear stress becomes amplified near the banks, accelerating bank erosion and delivering additional sediment downstream.

State, federal, and private agencies routinely employ a variety of erosion control best management practices (BMPs) for stream restoration. Some of the techniques commonly utilized include streambank stabilization, improvements to road/stream crossings, and sand trap installation. Although anecdotal evidence suggests that erosion control BMPs have been successful in stream restoration, quantitative assessments documenting their effectiveness are lacking. The failure to evaluate BMPs is attributed, at least in part, to an absence of clear methods for quantifying their success. Project managers, funding agencies, and stakeholders are in need of a framework that will generate answers to critical questions, such as: 1) how effective are erosion control BMPs at reducing sedimentation to streams; 2) are the appropriate BMPs being installed and are they at the appropriate locations; 3) how long does it take for a BMP to improve habitat; and 4) what measurements need to be taken, where, and for how long? Millions of dollars are being spent on erosion control BMPs each year, yet the data required to effectively monitor their success are generally not being collected.

This document presents a decision framework to facilitate better planning, promote constructive use of resources, and establish protocols to yield the quantitative evidence necessary to support and justify the implementation of erosion control BMPs. The methodology contains adequate scientific rigor for sound decision-making, while allowing for flexibility to suit individual project and site needs. We recognize that each restoration situation is unique and developing an all-encompassing methodology is not feasible. Rather, our aim is to provide a strong, scientifically-sound foundation on which project managers can build an assessment strategy.

2. Methodology

2.1 Erosion Control Decision Framework

Because of the complex nature of stream erosion and sedimentation, it is critical to employ a planned approach when considering a site for restoration. Commonly used sedimentation and erosion controls, such as bank stabilization, sand trap construction, and road/stream crossing improvement can be very effective in alleviating sediment stress to streams. However, improperly placed, sized, or maintained BMPs can negatively impact stream biota and habitat, creating a more severe sedimentation/erosion problem. Of particular concern are downstream effects, which can be substantial and unpredictable.

An Erosion Control Decision Tree (Figure 1) has been developed to aid project managers and funding agencies in making sound decisions regarding the use and assessment of erosion control BMPs. The goal of this framework is to encourage better planning and use of resources to ensure that BMPs are utilized in appropriate situations and, once in place, are adequately monitored for effectiveness.

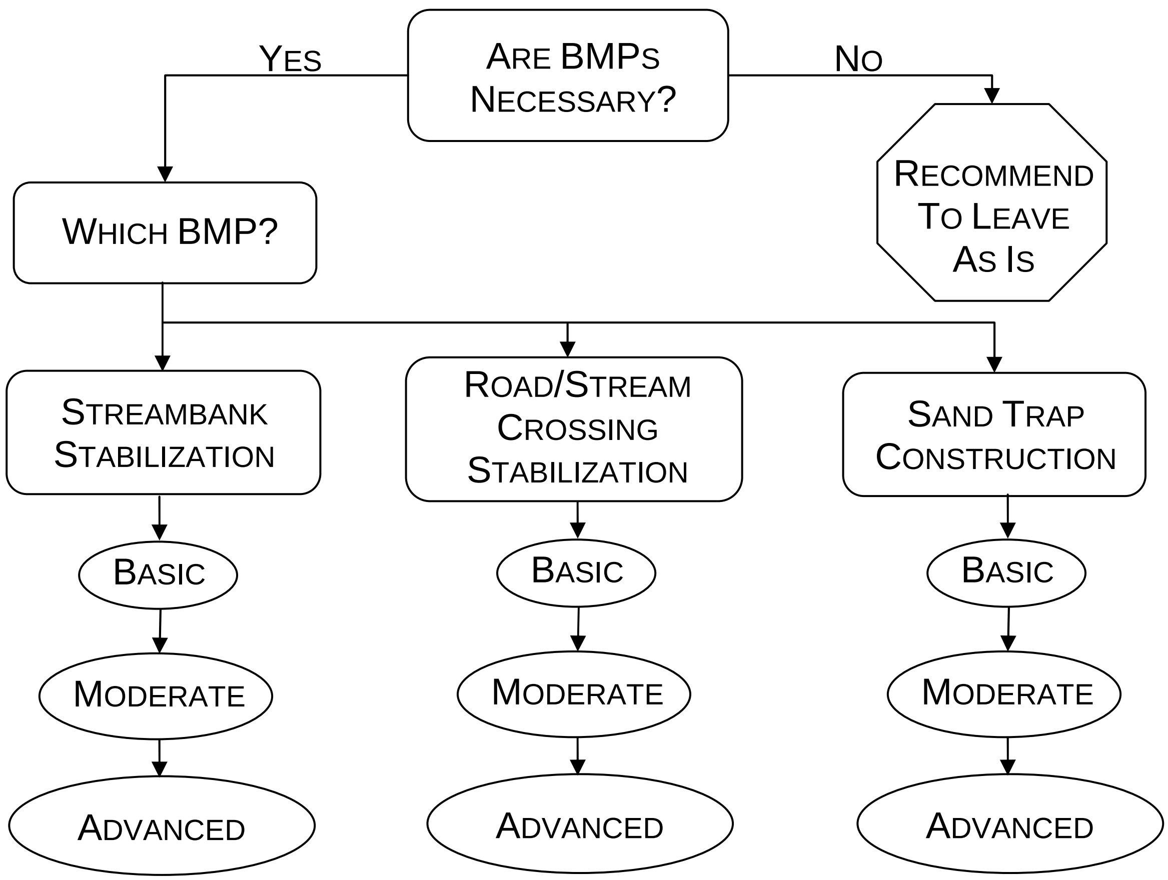


Figure 1: Erosion Control Decision Tree

The first level in the Erosion Control Decision process asks project managers if a BMP is necessary at the site in question (Figure 1). For this determination, it is crucial to identify both the causes and consequences of stream erosion (Rosgen 2001a). The key is to accurately recognize natural geologic erosion versus anthropogenic disturbance. Erosion and sedimentation are natural parts of stream dynamics, and human alteration of these processes can create major problems downstream as the system shifts toward a new equilibrium. Distinguishing between natural and human-induced erosion processes can be very difficult; therefore, local experts should be called upon to assist in their identification. In general, management of an area with no clear link to human impact should be avoided. Otherwise, the management itself could result in anthropogenic disturbance. On occasion, however, natural erosion problems may result in impacts that require attention. In those situations, managers can determine the appropriate BMP for the site, and follow the left branch of the decision tree (Figure 1) to assess erosion control.

If the cause of disturbance is clearly anthropogenic, the second stage in the Erosion Control Decision process involves choosing the appropriate BMP (Figure 1). Non-invasive procedures should be considered first. If possible, eliminate further disturbance of the area to allow the system to heal. For example, boulders could be placed to block all-terrain vehicle (ATV) stream-crossing paths. Severe bank de-stabilization, failing road/stream crossings, or high sediment loads may warrant a more intensive BMP. The criteria used to select a particular BMP are project-specific and beyond the scope of this deliverable, but numerous documents have been produced to guide managers in the selection process (U.S. EPA 1993, 2002, 2004a). Project managers should use best professional judgment to choose the appropriate BMP and ensure that it is effectively placed and scaled to yield maximum benefit to the system, with minimal additional disturbance. Potential downstream effects should be evaluated and given serious consideration.

After the appropriate BMP has been selected, the third stage in the Erosion Control Decision process entails choosing a level of assessment (Figure 1). Three tiers of assessment are presented in this methodology: basic, moderate, and advanced. Each tier contains protocols for BMP assessment that yield quantitative results to aid in the determination of BMP effectiveness. The assessment tiers differ in degree of effort, cost, and scientific rigor. The choice of which assessment tier best fits a particular project will depend, in part, on the amount of resources available. As a consequence, this methodology does not provide specific guidance on which assessment tier should be selected. Rather, the methodology builds flexibility into the decision-making process. The appropriate assessment tier will reflect the available resources, the driving force behind the assessment effort (e.g., conservation, litigation, research, etc.), and the desires of the stakeholders in the affected watershed.

2.2 Overall Monitoring Design

Evaluating a response to restoration can be confounded by the natural variability inherent in dynamic systems. A sound monitoring design can provide the basis for distinguishing between natural variation (i.e., noise) and a true response to restoration efforts (i.e., signal). Because of its ability to account for natural sources of variation, the Before-After Control-Impact (BACI) design is the most appropriate monitoring approach for evaluating BMP effectiveness (U.S. EPA 1997). In a general BACI design, a control site is selected that is exposed to the same environmental conditions (i.e., climate, geomorphology, lithology, etc.) as the site targeted for restoration. The two sites are monitored concurrently both before and after BMP installation (Figure 2). The data are analyzed by computing the differences between the control and treatment (BMP) sites; BMP effectiveness is determined by testing whether these differences change after the BMP is installed (Stewart-Oaten et al. 1986).

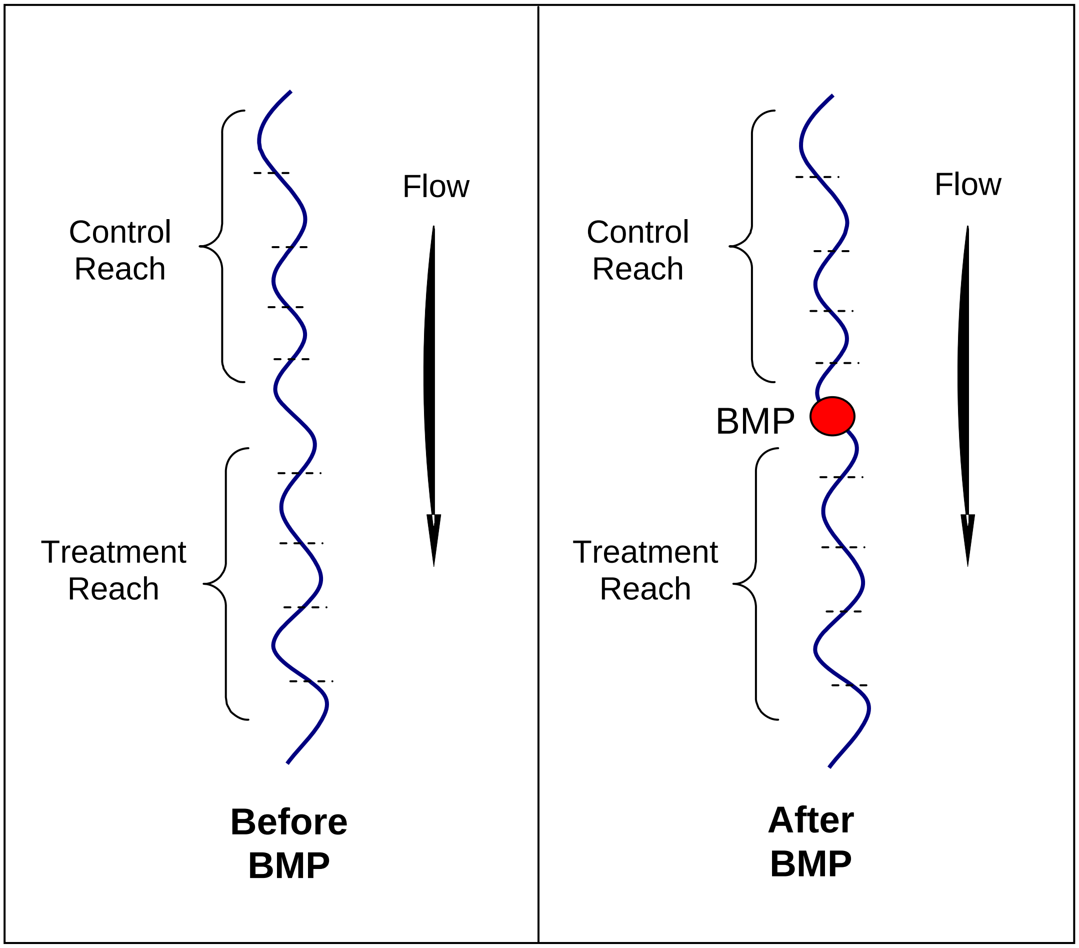


Figure 2: Before/After-Control/Impact (BACI) monitoring design, with upstream control and downstream treatment reaches. The dashed lines represent permanently established cross-sections.

Successful BMP assessment relies upon sufficiently long pre- and post-BMP monitoring. Adequate duration of pre-BMP monitoring is critical for understanding variability associated with intra- and inter-annual changes, differences between control and treatment sites, and sampling error (Stewart-Oaten et al. 1986, U.S. EPA 1997). Depending on the type of BMP used and the characteristics of the stream, the time it takes to detect a measurable response after BMP implementation can vary from less than 5 years to more than 20 years (U.S. EPA 1997, Nietch et al. 2005). As was the case in selecting the appropriate level of assessment (basic, moderate, or advanced), the appropriate length of time allotted for BMP evaluation will reflect available resources, the reasons for assessment, and desires of stakeholders. Appropriate sampling frequency also is important for assessing variability, as seasonal changes can strongly influence how a system responds. The recommendations for monitoring duration and frequency presented in this methodology are an attempt to balance feasibility, practicality, and scientific rigor.

BMPs are commonly installed with the objective of restoring biological integrity in systems experiencing impairment from sedimentation or erosion. However, intensive biological monitoring can be prohibitive because of cost and the requirement for technical expertise. Therefore, the methodology presented here uses surrogate variables, such as changes in physical habitat and sediment load, to infer effects on biological communities (U.S. EPA 1997, MDEQ

2004). If biological monitoring is desired and feasible, project managers are encouraged to incorporate it as a complement to this methodology.

2.3 Erosion Control Assessment Tiers

The assessment tiers are designed to be cumulative, with each successive tier building on the previous tier. For example, the moderate tier includes all of the assessment variables of the basic tier, and also incorporates an additional, more involved, set of variables. Similarly, the advanced tier involves measurement of the variables in the basic and moderate tiers, plus one final, more involved, set of variables. This tiered approach is intended to serve as a general framework for planning a monitoring program for BMP effectiveness assessment, and provides sufficient latitude that it can be tailored to suit individual project needs.

2.3.1 Basic Tier – Visual Evaluation of Erosion / Sedimentation Severity

2.3.1a Monitoring Design

i. Station selection – Once a site is selected for BMP installation, identify control and treatment reaches based on their proximity to the BMP. The control reach should begin just above the BMP location and extend upstream 20-30 channel widths (Figure 2; Rosgen 1996). The treatment reach should begin at the BMP site and extend 20-30 channel widths below the downstream extent of the BMP. In both the control and treatment reaches, permanently establish 3 to 4 cross-sections in riffle zones for measurement of assessment variables (Figure 2). Riffles are more sensitive than other habitats to increased sediment supply and exhibit changes more readily, making them good locations for assessing BMP effectiveness (Olsen et al. 2005). If riffles do not exist in a reach or if there is interest in another specific type of channel unit, permanent cross-sections can be established in pools or runs. However, it is important that all the multiple cross-sections (both upstream and downstream of the BMP) are placed in the **same** type of channel unit.

ii. Sampling frequency and duration – Prior to BMP installation, collect data on a monthly (if possible) or bimonthly basis for 1 year. After BMP installation, collect data at the same frequency as before BMP installation for 2 years and annually thereafter. Sampling should occur at the same general period during each month and at the same time of day. Annual sampling should continue as long as funding permits.

   Project resources may dictate which sampling frequency (monthly or bimonthly) is most appropriate. Monthly sampling is ideal because it best captures seasonal variation and gives a more accurate representation of annual sedimentation and erosion rates. However, monthly sampling may be cost-prohibitive for many projects, in which case sampling can occur on a less frequent basis (e.g., bimonthly or quarterly).

2.3.1b Assessment Variables

The Basic Tier relies upon visual methods for evaluating sedimentation and erosion severity. These are low cost techniques that require little technical expertise, although training is recommended to reduce variability resulting from observer bias. Further, the methods suggested are semi-quantitative and support statistical analyses, yielding potentially useful information for evaluating BMP effectiveness.

i. <u>Sedimentation severity</u>

Modified Wolman Pebble Count – The Wolman pebble count is one of the most widely used techniques for monitoring the effects of sediment inputs to streams (Olsen et al. 2005). Its utility lies in the determination of the cumulative particle size distribution of channel materials, in which departures can indicate trends in river stability (Rosgen 1996). In addition, the percentage of sand and fine sediment is highly correlated with embeddedness (Sylte and Fischenich 2002). Considerable observer and natural variability are commonly associated with pebble counts, possibly precluding the detection of changes in particle size distribution that are less than 15 percent (Olsen et al. 2005). All technicians involved in conducting pebble counts should complete training exercises to calibrate their techniques and minimize observer variability. Using a single observer to conduct all counts can further reduce variability (Olsen et al. 2005), but adds time to complete the counts. To reduce natural variability, Olsen et al. (2005) recommend increasing the sample size from 100 to 300, evaluating several riffles within a reach, and narrowing the seasonal window during which pebble counts are conducted. The methods presented here are modified from Wolman (1954).

Conduct a pebble count at each permanent cross-section according to the following procedure:

a. Identify the upstream and downstream extent of the riffle (or other channel unit) at which the permanent cross-section is located and within it establish 4 equally-spaced transect lines across the wetted width of the stream, perpendicular to stream flow (Olsen et al. 2005).
b. Sample at least 100 particles at equally-spaced intervals along the 4 transect lines. For a 100-particle sample, measure 25 particles per transect line within a riffle. For samples larger than 100 particles, adjust the number of particles per transect line accordingly.
c. Select particles to measure based on "first blind touch." Avoid looking into the water before reaching for a particle.
d. Measure particles using a gravelometer. For larger particles, measure along the intermediate axis (Figure 3) to the nearest mm using a ruler or meter stick.
e. Return particles to their original position to minimize disturbance (Olsen et al. 2005).
f. Plot data as a cumulative distribution curve (Table 1, Figure 4).

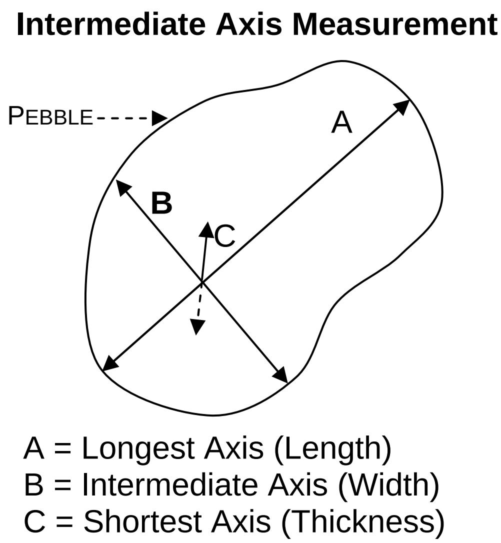
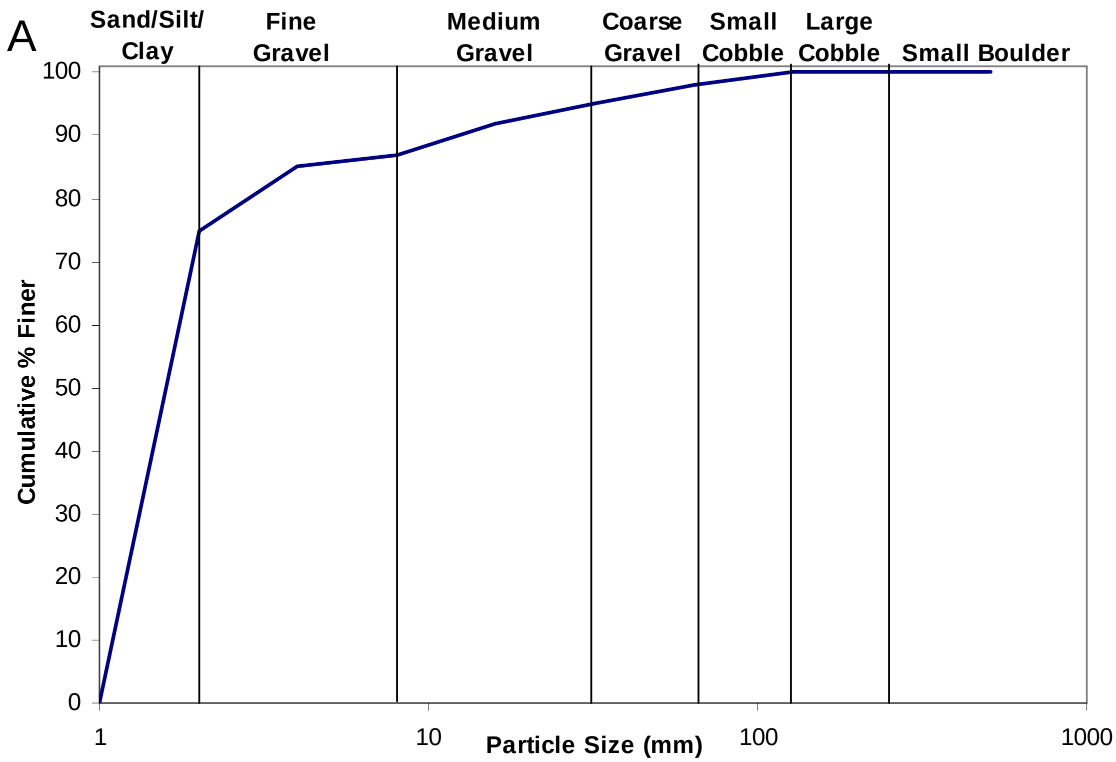


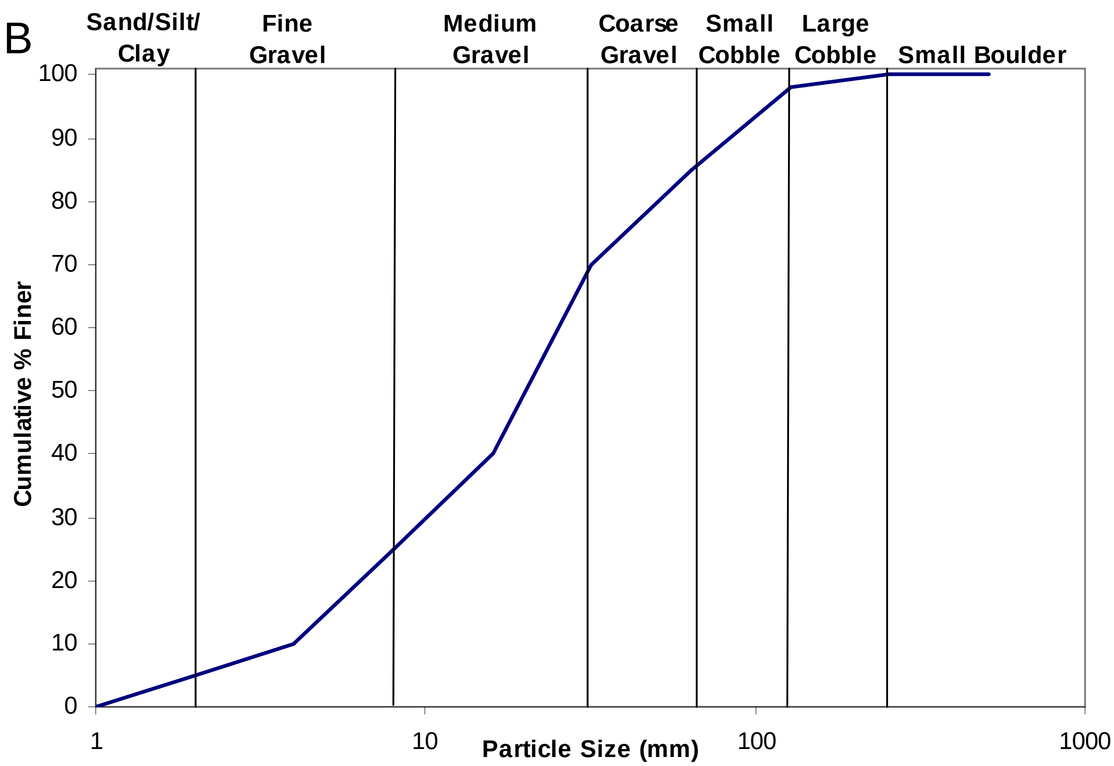
Figure 3: Orientation of particle for measurement of the intermediate axis for the Wolman pebble count: A=longest axis, B=intermediate axis, C=shortest axis.

Table 1: Particle size classes for stream bed material (Wolman 1954).

Size Class	**Particle Size (mm)**
Silt, Clay, Sand	0–2
Very Fine Gravel	2–4
Fine Gravel	4–8
Medium Gravel	8–16
Coarse Gravel	16–32
Very Coarse Gravel	32–64
Small Cobble	64–128
Large Cobble	128–256
Small Boulder	256–512
Medium Boulder	512–1024
Large Boulder	1024–2048
Very Large Boulder	2048–4096

Figure 4: Hypothetical examples of cumulative distribution curves for bed material particle size, as determined by the modified Wolman pebble count. Panel A depicts a reach with a higher percent of fine particles (i.e., sand, silt, clay) and panel B shows a reach with a lower percent of fine particles.





ii. Channel stability

Bank Erosion Hazard Index – The Bank Erosion Hazard Index (BEHI; Rosgen 2001c) consists of five metrics (detailed below) that are used to assess the erosion resistance of a stream bank, and thus to evaluate the lateral stability of the channel (Table 2).

Calculate the BEHI score at each cross-section. First examine the condition of both banks; if the right and left banks (facing upstream) are substantially different, compute the BEHI score separately for each bank (Rathbun 2004). Otherwise, score metrics according to the overall bank characteristics near the cross-section (Figure 5). Again, improve data rigor by using two observers to make independent assessments and record the mean score.

Table 2: Bank Erosion Hazard Index (BEHI), modified from Rosgen (2001c). Metric scores were modified from a range of values to a single value to reduce subjectivity (Rathbun 2004).

	Bank Height/ Bankfull Height		**Root Depth (%)**		**Root Density (%)**		**Bank Angle (°)**		**Surface Protection (Avg. %)**		
BEHI Rating	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	***Total Score***
Very low	1.0–1.1	1.5	90–100	1.5	80–100	1.5	0–20	1.5	80–100	1.5	≤7.5
Low	1.11–1.19	3	50–89	3	55–79	3	21–60	3	55–79	3	7.6–15
Moderate	1.2–1.5	5	30–49	5	30–54	5	61–80	5	30–54	5	16–25
High	1.6–2.0	7	15–29	7	15–29	7	81–90	7	15–29	7	26–35
Very high	2.1–2.8	8.5	5–14	8.5	5–14	8.5	91–119	8.5	10–14	8.5	36–42.5
Extreme	>2.8	10	<5	10	<5	10	>119	10	>10	10	42.6–50

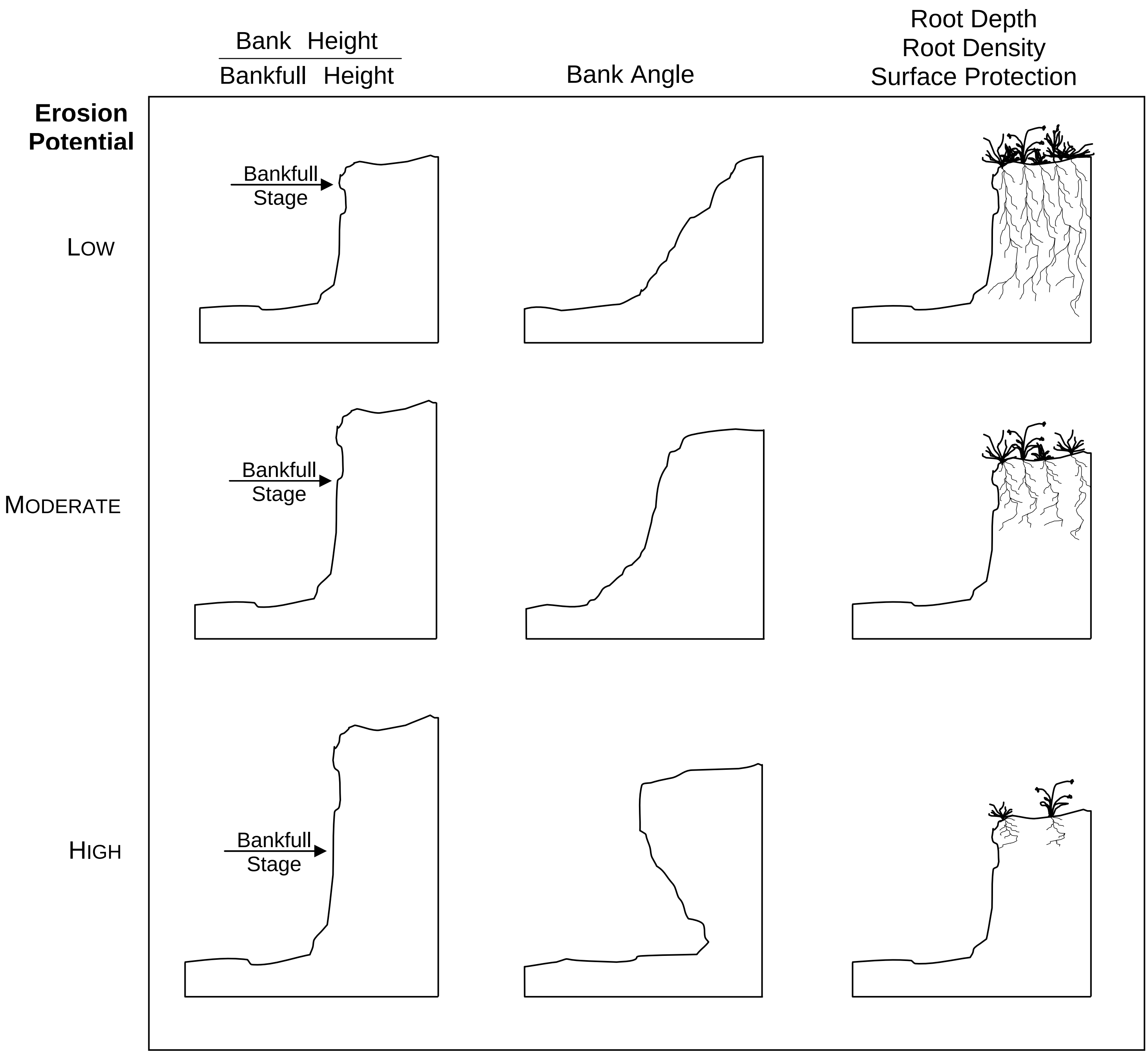


Figure 5: A visual guide for ranking Bank Erosion Hazard Index (BEHI) metrics. Adapted from Rosgen (1996).

a. Ratio of Bank Height to Bankfull Height

Of the 5 BEHI metrics, this is the most subjective and training may be required in recognition of bankfull indicators (Rathbun 2004). In general, bankfull indicators in stable Michigan streams are the top of bank, a point bar, or other change in channel slope. Bankfull height is more difficult to recognize in unstable streams, but is usually below the top of the bank (Rathbun 2004).

Streams in which the top of the bank is equal to bankfull are considered to have very low erosion potential; as bankfull height becomes lower in relation to total bank height, the bank erosion rating becomes worse (Table 2; Figure 5). Guides to aid in bankfull indicator identification can be obtained from the U.S. Forest Service (USDA Forest Service 2003, 2004).

One approach to determine the bank height to bankfull height ratio uses the following procedure:

1. Place a surveyor's rod on the streambed at the base of the bank. Use a rod level to align the rod perfectly vertical.
2. Measure the bank height and bankfull height by tightly stretching a measuring tape horizontally from the respective bank feature to the surveyor's rod. Read the height of the feature on the survey rod. Alternatively, use a laser measuring device to determine the height on the rod.
3. Calculate the ratio by dividing the total bank height by the bankfull height.

b. Root Depth

This metric is scored based on the ratio of average plant root depth to bank height, expressed as a percent (Table 2; Figure 5). For example, if roots extend on average 3 ft into a 6 ft bank, the root depth is 50%. Greater root depth ratios represent decreased risk for erosion. Stand at the base of the bank and visually estimate the average depth of the bank (as a percentage) that is penetrated by roots. If desired, a surveyor's rod can be used to determine the average depth of root penetration (as described above).

c. Root Density

This metric represents the percentage of stream bank that is covered, and thus protected, by plant roots. A stream with 100% of its banks covered in roots is rated very low for erosion severity (Table 2; Figure 5). Stand at the base of the bank and visually estimate the percentage of stream bank covered by roots.

d. Bank Angle

Bank angle is determined by estimating the degree of bank slope from the water line at base flow to the top of the bank. Undercut banks will have a value greater than 90°. Lower bank angles correspond to lower erosion severity ratings (Table 2; Figure 5). Bank angle can be measured using a clinometer; however, the BEHI categories are sufficiently broad that visual estimates are generally adequate.

e. Surface Protection

This metric is an estimation of the average percentage of the stream bank that is covered, and thus protected, by plant roots, logs, rocks, etc. It should be noted that in many cases root density and surface protection are synonymous (Rathbun 2004). The greater the proportion of bank surface that is protected, the lower the erosion hazard rating (Table 2; Figure 5). From the base of the bank, visually estimate the percentage of stream bank that is covered by roots, logs, rocks, etc.

2.3.2 MODERATE TIER – GEOMORPHIC EVALUATION OF EROSION / SEDIMENTATION SEVERITY

2.3.2a Monitoring Design

i. Station selection – Follow the Basic Tier guidelines presented in Section 2.3.1a.

ii. Sampling duration and frequency – In general, follow the Basic Tier guidelines presented in Section 2.3.1a, but note changes in recommended sampling frequency for some variables.

2.3.2b Assessment Variables

The Moderate Tier incorporates geomorphic measurements of erosion severity, sedimentation severity, and channel stability into BMP assessment. The direct quantification of erosion/sedimentation rates and the extent of channel modification is highly valuable for evaluating BMP effectiveness. Much of the observer bias inherent in semi-quantitative methods is eliminated, reducing variability in the data. Further, more powerful statistical analyses can be performed on these data, lending greater confidence to management decisions. The geomorphic methods suggested are all moderate in cost and are relatively simple, although a moderate amount of training and/or experience is recommended for some of the variables. Because the Moderate Tier builds upon the Basic Tier assessments, the techniques presented here are designed so that they can be performed in addition to those in the Basic Tier (Section 2.3.1b).

i. Erosion severity

Bank Erosion Pins – Bank erosion pins are a very simple, low cost method to quantify bank erosion rates. They should be installed at each permanent cross-section according to the following procedure (Figure 6; Rosgen 1996):

a. Drive 2–3 smooth rods (4–5' long, 0.3–0.5" diameter) horizontally into the bank at different elevations, both above and below the water surface.
b. Measure the horizontal distance of pin exposed during each sampling event.
c. Compute bank erosion rates in cm/yr.

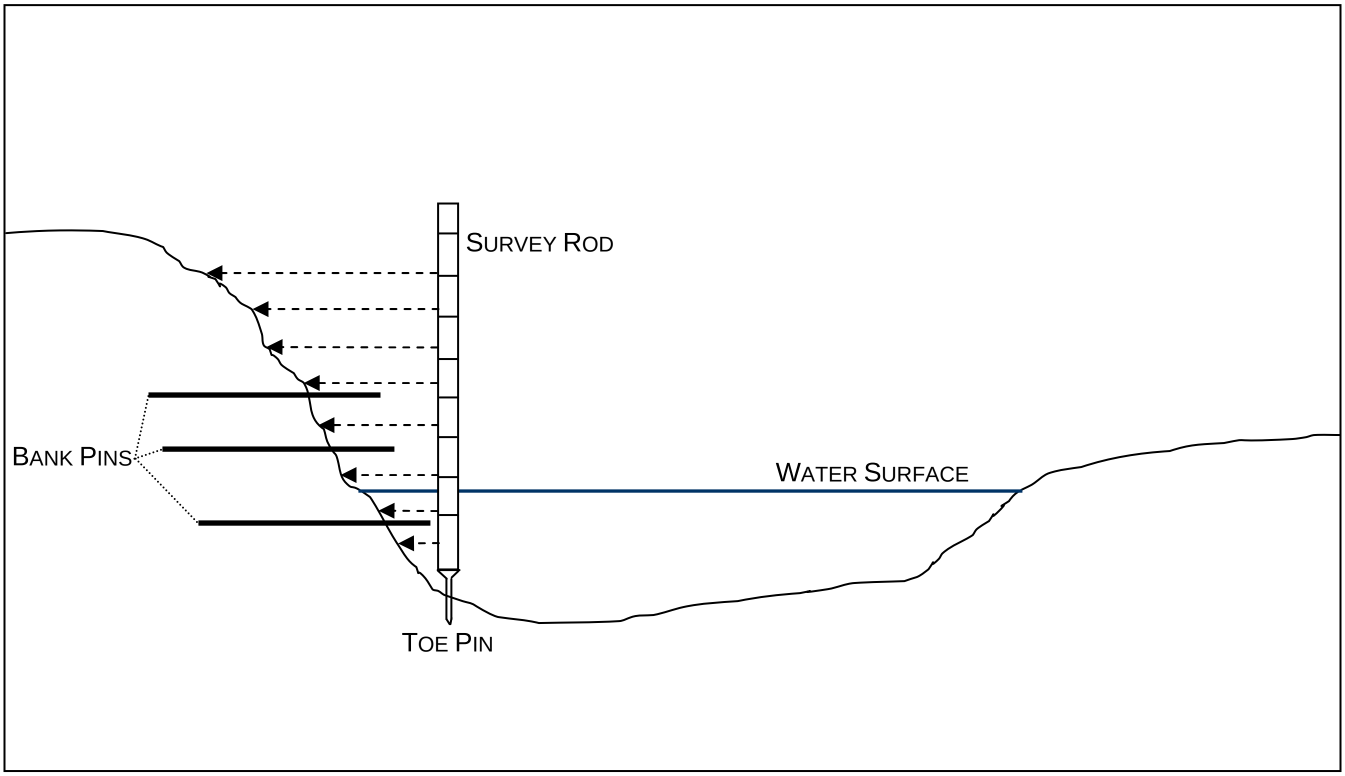


Figure 6: Example of bank pin placement and bank profile measurement. The arrows indicate measurement points for the bank profile. Modified from Rosgen (1996).

Bank Profiles – Measuring bank profiles over time is another low cost, simple technique for detecting changes in bank erosion. Bank profiles should be measured at each permanent cross-section according to the following procedure (Figure 6; Rosgen 1996):

a. Install a permanent toe pin into the bed material at the base of the bank.
b. Place surveying rod on top of the toe pin and use a tripod or frame attached to the bank to hold it in place.
c. Place a rod level on top of the survey rod to ensure it has perfect vertical alignment.
d. With a tape measure or laser measuring device, measure horizontally from the vertical rod to the bank, record this distance, and the height from the survey rod.
e. Repeat measurement at regular, frequent intervals to describe bank dimensions and features.
f. During each sampling event, use the same measurement interval to facilitate comparison.
g. Plot the data to depict the bank profile for each sampling event.
h. Determine the change in bank profile by calculating the difference between measurements at the same location on the bank taken on different sampling days.
i. For each sampling day, calculate the average rate of change in bank profile by dividing the mean difference by the period of time between sampling events.

iii. Channel stability

Longitudinal Profiles – Longitudinal profiles approximate the average slope of features such as the water surface, bed, and bankfull height along a stream reach (Rosgen 1996). This information is important for detecting changes in vertical stability (i.e., aggradation, degradation) and for monitoring the migration of head cuts, which can be an issue especially following sand trap construction (Rosgen 2001b). Creation of longitudinal profiles can be time consuming and training may be required for technicians inexperienced in survey techniques. Harrelson et al. (1994) gives a thorough guide to survey methods for stream assessment. Measure the longitudinal profile of both the upstream and downstream reaches annually according to the following procedure (Figure 7; Rosgen 1996):

a. Place a surveyor's or laser level near the center of the reach.
b. Measure the elevation of the water surface at each permanent cross-section using a surveyor's rod.
c. Measure the distance between cross-sections along the channel. Avoid simply running a tape straight between features without following the channel alignment, as this leads to overestimation of slope.
d. Calculate the average slope between cross-sections (m/m) by dividing the difference in elevation by the distance between cross-sections.
e. Calculate changes in the average slope over time.

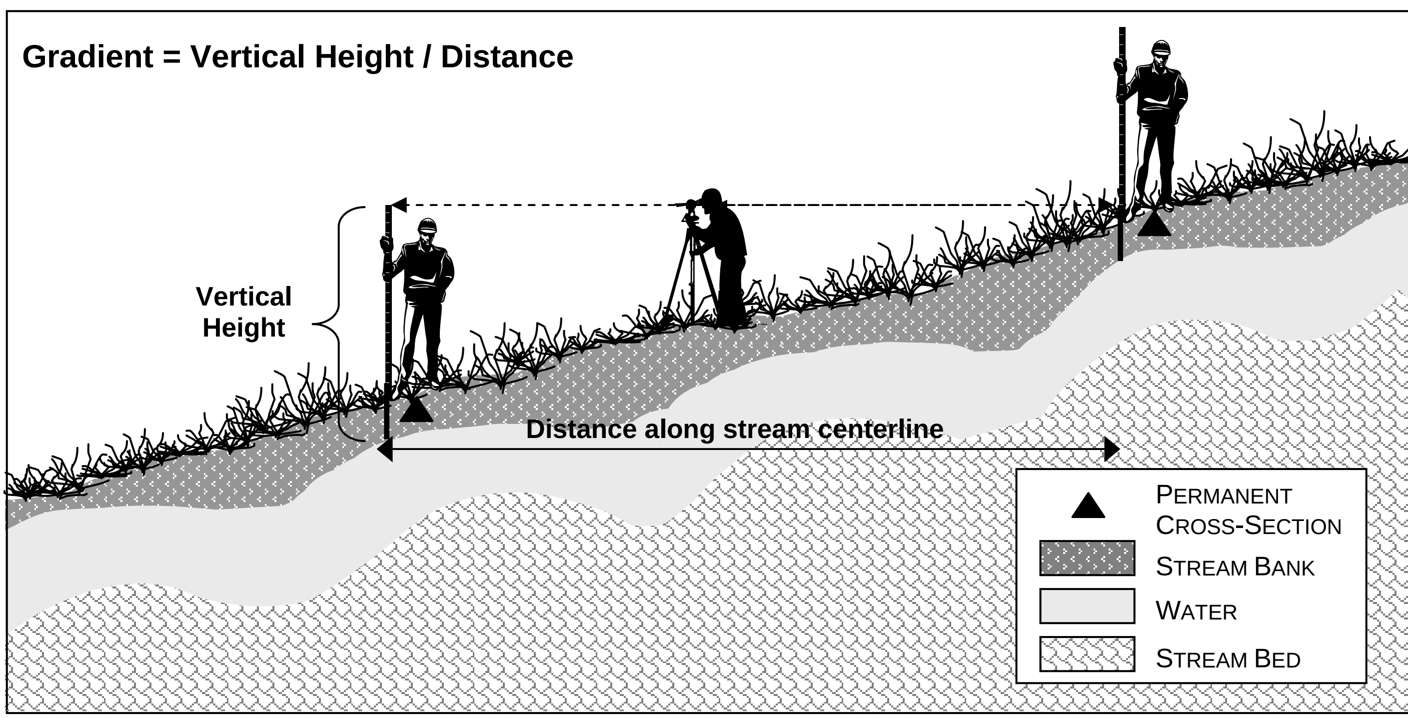


Figure 7: Longitudinal cross-sectional view of a stream, demonstrating the technique for measuring the longitudinal profile of a channel. The riffle-to-riffle gradient is an approximation of the average water surface slope of the reach. Adapted from Rosgen (1996).

Cross-sectional Profiles – Monumented cross-sectional profiles are useful for documenting changes in vertical (i.e., bed) and lateral (i.e., bank) stability. Before measuring the cross-sectional profile, create a benchmark to monument the cross-section. This can be done in various ways, such as by inserting a large bolt or other pin into a concrete-filled hole. Users of this method should check with local agencies to seek approval before installing any permanent benchmarks. Alternatively, a large natural object, such as an embedded boulder, can be used for a benchmark (Harrelson et al. 1994). Cross-sectional profiles should be measured at each permanent cross-section according to the following procedure (Figure 8; Rosgen 1996):

a. Locate the permanent benchmark and stretch a measuring tape across the stream. Affix the tape tightly to the opposite bank at the same elevation as the bench mark.
b. At regular intervals across the channel, read the distance from the bank and the elevation of the rod/tape intercept.
c. Measure features such as the bankfull height, bank height, edge of water, bed features, and thalweg.
d. Plot data to depict the channel profile for each sampling event.
e. Determine the change in channel profile by calculating the difference in elevation and distance from bank for each feature (e.g., riffle, bank height, edge of water) on different sampling days.
f. For each sampling day, calculate the average rate of change in channel profile by dividing the mean difference by the period of time between sampling events.

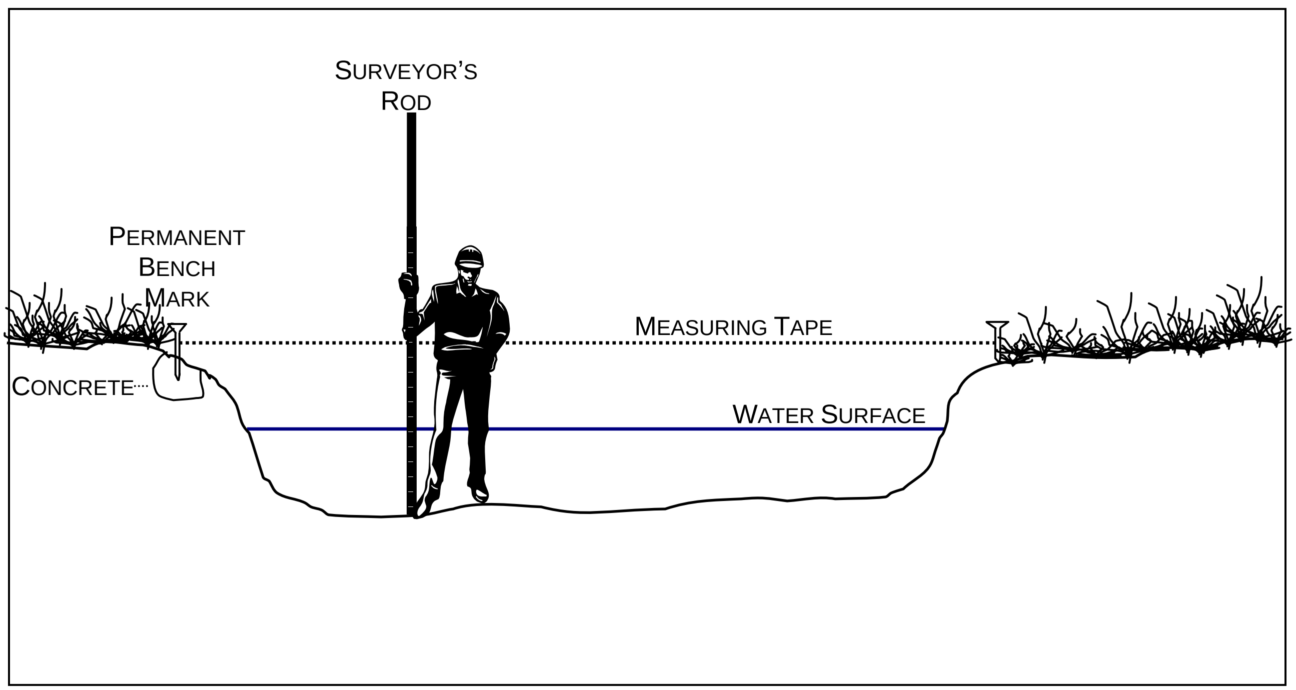


Figure 8: Technique for measuring the cross-sectional profile of a channel. Adapted from Rosgen (1996).

Width/Depth Ratios – Because of its sensitivity to trends in channel instability, the ratio of stream width at bankfull to mean bankfull depth is especially useful to monitor after BMP implementation. As a stream becomes shallower and wider (evidenced by increasing width/depth ratios), its capacity to transport sediment is reduced. At the same time, sheer stress becomes greatest near its banks, thus accelerating bank erosion. This increases the overall sediment supply to the stream and can lead to downstream impacts (Rosgen 1996). Increased width/depth ratios are often an unintended result of restoration attempts (Rosgen 1996). Although determination of width/depth ratios requires training in the recognition of bankfull indicators, it is easily performed in conjunction with cross-sectional profiles. Width/depth ratios can be measured at each permanent cross-section according to the following procedure (Rosgen 2001b):

a. Using the permanent bench mark established for the cross-sectional profile, stretch a measuring tape across the channel and affix it tightly to the opposite bank at the same elevation.
b. Record the channel width at bankfull stage.
c. Using a surveyor's rod, read the bankfull depth at regular intervals across the channel.
d. Calculate the width/depth ratio by dividing the bankfull width by the mean bankfull depth.
e. Analyze trends in width/depth ratios over time. In general, trends of increasing width/depth ratios indicate a decreased ability for a stream to move sediment. Bank erosion is commonly accelerated as width/depth ratios increase (Rosgen 1996).

Scour Chains – Installed vertically in stream beds, scour chains (Figure 9) provide measured depths of scour and fill of bed material (Rosgen 1996). They should be installed at each permanent cross-section and re-measured periodically as follows (Bigelow 2003):

a. Create a pilot hole with a sledge hammer and drive rod.
b. Remove drive rod and insert a smaller probe, with scour chain attached to bottom, into the pilot hole.
c. Scour chain should have a "duckbill" anchor attached to the bottom that can be inserted vertically into the hole.
d. Tap probe to the bottom of the pilot hole with hammer.
e. Pull the probe out of the hole and pull up on the chain to rotate duckbill to a horizontal position, anchoring the chain in place.
f. Use a metal detector to help re-locate scour chain, if necessary.
g. Measure exposed chain, if scour has occurred.
h. If the chain is buried, dig down to the chain and measure the depth of fill. If the chain is laid over 90 degrees, then a combination of scour and fill has occurred. Measure the length of chain from the point at which it bends to determine the depth of scour (Figure 9).

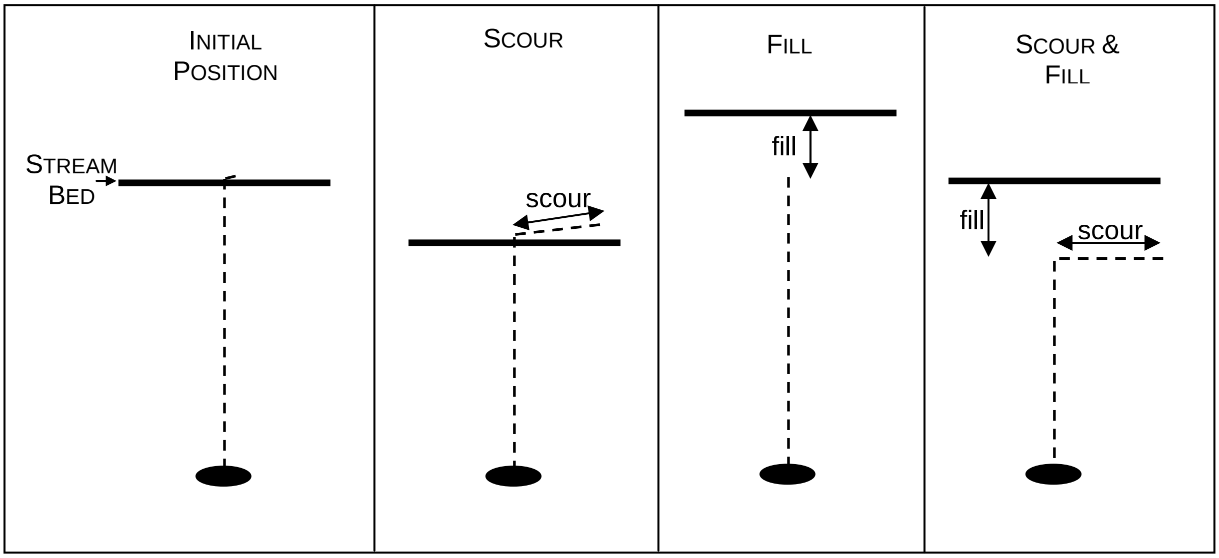


Figure 9: Use of scour chains to measure scour and fill depth of bed material. Arrows indicate points of measurement. Adapted from Bigelow (2003).

iv. Concurrent measurements

To complement the geomorphic assessments, discharge should be measured at each permanent cross-section. Measure discharge according to the velocity-area method (for stream discharge methods, see U.S. EPA 2004b).

2.3.3 ADVANCED TIER – SEDIMENT LOAD ESTIMATION

2.3.3a Monitoring Design

i. Station selection – Follow the Basic Tier guidelines presented in Section 2.3.1a.

ii. Sampling duration and frequency – As in the Moderate Tier, the Advanced Tier sampling strategy is based in general on the guidelines described for the Basic Tier (Section 2.3.1a), but also includes storm chasing to detect high flow conditions and to reduce error in annual load estimations (Robertson 2003). In addition to the monthly sampling prescribed for the Basic and Moderate Tier assessments, the Advanced Tier variables should be measured during storm events for 1 year prior to, and 2 years following, BMP installation.

The inherent variability in flow and sediment transport lends considerable error to sediment load estimation. Robertson (2003) reported that even with the best sampling strategy, up to 40 percent error is possible in mean, median, and maximum suspended sediment estimates; regression analysis resulted in a minimum of 30-50 percent error in annual load estimates. The Michigan Department of Environmental Quality (MDEQ 2004) estimates that 200 samples per year are required to detect a real change of 10 percent in suspended sediment loads in stable streams; the annual sampling burden increases to 1500+ for flashy streams. For most monitoring projects, such intensive sampling is not practical. The aim of this methodology is to provide a baseline recommendation for acquiring sediment load data that is realistic and also yields useful scientific information.

2.3.3b Assessment Variables

The Advanced Tier incorporates measurements of suspended and bedload sediment into BMP assessment. When coupled with geomorphic measurements of channel stability, direct measurement of sediment load provides a powerful indication of erosion control BMP effectiveness (Rosgen 1996). The strength of measured suspended and bedload sediment lies in the analysis of sediment rating curves, which are valuable for detecting changes in channel stability following restoration attempts (Figure 10; Beschta 1996, Rosgen 2001a).

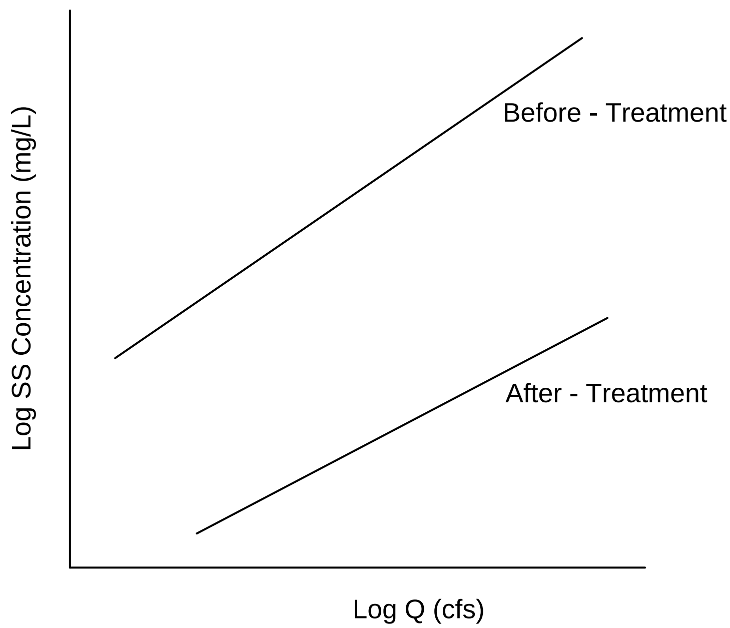


Figure 10: Hypothetical example of sediment rating curves, showing the relationship between suspended sediment (SS) and discharge (Q) for a treatment reach before and after BMP installation.

This level of monitoring will provide the most robust data for determining BMP effectiveness, but also is the most time and cost intensive. The methods presented here are simple, however, and require little training. The Advanced Tier builds upon the Basic and Moderate Tier assessments; therefore, the techniques presented here are designed so that they can be performed in addition to those in the previous tiers (Sections 2.3.1b, 2.3.2b).

i. <u>Suspended sediment load</u>

Stream type will determine the most appropriate sampling method for total suspended solids estimation. Two options are presented below. Choose the technique that fits the site conditions and collect samples at each permanent cross-section.

Grab Sample – When used in appropriate situations, this procedure may provide an adequate representation of suspended sediment concentration. This method is appropriate **only** in shallow (≤ 0.5 m), well-mixed streams. The benefit of grab samples is that they are substantially easier and faster (i.e., cheaper) to collect than depth-integrated samples (described below). However, grab samples are insufficient for determining suspended sediment concentration in most streams (Beschta 1996). If you are considering using this method at a site, we recommend first comparing samples collected using both the grab sample and depth-integrated sample techniques. To collect a grab sample, simply hold an open sample bottle under the water surface.

Depth-Integrated Sample – Depth-integrating samplers composite the entire water column at a given point along a cross-section, thereby accounting for changes in suspended sediment that commonly occur with depth. They are most useful in wadeable streams, however heavier models are available that can be used in deeper streams. Davis (2005) provides an excellent guide for selecting the depth-integrated sampler most appropriate for site characteristics. Collect depth-integrated samples according to the following procedure (Beschta 1996):

a. Stretch a measuring tape across the stream and divide the wetted width into several equal width segments. For small streams, 3-5 segments are usually adequate.
b. At the midpoint of each subsection, take a subsample for suspended sediment. Orient the nozzle of the sampler upstream and lower it to the stream bed and back up to the water surface at a uniform rate. The sample bottle should be ⅔ to ¾ full. Be careful not to overfill the bottle.
c. Subsamples may be composited into a single sample that represents the average suspended sediment concentration for the cross-section. However, care must be taken to raise and lower the sampler at the same rate for each subsample.
d. Alternatively, subsamples may be analyzed separately and used to calculate the average suspended sediment concentration for the cross-section.
e. Measure stream discharge.
f. Analyze samples in the lab using gravimetric procedures.
g. Calculate the following:

    1. Suspended Sediment Concentration (C), expressed in mg/L:

    $$C = \frac{M_S}{V_S} \;;$$

    where M_S is the mass of sediment and V_S is the volume of sample analyzed.

    2. Sediment Yield (Y_S), expressed in kg/day, mt/year, etc.:

$$Y_S = C \times Q \times T_p \;;$$

where C represents the average sediment concentration over the time period; Q, average stream discharge over the time period; T_p, period of time.

h. Create sediment rating curves (Figure 10).

ii. Bedload sediment

Coarse sediment is more sensitive to energy requirements than fine sediment, making bedload measurement critical for assessing stream stability (Rosgen 1996). The Helley-Smith pressure differential sampler is the conventional equipment for collecting bedload samples. However, excellent results have been reported for core samples taken annually from the same riffle location (Rosgen 2001b). Such samples are useful for showing shifts in particle size distribution of bedload. The procedure outlined below is for use of the Helley-Smith sampler, but core samples can be taken as an alternative if time or money are lacking.

Collect bedload samples at permanent cross-sections according to the following procedure (Beschta 1996):

a. Record the wetted width of the channel.
b. Collect bedload subsamples for compositing at the same subsection midpoints used for sampling suspended sediment.
c. Lower the sampler quickly through the water column and place it firmly on the stream bed.
d. Leave the sampler in place for a specific amount of time. Sample time depends on the amount of bedload in transport. Thirty seconds or less may be adequate. The sampler should remain on the stream bed for the same length of time for each subsample.
e. Record this time.
f. Raise the sampler quickly out of the water. The sampler should be no more than 20-25 percent full.
g. Empty the subsample into a container and rinse the sampler bag with stream water.
h. Continue to the next midpoint and repeat steps c-g.
i. Record the number of subsamples collected.
j. Measure stream discharge.
k. Analyze samples in the lab for total dry mass and grain size distribution using gravimetric procedures and sieving, respectively.
l. Calculate the following:

    1. Total Bedload Mass (M_b), expressed in kg:

       This is simply the dry weight of the sample.

2. Instantaneous Bedload Transport Rate (Q_b), expressed in kg/s:

$$Q_b = \frac{M_b}{T} \times \frac{1}{N} \times \frac{W}{0.076 \text{ m}} \;;$$

where M_b is the total mass of bedload sediment in kg; T, subsample duration in s; N, number of subsamples; W, wetted width of the channel in m; 0.076 m represents the width of a 3x3" Helley-Smith sampler opening.

m. Create weight-based cumulative distribution curves (Figure 4).

3. Data Analysis Example

As noted previously, applying the appropriate statistical analysis to BMP assessment data is crucial for understanding the effectiveness of a restoration project. In this section, we provide an example showing how BMP assessment data can be analyzed statistically. This example is meant solely for illustrative purposes.

Our example uses hypothetical substrate embeddedness data (Table 3) to which we apply an unreplicated (i.e., one stream; Figure 2), BACI analysis (Stewart-Oaten et al. 1986). As with many statistical techniques, there are potential limitations associated with this approach. One of our key assumptions is that replication through time results in statistically-independent samples, which then can be analyzed with the BACI approach. It is possible to argue that environmental conditions that existed during a previous sampling event are still influencing the responses being measured in a future sampling event, and therefore that samples taken over time from the same location are not truly independent of each other. Statistical independence and true replication are important considerations of a rigorous experimental design (cf. Hurlburt 1984), and users of this document should consult a statistician or have expertise in the subject **before they start their assessment program,** to ensure that their statistical analysis is appropriate given their experimental design. If resources allow, a replicated BACI design that incorporates multiple streams, each having replicated sampling designs focusing on the same BMP, will be the optimal and most statistically-powerful approach.

In the example presented below, we use embeddedness data, but all of the assessment variables presented in this methodology can be analyzed in a similar fashion. However, if the data represent simple counts (e.g., invertebrate counts, pebble counts), a Mann-Whitney U-test should replace the Student's t-test. Like all ratios, the raw data for embeddedness are percentages (Table 3). These data are not normally distributed, so we transform them (by taking the square root of each value and then converting it to its arcsine), as shown in columns 5 and 6 of Table 3. The BACI design focuses on differences between the treatment site and the control through time; therefore, the statistical analysis will be conducted on these differences (column 7 of Table 3). For each observation, we subtract the treatment data from the control data.

Table 3. Embeddedness data at an upstream control and a downstream treatment site. Data are presented as raw, transformed, and the difference between treatment and control for transformed values. See text for more detail.

Time	Month	Control (raw data)	Treatment (raw data)	Control (arcsin-square root transformed)	Treatment (arcsin-square root transformed)	Difference (Control minus treatment)
Before	1	60%	72%	50.77	58.05	-7.28
	2	62%	74%	51.94	59.34	-7.40
	3	64%	68%	53.13	55.55	-2.42
	4	61%	69%	51.35	56.17	-4.81
	5	58%	64%	49.60	53.13	-3.53
	6	57%	70%	49.02	56.79	-7.77
	7	56%	73%	48.45	58.69	-10.25
	8	45%	77%	42.13	61.34	-19.21
	9	58%	68%	49.60	55.55	-5.95
	10	59%	71%	50.18	57.42	-7.23
	11	60%	73%	50.77	58.69	-7.93
	12	63%	71%	52.54	57.42	-4.88
After – Yr 1	1	72%	80%	58.05	63.43	-5.38
	2	68%	79%	55.55	62.73	-7.18
	3	61%	80%	51.35	63.43	-12.08
	4	58%	82%	49.60	64.90	-15.29
	5	54%	76%	47.29	60.67	-13.37
	6	60%	58%	50.77	49.60	1.17
	7	64%	60%	53.13	50.77	2.36
	8	63%	65%	52.54	53.73	-1.19
	9	67%	66%	54.94	54.33	0.61
	10	58%	68%	49.60	55.55	-5.95
	11	59%	64%	50.18	53.13	-2.95
	12	60%	68%	50.77	55.55	-4.78
After – Yr 2	1	62%	62%	51.94	51.94	0.00
	2	65%	58%	53.73	49.60	4.13
	3	69%	54%	56.17	47.29	8.87
	4	67%	57%	54.94	49.02	5.91
	5	64%	52%	53.13	46.15	6.98
	6	62%	45%	51.94	42.13	9.81
	7	58%	46%	49.60	42.71	6.90
	8	63%	57%	52.54	49.02	3.51
	9	67%	41%	54.94	39.82	15.12
	10	64%	43%	53.13	40.98	12.15
	11	62%	42%	51.94	40.40	11.55
	12	67%	41%	54.94	39.82	15.12

When we compare the before-differences with the Year 1 after-differences using Student's t-test, we obtain the following results (Table 4):

Table 4: Results of Student's t-test between the before data and the Year 1 after data calculated using Systat v8.

	n	mean	SD
Before	12	-7.388	4.296
After – Year 1	12	-5.336	5.823
	t=-0.983	df=22	p=0.337

The results as shown in Table 4 are not statistically significant ($p > 0.05$). Therefore, we conclude that the BMP did not significantly decrease substrate embeddedness. Further inspection of our data reveals the reason for the insignificance. It appears that for the first five months after BMP installation, embeddedness actually increased at our treatment site (Table 3). Next, we compare the before-differences with the Year 2 after-differences in the same manner as above (Table 5).

Table 5: Results of Student's t-test between the before data and the Year 2 after data calculated using Systat v8.

	n	mean	SD
Before	12	-7.388	4.296
After – Year 2	12	8.338	4.667
	t=-8.588	df=22	p=0.000

In this comparison, our results are statistically significant ($p < 0.05$) so we can conclude that our BMP did in fact result in lower substrate embeddedness, and is working as intended. Our example illustrates the importance of maintaining a monitoring program for longer than one year; if we had stopped sampling after one year, we might conclude that the BMP was ineffective. However, in this example, it took two years for the effectiveness of the BMP to be realized. Continued monitoring of embeddedness is recommended to identify future changes in stream structure.

4. Summary

River restoration is receiving increased attention in terms of its ecological impacts, as well as a business niche (Lavendel 2002, Malakoff 2004). Although the number of river restoration projects has increased exponentially over the past decade (Bernhardt et al. 2005), only ~10% of those projects appeared to include any form of assessment or monitoring, according to the National River Restoration Science Synthesis database (http://nrrss.nbii.gov). Failure to assess or monitor the effects of restoration projects precludes our ability to learn from successes and failures, and thereby to develop best practices for the future. This failure to assess is astonishing given current estimates that >$1 billion per year is being spent on river restoration projects in the continental United States (Bernhardt et al. 2005). Interestingly, most of these restoration projects are relatively small in scale (implemented on <1 km of stream length), although a few huge projects account for a disproportionately large amount of the total dollars expended.

Bernhardt et al.'s (2005) analysis indicates that assessment is rarely integrated into river restoration projects. However, their analysis, coupled with a recent set of recommended standards for successful river restoration (Palmer et al. 2005), make it clear that monitoring and assessment are critical components of restoration. Indeed, one of the five criteria that Palmer et al. (2005) proposed for measuring success explicitly notes that both pre- and post-restoration assessment must be completed and be made available to the public.

The call for pre- and post-restoration assessment is an important step, but if the assessment process is done without rigor, the conclusions drawn from the project may be erroneous and lead to inappropriate management recommendations. This, in turn, can lead to management practices that harm the resource, as well as negative public perceptions of the resource manager's credibility. The goal of the current report is to provide an outline of how to assess the success of erosion control BMPs that combines both flexibility and rigor.

Table 6 summarizes the hierarchical approach laid out in this report. Depending upon the resources available for assessment, and the questions that need to be answered, we provide three levels of effort: basic, moderate, and advanced. Each build on their predecessor, and include a variety of techniques that allow the practitioner to decide which methodology works best for their system. We also provide explicit examples of how the collected data can be analyzed. These examples are included for illustrative purposes only, but they identify potential pitfalls to be wary of during the analytical phase of the study. We recognize that no single document can be designed to cover all contingencies, as each restoration project is different and each site has unique features. However, by 1) basing assessment on sound science and experimental design, 2) building flexibility into the assessment process; and 3) providing specific examples of how an analysis can be conducted, we believe this document provides a strong foundation on which to build an assessment framework.

Table 6: Summary of variables for assessing erosion control BMP effectiveness for Basic, Moderate, and Advanced Tiers.

BMP Assessment Techniques		**Basic**	**Moderate**	**Advanced**
GEOMORPHIC-VISUAL	Bank Hazard Erosion Index (BEHI)	x	x	x
	Wolman Pebble Count	x	x	x
GEOMORPHIC-MEASURED	Bank Erosion Pins		x	x
	Bank Profiles		x	x
	Longitudinal Profiles		x	x
	Cross-sectional Profiles		x	x
	Scour Chains		x	x
	Width/Depth Ratios		x	x
OTHER	Discharge		x	x
SEDIMENT LOADING	Suspended Sediment			x
	Bedload Sediment			x

5. Acknowledgements

We are very grateful to Joe Rathbun (MDEQ), John Suppnick (MDEQ), Andy Nuhfer (MDNR), Stephanie Ogren (Little River Band), and Kim Balke for their insightful and constructive comments on a draft version of this report.

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