

Stream Bank and Bed Stability Assessment Protocol

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Introduction

Streambank erosion is often part of equilibrium stream processes resulting from lateral migration stream meanders down valley over time. In this setting the coarse material eroded from the banks is generally deposited downstream in point bars resulting in a rough balance between erosion and deposition over time (Knighton 1998). However, disturbance to streams from land use change and the resulting changes in runoff hydrology, channel straightening, and flood impacts can lead to conditions in which banks become unstable and are a net source of sediment to a stream channel, exceeding its natural balance. In fact, sediment from bank erosion under these situations has been cited as one of the leading sources of fine sediment to streams in the U.S. (EPA 2009).

This stream bank and bed stability assessment protocol has been developed to rapidly assess factors contributing to channel stability and identify which areas along a stream reach have the greatest amount of active erosion or are at the greatest risk of future erosion. It also considers the stability and effectiveness of channel restoration structures as a post-restoration monitoring class. Each sub-reach (100-200 feet) is evaluated for bed and bank material properties, bank slope and vegetation coverage, as well as evidence of active bed and bank erosion. An aggregated score is calculated for each sub-reach allowing one to identify which sub-reaches pose the greatest concern to channel stability along the reach as well as identify what factors contribute to this. Finally, this protocol can be used for repeated assessments to monitor change over time and compare pre- and post-restoration results in a manner that allows for targeted maintenance treatments necessary to address project goals.

We begin this protocol with background information on channel stability and instability processes. We follow with a description of the protocol, and end with a discussion on interpreting the results.

Background

Many models of channel evolution in response to a disturbance exist. One intuitive model introduced by Schumm et al. (1984) describes the series of stages a channel may go through in response to a disturbance such as channelization, urbanization, or flooding (Figure 1). Beginning with Stage III, post disturbance, channel incision occurs by degradation (incision) of the channel bed and migration of head cuts (break in slope in erodible material) upstream. This increases the heights of the banks, reduces their stability, and can lead to enhanced scour at the toes of the banks. Bank erosion and failure result and the

channel widens (Stage IV). As the channel widens, the erosive force of the flow dissipates, deposition of sediment results (aggradation), and a new floodplain begins to form within the incised channel (Stage V). Over a period of time (10 to > 100 years depending on the flow regime, vegetation, and bed and bank material) a new stable channel forms (Stage VI). Bank erosion resulting from channel instability may be observed along Stages III to V.

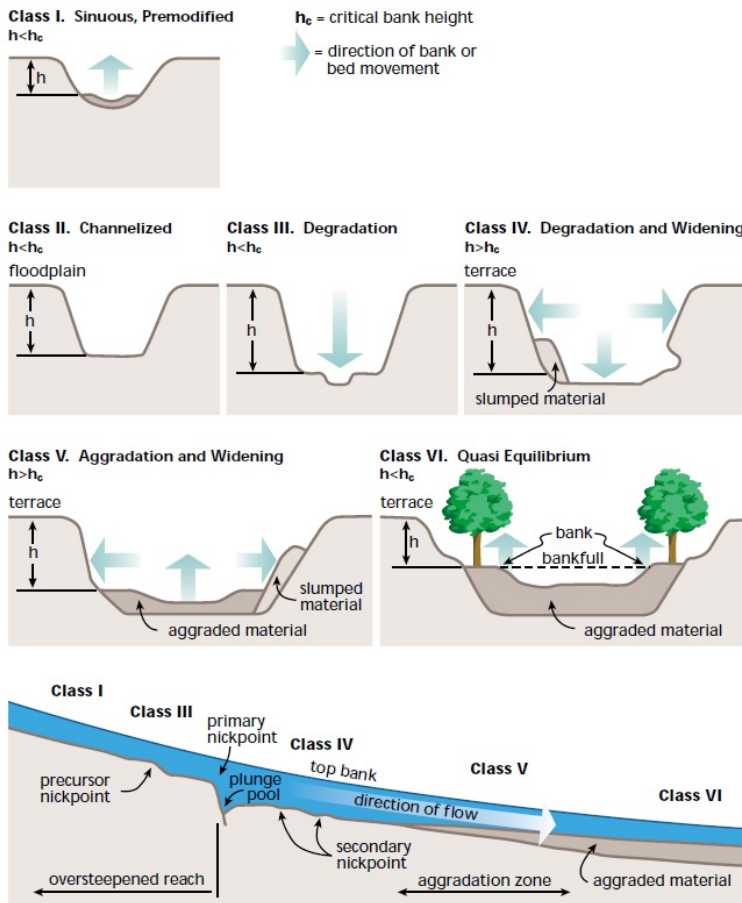


Figure 1. Channel evolution model following a disturbance (FISWRG 1998), modified from Schumm et al. (1984).

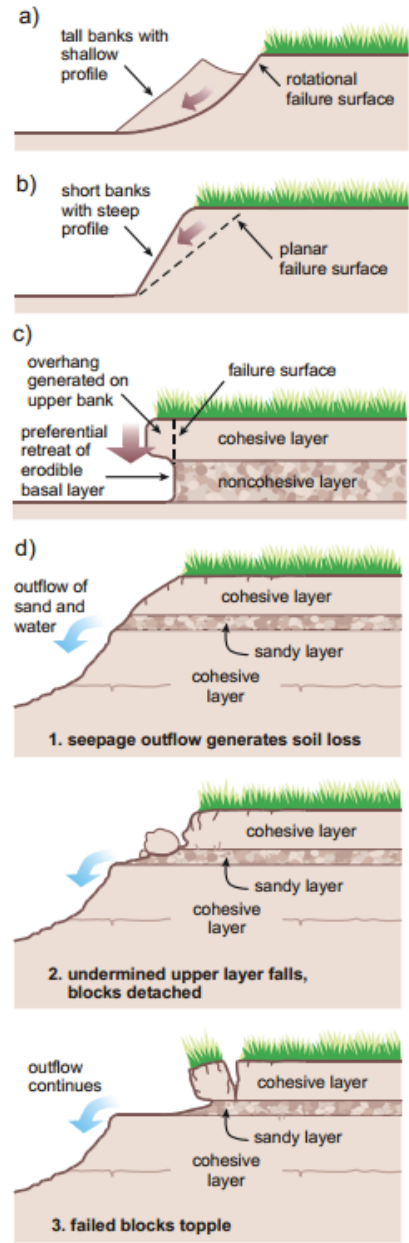


Figure 2. Bank failure mechanisms: a) rotational failure, b) planar failure, c) cantilever failure, d) piping or sapping failure from groundwater. (FISWRG 1998), modified from Hagerty (1991).

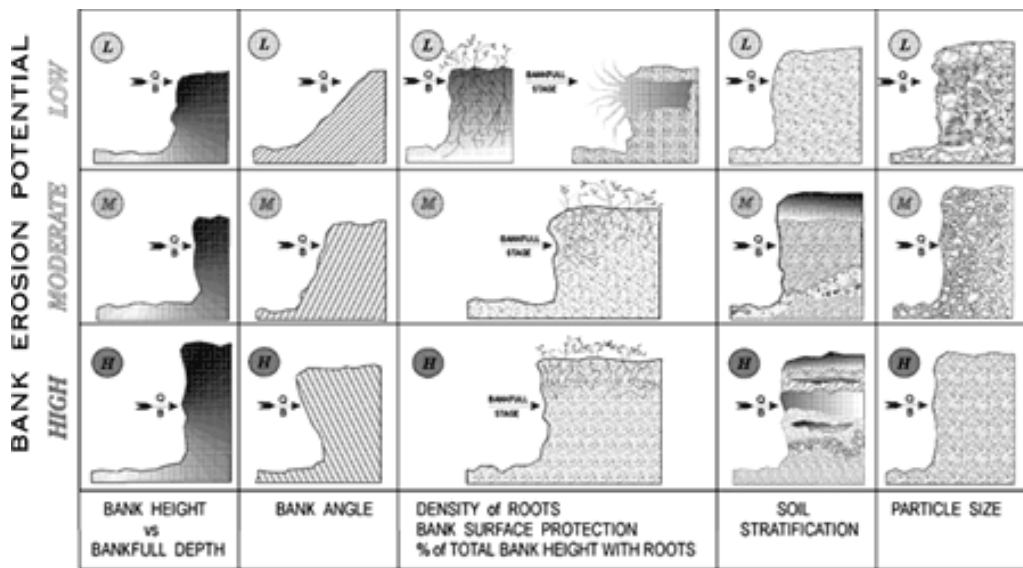


Figure 3. Bank erosion potential diagram as function of various factors. Arrows indicate bankfull height (Rosgen 2006).

Loss of bank material to the channel occurs by two primary processes that work in tandem: slope instability and erosion. Slope stability is a geotechnical property of banks that involves the type of material comprising the banks, the angle of the banks, pressure from groundwater entering the banks, as well as the amount of roots in the bank. All materials have a natural “angle of repose” below which they are stable. Besides bedrock, cohesive bank materials such as silty and clayey soils have the largest stable angle of repose because of the inter-particle cohesion inherent in this material. However, they are susceptible to mass wasting or the loss of large chunks of bank material when they become geotechnically unstable (Haggerty 1991, Simon et al. 1999) (Figure 2a & b).

Scour at the toe of cohesive banks can lead to undercut banks and bank slumping or mass wasting (Figure 2c). Non-cohesive materials such as sand up through cobble material have lower angles of repose, with sand having the lowest. This means that for a sandy bank to be stable it must have a shallow angle. In deeply incised channels and gullies, the groundwater table may intersect the bank. Pressure in the pore space of bank material from this groundwater can reduce the stability of the bank and assist in bank failure (Figure 2d). Finally, roots from vegetation growing on the bank face and on the floodplain just beyond the bank face greatly assist in increasing the tensile strength of the bank. Dense shallow-rooted vegetation such as grasses can prevent erosion of the bank face, but do not contribute greatly to enhancing tensile strength, while deep-rooted woody vegetation (i.e., willows, cottonwoods, and other shrubs and trees) are most effective at increasing the tensile strength of the bank (Figure 3, middle column).

Bank erosion involves the properties of the bank sediment as well as the hydraulic (flow) conditions along the bank face. Bank material erodibility (susceptibility to erosion) tends to follow the angle of repose trends of different bank materials previously discussed with sand being the most erodible of non-cohesive sediments. The erodibility of cohesive sediments falls between sands and gravels and is a

function of the relative percentages of sand, silt, and clay, as well as organic matter. Soils with larger percentages of sands and silts and lower percentages of organic matter tend to be more erodible (Schwab et al. 1981). Banks may have horizontal layers of different types of material each with different degrees of proneness to erosion (soil stratification, Figure 2, 3).

Flow hydraulics near the bank also play an important role in erosion. Shear stress in flowing water—the friction-like stress working parallel to the bank and responsible for scour—is concentrated along the channel bed and toe of the bank. This can lead to toe scour, and cantilevered (undercut) banks, which are more susceptible to geotechnical failure, as described above (Figure 2c). Meandering channel form concentrates shear stress on the outside of meander bends resulting in a steeper “cutbank”, which can be very steep in incised channels, eventually becoming unstable.

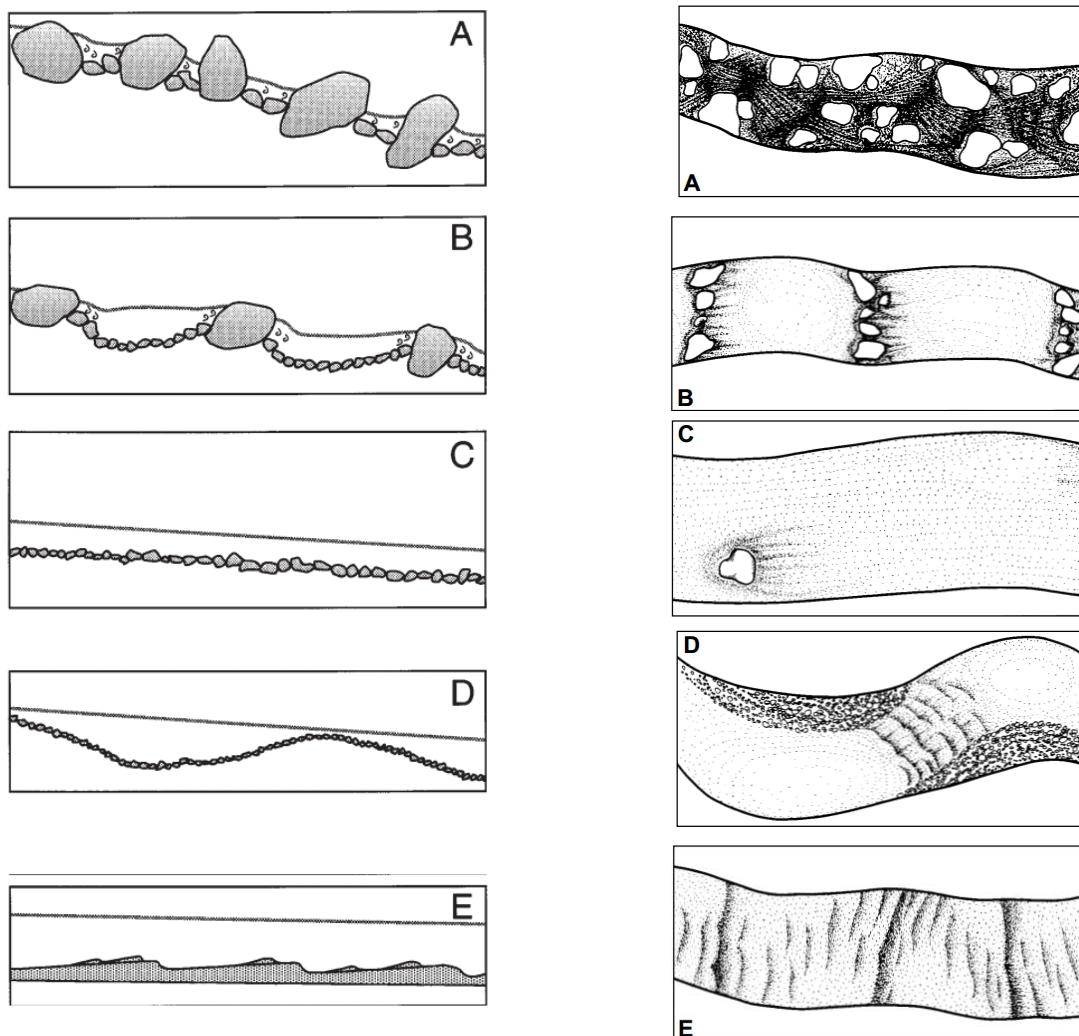


Figure 4. Channel morphologies and bedforms for mountain rivers. Longitudinal profile in left column, and planform view in right. (A) cascade; (B) step pool; (C) plane bed; (D) pool riffle; and (E) dune ripple. (Montgomery and Buffington, 1997). Reprinted under GSA Bulletin’s Fair Use Policy.

Channel bed stability also plays an important role in overall stream stability and influences bank stability. Channel incision can lead to steeper banks and more concentrated flow, both of which contribute to bank instability and erosion. Bed material in most perennial natural channels is for the most part non-cohesive, that is, it is composed of sediment deposited by flow from upstream. Channel beds are often a mixture of many grain sizes ranging from purely sand and sand and gravel mixtures, up to boulder and cobble dominated beds (Figure 4). As a rule: the steeper the channel the coarser the bed material. This model excludes gullies and other channels that form in cohesive soils in dry climates.

While finer bed channels may be more susceptible to vertical incision, streams with fine beds tend to have mild slopes, and less vertical relief to erode. Steeper channels with coarser material are also susceptible to incision, especially where large boulders are lacking to provide grade control. Evidence of active incision often comes in the form of headcuts (or knickpoints), which are steps or discontinuities in the slope of the bed. Headcuts migrate upstream as their faces erode until they encounter a vertical grade control such as boulders or bedrock (Figure 1). They serve to reduce channel slope and erosive energy allowing a channel to adjust to the disturbance that initiated this vertical instability. A range of natural mountain stream types is shown in Figure 4, above.

A final consideration of channel stability concerns the stability and quality of installed grade control, habitat enhancement, and bank protection structures, otherwise known as restoration treatments. Hard engineering approaches such as rip-rapped banks and grade control vanes can be undermined or circumvented by erosion processes. Bank bioengineering treatments such as planted erosion control fabric, live stakes, and use of wood installed along the bank toe can fail if subjected to high flows before plant establishment or if installed improperly. These examples of restoration treatment failures are not exhaustive, and it is outside of the scope of this protocol to discuss different stream restoration treatments and their failure mechanisms. However, part of this protocol involves assessing the integrity of these structures as described below.

Assessment Protocol

This stream bank and bed assessment protocol was developed to allow a field crew of one to two people assess the stability of a stream reach rapidly, thoroughly, and in a spatially explicit manner so that stability concerns may be identified and located along a reach. The field team will ideally comprise at least one person with experience in fluvial geomorphology and another with experience in field botany/ecology. Factors leading to bank stability (or risk of instability) included in this protocol are: bank and channel material composition, bank angle, bank and riparian vegetation type and percent coverage, evidence of active or recent bank erosion, channel bed composition, bed morphology, and evidence and severity of recent vertical incision.



Figure 5. Example of mapped stability scores

This protocol was designed to allow inter-annual comparison and tracking changes over time, possibly after a restoration effort. It is largely a visual assessment, conducted along a 100 – 200 ft sub-reach within which channel and bank information is aggregated. The length of the sub-reach may vary according to the channel size, but its length should be on the order of 10 to 20 times the bankfull width of the channel (floodplain edge to floodplain edge). Each category of the stability assessment may be evaluated separately to identify specific factors leading to stability issues within a sub-reach or along the entire project reach. These factors are also aggregated to identify unstable sub-reaches within the larger reach. For example, lack of bank and riparian vegetation may be a leading cause of risk of instability along the project reach. Bank instability may only be an issue for select areas within a project reach, and not a pervasive problem. This assessment protocol will aid in identifying each of these.

The general assessment procedure involves laying a measuring tape along a stream bank for the specified length of the sub-reach and characterizing bed and bank properties along this sub-reach. A handheld GPS may be used to mark the starting point of each sub-reach as well as the location of any failed stream restoration structures. Stream stability information may be later incorporated into a GIS database allowing the stability metrics to be mapped (Figure 6). Photos should be taken in the middle of each sub-reach (upstream, downstream, leftbank, right bank), as well as of any noteworthy observations, such as a particularly severe example of erosion or a failure restoration structure. In addition to using the accompanying field sheet to document each sub-reach, notes should be taken of the photo numbers, any waypoints collected on the GPS, as well as one to two sentences of narrative describing the sub-reach.

Below is a description of each assessment category. NOTE: if specific metrics listed below differ from those in the SSA field sheet, the metrics in the field sheet should take precedence. The monitoring program manager may alter the metrics (i.e., cover categories) as necessary to meet specific project goals or to reflect monitoring resources/expertise.

Bank Composition

Visually and tactilely (i.e., using your hands) assess the relative size of the bank material. Assign percent of sub-reach length to each material category. Note that cohesive banks are composed of soil, which has a certain percentage of silt and clay. Non-cohesive banks lack silt and clay, though can be a mixture of sands, gravel, cobbles, etc. Table 1 contains descriptions and lengths associated with each sediment class. If using the Daubenmire or Line-point-intercept method to measure vegetation, you may also measure bank composition using that same method.

Table 1. Grain size descriptions

	<i>Cohesive</i>	<i>Non-Cohesive</i>			
<i>Type</i>	<i>Silt / Clay (soil)</i>	<i>Sand</i>	<i>Gravel</i>	<i>Cobble</i>	<i>Boulder</i>
<i>Grain Size</i>	< 0.062 mm	0.063 to 2 mm	2 to 64 mm	64 to 256 mm	256 + mm
<i>Description</i>	Fine texture, cohesive, smooth when rubbed between fingers	Fine sugar to kosher salt sized particles	Peppercorn to egg sized	Baseball to grapefruit sized	Melon sized and larger

Bank Angle

The bank angle categories are as follows: *Mild* (0°-30°), *Moderate* (30°-60°), *Steep* (60°-90°), and *Overhang* (> 90°). Evaluate percent of each sub-reach having each bank angle category.

Vegetation: Bank and Riparian Zone

A plotless cover estimate method (visual estimate of vegetation cover in the entire survey reach) may be used to estimate vegetation cover, by aerial cover (Figure 7). In this cover estimate, the gaps between leaves of a given plant are imagined to be part of the entire canopy of the plant, and it is the canopy cover that is estimated. The plotless cover estimate approach requires some vegetation monitoring experience and/or an effective calibration before beginning the process. To calibrate the observers' eyes, follow a line-intercept procedure (Herrick et al., 2005) over a representative 100-foot section of bank, measuring the cover classes below as first hits (i.e., no ground cover below a leaf will be recorded, and no leaf cover below the first hit leaf will be recorded).

Once your eyes are calibrated, assess percent of bank and stream edge (riparian zone) covered by *ground cover* (soil, rock, and/or organic litter), *herbaceous vegetation* (grasses, sedges, rushes, forbs, etc.), *shrubs*, and *trees*. The bank cover estimate addresses the zone between the toe of the bank (under water during bankfull flow) and the top of bank (i.e., the edge of the overbank zone). See Figure 6 for typical representation of various riparian zones. The "overbank" riparian area is the area adjacent to the top of bank, which is inundated every 3-5 years by floodwaters. Because we are interested in the influence of the overbank zone on bank stability, we assess cover of the overbank zone only within 30 feet the bank. If the overbank zone is less than 30 feet wide, then your assessment area will be the width of the entire overbank zone.

If a plotless method to estimated vegetation cover is not feasible, use of a standard vegetation cover method (Daubenmire, line-point intercept, etc.) to calculate cover. The key is to be consistent over time and among observers in order to provide usable data. If using Daubenmire, standard cover classes are recommended, rather than trying to estimate cover to nearest 1%. If using a visual estimate over cover over the entire transect, avoid looking upstream to assess vegetation coverage, as oblique visual assessments of vegetation cover often lead to gross cover overestimates. Rather, walk the bank while looking down and note the percent cover for that transect (measured distance of the cover for each vegetation category divided by the total transect length). A greater level of experience is needed to use the plotless visual estimate of vegetation cover. For instance, if a combined 10 feet of a 100 foot transect is comprised a combination of annual forbs and grasses and/or 1-year-old (juvenile) perennial plant cover, the score for nascent vegetation would be 10 (10%). In estimating cover, include the gaps between the leaves as part of the canopy estimate. Imagine a polygon drawn around the very perimeter of the plant canopy in question, and tally the number of linear feet that canopy intercepts the tape measure.

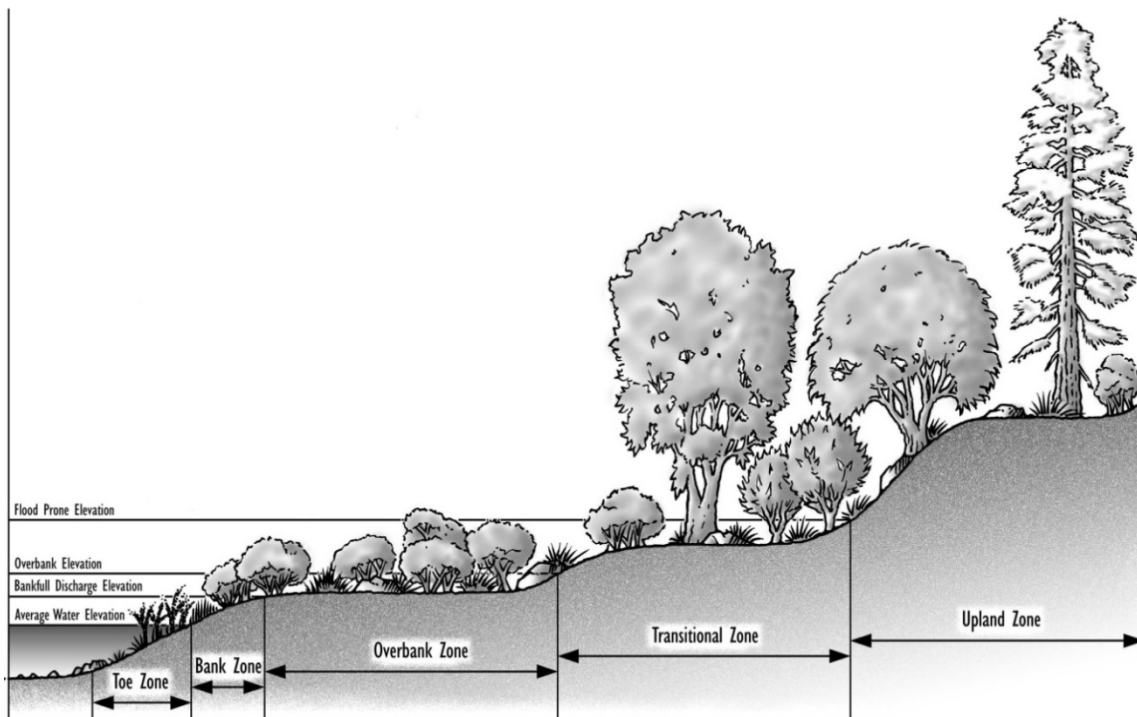


Figure 6. Riparian Planting Zones in Semi-Arid Climates (Hoag and Fripp, 2005)

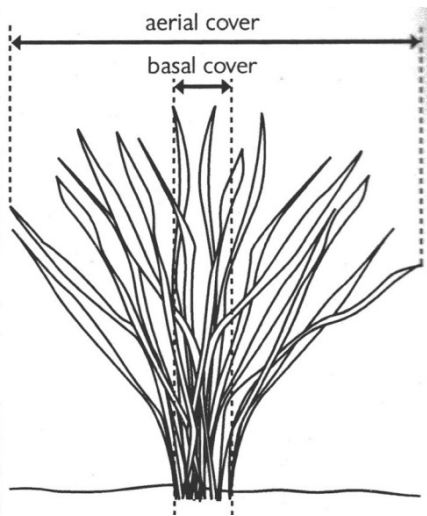


Figure 7: Aerial cover versus Basal cover (Elzinga et. al., 1998)

Count understory vegetation separately from overstory vegetation. For example, if a shrub canopy covers the transect from 20-30 ft, and again from 50-60 ft, then the shrub cover is 20% $[(10+10)/100]$. If an understory of perennial grasses/sedges occurs under that shrub canopy, then record the percent

cover of that perennial cover in addition to the shrub cover estimate and record it in the appropriate row on the form. In this regards, it may be possible in mature riparian stands to record a total vegetation cover greater than 100%.

In addition to determining the percent cover of each vegetation category along the sub-reach, multiplier weights are given to more mature (and hence often taller) vegetation for all perennial vegetation categories, as more mature woody plants often have more extensive root systems. The maturity categories are 1st year (saplings), 2-10 year old woody vegetation (height will vary by species), mature (> 10 years old, or otherwise visually mature), and old growth (visually a very old plant, and near senescent). For short vegetation, no change is made to the score associated with that vegetation category, for medium vegetation, the category score is multiplied by 1.25 during the banks stability calculation procedure, and for tall vegetation, the score is multiplied by 1.5. The field crew needs only to document the height category for each vegetation class in the field. The multipliers are added when the bank stability score is calculated later. These qualitative height categories are relative to each type of vegetation and the field crew should use their best judgment in assigning them while remaining consistent throughout the survey.

Active Bank Erosion

The previous categories indicate bank susceptibility to erosion. This category assesses recent or ongoing bank erosion processes. Bare soil or bank material does not necessarily indicate active erosion. Look for clues such as vegetation, exposed roots, evidence of bank material deposited at the bank toe, and fresh erosion on bank faces. Here, instead of assigning a percent length to each category, pick the category that best matches the observed extent (percent length) of active bank erosion. Low (0 – 25%), Moderate (25 – 50%), High (50 – 75%), Severe (75 – 100%). Bank restoration treatments that are underperforming or failing may coincide with active bank erosion. Note the active erosion here and document the bank treatment under the “Restoration Treatment Assessment” described below.

Bed Stability

Equally as important as assessing bank stability is channel bed stability. For the sake of brevity, percent lengths are not included in this portion of the assessment. Rather, the field crew selects the dominant bed sediment type (following Table 1) and dominant morphology type (Figure 4) of the sub-reach. They note whether active or recent incision exists. Clues from positions of roots along the bank and presence of migrating headcuts help inform this. Finally, if recent or active incision exists, the field crew estimates the depth of erosion along the sub-reach. Active incision may occur at or as a result of a stream restoration structure failure. Please note the incision or instability here and document the structure under the “Restoration Treatment Assessment” described below.

Restoration Treatment Assessment

Here, the field team assesses the quality and integrity of any stream restoration treatments/structures in the channel (e.g., grade control vanes or habitat enhancements) and banks (e.g., erosion control fabric,

live stakes, toe wood or root wads). Bank and in-channel treatments encountered are each numbered, identified by type, and then scored. This assessment follows the spirit of the bed stability assessment in that it does not consider percent lengths of each sub-reach. Rather, each structure or treatment encountered is scored as follows: *Good*: Stable and meeting design goals (e.g., bed or bank stability and reduction of erosion), *Moderate*: Could use some minor maintenance, *Poor*: evidence of erosion, plant death, or processes that may soon lead to restoration treatment failure, *Failed*: restoration treatment no longer serving its intended function and/or the structure/treatment is damaged to an extent that is problematic to the stability of the channel. The field crew should have an annotated “as-built” drawing of the reach that identifies what restoration treatments were installed where to aid in the inventory and assessment of these.

General Assessment Notes

Round estimates of percent length of each category to the nearest 10, 20, or 25%. Because this assessment protocol is visually based, precision beyond the nearest 10% is likely inaccurate and unnecessary. If working as a team, each team member should evaluate each category independently. Results can then be averaged. For a more comprehensive view of channel change over time, bank and channel bed monitoring should also incorporate repeated cross section and longitudinal profile surveys as well a repeated photographs from monumented locations. A good primer on stream surveying methods can be found in Harrelson et al. (1994).

Bank Erosion Hazard Score Calculations

To calculate bank stability scores, data collected on each sub-reach is entered into the “Calculations Spreadsheet” in which one column represents a sub-reach. Categories within each group (e.g., bank composition, bank vegetation) are assigned a value from 1 – 4 with 4 indicating the highest risk of instability. Based on the percent lengths attributed to each group category, a weighted average score is calculated for each bank for each category. These scores are then aggregated as a percent of total score, with higher scores indicating a higher risk of instability. Because this index-based approach is arbitrary (is bank angle equally as important as riparian vegetation coverage?), weights can be assigned to each category to give more or less weight to a particular category in the overall “Composite Bank Erosion Hazard Score”. Currently, all categories have a weight of 1 with the exception of “Active Bank Erosion”, which has a weight of 2.

Bed stability and stream restoration treatment assessments are scored separately from the composite bank erosion hazard score. Each sub-reach with active incision is flagged. Each restoration treatment is assessed and tallied for each category of quality / stability. These can then be inventoried at the project reach level.

Interpretation of Results

The results from this monitoring protocol may be used in a number of ways. They may be used to gather a baseline assessment of the stability of a reach of interest, and to document restoration needs. It can

then be used to track the evolution of the channel's stability over time in response to restoration efforts. Repair and maintenance needs may also be identified by this protocol. These assessments cannot at this time be used to estimate the quantity of eroded sediment entering a stream or the rate of bank erosion. However, they can provide objective and transparent evaluations of bank and bed stability that can aid in documenting overall changes and / or improvements to stability as a result of a restoration effort.

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