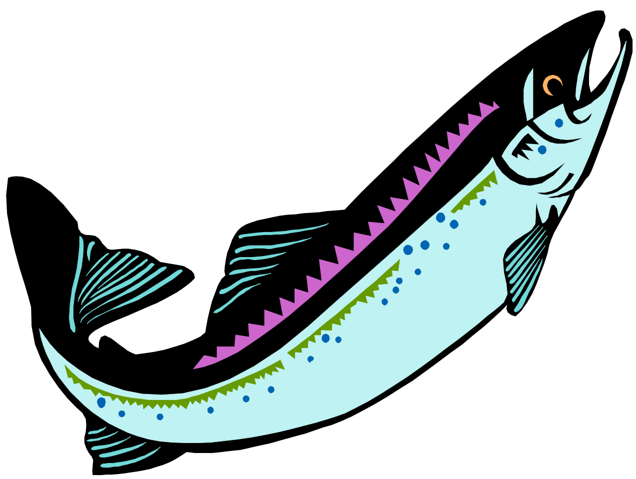
Monitoring the Effectiveness of Bank Stabilization Restoration

Final Report



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INTRODUCTION

Stream banks are the interface between the aquatic and terrestrial environments within stream systems. The following parameters of salmonid habitat may be influenced by stream bank condition: water temperature, water depth, suspended sediment, hiding cover, substrate composition, allocthonous nutrient contributions and habitat types. Erosion of stream banks can contribute essential components of fish habitat such as spawning gravels and large woody debris. Stream bank erosion must be viewed in a context of watershed processes and stream channel dynamics. It is half of the necessary couplet of erosion and deposition that contributes to floodplain formation and instream habitat sustainability (Trush et al. 2000). In many cases, stream bank erosion cannot be effectively treated at the local level (Kondolf and Piegay 2004). Stream bank stabilization projects are usually initiated when erosion appears to be outside the range of natural variability, is related to anthropogenic activities or imperils property or infrastructure.

Figure 1. Eroding Stream Bank Proposed for Stabilization Treatment. Common characteristics of unstable stream banks include: steep angle, lack of vegetation, material recently deposited at toe of slope, and exposed roots. Although this stream bank is eroding, the material consists of gravels suitable for spawning.

Stream bank erosion may be caused by: 1) natural or management related site level factors such as obstructions in the stream channel (e.g., fallen tree, landslide deposit or local bank trampling by livestock): 2) confinement of the channel by adjacent roads or development: 3) management related alterations to the hydrologic or sediment supply regime: and/or 4) natural processes of channel movement within the channel migration zone such as channel realignment and/or incision. Successfully stabilizing stream banks over the long term without causing other erosion in the vicinity depends on correctly identifying the cause and prescribing appropriate treatments. This report provides methods for monitoring the effectiveness of the treatment in stabilizing the banks. It does not give guidance for analyzing the appropriateness of the restoration treatments, i.e., determine if the actual (watershed scale) causes of bank erosion were addressed.

Banks may be stabilized in a number of ways. The first step is often removal of the primary land use stressor causing bank erosion, if it can be identified. In many cases livestock contribute to bank erosion, so riparian fencing or other techniques to reduce grazing pressure may be applied. Sometimes simple removal of grazing pressure is adequate to slow or halt bank erosion. This is known as “passive restoration” (Kauffman et al. 1997). In other cases, no single cause of erosion can be identified or the causes cannot be stopped. In these instances active restoration treatments may be used- ranging from planting barren stream banks to major excavation, re-contouring and armoring of banks. Success of stabilization efforts will depend on the techniques used and a realistic appraisal of the potential to halt bank erosion in the particular geomorphic setting.

For either passive or active restoration, relatively simple evaluations of biological and physical characteristics of stream banks are sufficient to determine the effectiveness of treatments. This report focuses on direct measures of stream bank condition, rather than the indirect effects of bank stability/erosion on stream channel conditions. Other methods may be used to assess secondary effects on water temperature, substrate composition, habitat type, etc. It is expected that this report will be used as a guide for preparing monitoring study plans. The monitoring time frame is 10 years, the period of time during which access to treated sites is allowed under FRGP contracts.

Measurements of the type and continuity of vegetation cover along with the physical condition of stream banks are used to assess stability. Although local conditions should be used to define stability, some typical indicators of unstable banks are shown in Figure 2.

Figure 2. Example of the Type of Streambank Commonly Treated Using Bank Stabilization Techniques in California.
Common characteristics include: vertical bank angle, lack of vegetation, evidence of recent slumping and located on outside of meander bend. *Photo courtesy of E. Engbar.*

Use of these methods presupposes a working knowledge of stream geomorphology, basic plant ecology, forest and vegetation sampling and plant identification. References provided at the end of this report provide details on the field methods presented.

RESTORATION OBJECTIVES

This report applies to the following restoration project types:

Deflect Stream Flow:
Increasing stream bank stability by reducing stream power at erodible surfaces. Boulders (rip rap) and/or pieces of LWD are typically used to construct deflectors. Picture at right illustrates streamflow deflector composed of boulders and a large rootwad against right bank, flow is from right to left.

Bioengineering:
Increasing stream bank stability by protecting erodible surfaces with living material and/or stored sediment. Willow and other fast growing riparian species are used to construct baffles, fences or mattresses. Picture at left illustrates willow plantings along toe of eroding streambank. Boulder J-hooks (not visible in photo) are also included in the channel to divert flows from stream bank.

Armoring:
Increasing stream bank stability by protecting erodible surfaces with rock. Picture at right illustrates armoring of streambank using boulders and a small rootwad anchored into the streambank. Willows have grown in around armor naturally, but in some projects are installed along with armor.

The primary objectives of these types of projects include:

- Reducing or eliminating bank erosion at treated sites.
- Increasing vegetative cover at treated sites.
- Altering width/depth ratios within vicinity of treated sites.
- Rebuilding streambanks and floodplains by trapping sediments and storing them locally.

EFFECTIVENESS MONITORING QUESTIONS AND STUDY DESIGN

It is expected that questions regarding the effectiveness of bank stabilization practices will focus on use of alternative practices (e.g., bioengineering versus armoring as a means of achieving increased bank stability), effects of environmental conditions on practices (e.g., channel width or soil type) or durability of structures over time. It is further anticipated that studies addressing these topics will be conducted by sampling multiple sites and/or treated reaches over time. The following is a list of potential questions that might be addressed:

- Did the percentage of stream bank with vegetative cover increase after treatment?
- Did the percentage of unstable stream bank decrease after treatment?
- Did the width to depth ratio of the stream change after treatment?
- Did the restoration practice stop bank retreat?
- Did the restoration practice store sediment locally, i.e. re-build stream banks?

For studies evaluating these questions at the stream reach scale, the general study design recommended is a modified before-after-control-impact approach (BACI). The BACI design is ideal for evaluating the effectiveness of restoration activities (Stewart-Oaten et al. 1986; Crawford and Johnson 2003). Sampling of the control and the impact area is conducted before and after treatment. Unique attributes of sampling related to the BACI design are discussed below in the field methods description.

For studies of the relative effectiveness of one or more treatments at the site scale, in which individual treatment sites will be sampled, a BACI design may not be feasible. For those studies, comparisons before and after treatment over time may be the approach used. Retrospective studies of bank stability treatments have also yielded useful results (Shields et al. 2000).

Table 1 indicates the parameters, effectiveness criteria and field methods to be used to address each of these questions. Field method numbering corresponds to their description in the next section of this report. Specific effectiveness criteria (e.g., targets such as desired cover increases, etc.) should defined in project contracts and/or within study plans for effectiveness monitoring. For all of the questions, data should be collected before treatment, immediately after treatment and at one or more future dates, depending on how long it takes for a response to occur in both treated and control areas.

Goals for detecting differences due to treatments should be based on the restoration objectives typical for the treatments being evaluated. Generally, most bank stabilization practices are expected to make big changes in conditions, e.g., convert barren streambanks to fully vegetated streambanks, totally eliminate bank erosion at the site, etc. Since most practices occur at the site or the stream reach levels, however, changes may represent a relatively small proportion of the total length of streambank in the watershed.

Table 1. Monitoring Questions, Parameters, Effectiveness Criteria and Field Methods.

Monitoring Question	Parameters	Effectiveness Criteria	Field Methods
Did the restoration practice decrease the length of un-vegetated stream bank?	Percent of bank with vegetative cover.	Percent cover equals or exceeds contract specifications e.g., the bank is fully vegetated within 10 years.	Line intercept transects (field method 1).
Did the restoration practice decrease the length of unstable stream banks?	Percent unstable stream bank.	Percent unstable stream bank is equal to or less than level in contract specifications e.g., 75 percent of bank within the treated reach is rated "stable"	Line intercept transects (field method 1)
Did the restoration practice change width to depth ratios of the channel?	Width/depth ratio of channel.	Width/depth ratio meets targets specified in contract e.g., w/d decreased to 3:1.	Cross section surveys (field method 2)
Did the restoration practice stop bank retreat?	Location of top and bottom edges of stream bank relative to benchmark.	No movement of bank edges away from channel.	Cross section survey (field method 2)
Did the restoration practice reduce the bank angle in treated area?	Angle of bank.	Bank angle meets target values specified in contract e.g., 1:1.	Cross section survey (field method 2)
Did the restoration practice store sediment onsite?	Location of stream bank surface relative to benchmark.	Storage of material meets volumetric or height targets specified in contract.	Cross section survey (field method 2)

DATA QUALITY

It is assumed that studies using this method will be conducted by agency staff, experienced consultants or practitioners who are trained in riparian and streambank sampling methods. There are data quality objectives inherent to the field methods presented here. Additional data quality objectives should be described within specific study designs. Generally, a goal of between-observer variability of plus or minus 10 percent in measurements is desirable. Quality control will be achieved through a combination of: 1) initial training; 2) repeat surveys by independent surveyors; and 3) follow-up training.

FIELD METHODS

Delineation of Study Areas

Study areas may be individual treatment sites or stream reaches extending above and below the treated or control area(s), depending on study objectives. If the study objective is to determine how well bank stabilization treatments worked at each restoration site or to assess durability of individual treatments, the study area may be confined to the treated site(s). If the study objective is to evaluate effectiveness of the restoration treatments at the reach scale and/or evaluate potential off-site impacts the study area will include a larger area. In either case, the study area and individual treatment sites need to be documented according to methods included in *Documenting of Salmonid Habitat Restoration Project Locations*.

Control reaches will be established for studies of reach-level effectiveness. Reach-level effectiveness may be evaluated when numerous treatments are located within a reach or when a large, single project may have effects at that scale. Studies of the local effectiveness of individual treatments may not include control sites. Instead, sites may be sampled before and after treatment for a sufficient time to determine effectiveness.

If the study objectives include an evaluation of onsite effectiveness as well as potential off site impacts, the study reaches need to include areas upstream, downstream and on the opposite bank(s) from the treated areas. No published guidelines are available to define how large of a study area is required to capture all potential impacts from streambank stabilization treatments. It is reasonable to assume that the study area will need to increase as the channel size increases in order to capture potential effects. Until further data are available to refine the area of potential effects, the study area should extend 10-20 bankfull channel widths above and below treated areas (Barry Hecht, personal communication). The length of channel subject to un-intended impacts will depend on the current conditions causing bank erosion in the watershed (e.g., peak flow size and timing, sediment yield, channel access to floodplains, etc.) and the degree to which the project alters local conditions (e.g., velocity, bed elevation, roughness, floodplain access, channel geometry, etc.) (Sherman Swanson, personal communication).

Criteria for determination of bankfull width are shown in Figure 3 and Table 2.

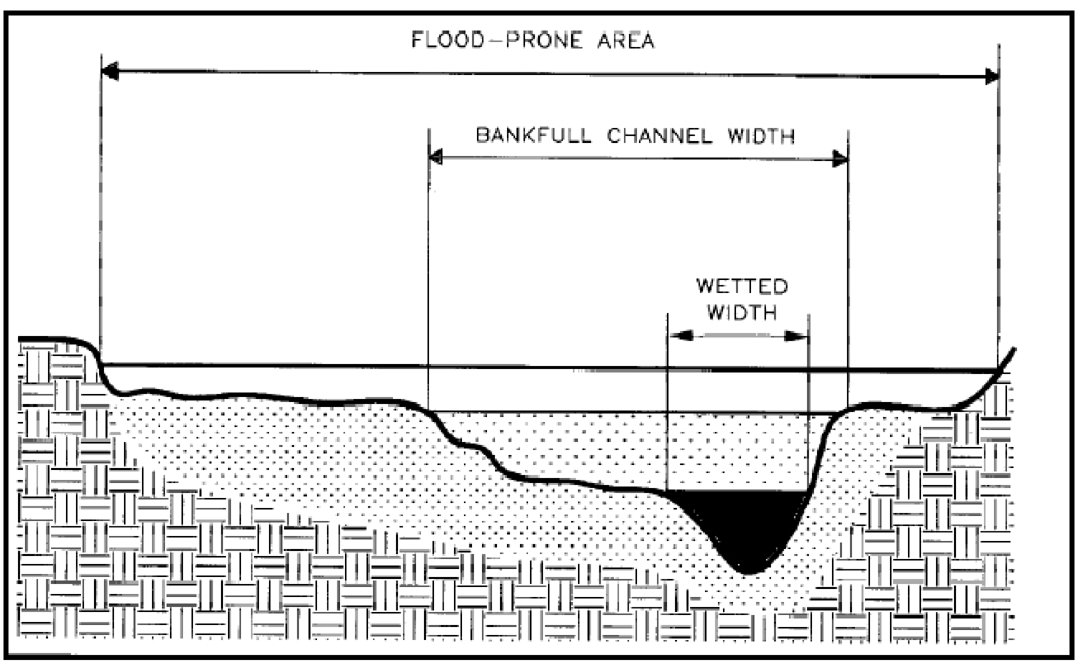

Figure 3. Geomorphic Position of Bankfull Width.
This is the width of the water surface during a flow with a 1.5 year recurrence interval. *Source:* (Flosi et al. 1998).

Table 2. Bankfull Width Indicators in the Stream Channel.

Indicators used to determine Bankfull Width

1. Examine stream banks for an active floodplain. This is a relatively flat, depositional area that is commonly vegetated and above the current water level.
2. Examine depositional features such as point bars. The highest elevation of a point bar usually indicates the lowest possible elevation for bankfull stage. However, depositional features can form both above and below the bankfull elevation when unusual flows occur during years preceding the survey. Large floods can form bars that extend above bankfull whereas several years of low flows can result in bars forming below bankfull elevation.
3. A break in slope of the banks and/or change in the particle size distribution from coarser bed load particles to finer particles deposited during bank overflow conditions.
4. Define an elevation where mature key riparian woody vegetation exists. The lowest elevation of birch, alder and dogwood can be useful, whereas willows are often found below the bankfull elevation.
5. Examine the ceiling of undercut banks. This elevation is normally below the bankfull elevation.
6. Stream channels actively attempt to reform bankfull features such as floodplains after shifts or downcutting in the channel. Be careful not to confuse old floodplains and terraces with the present indicators.

Source: AREMP/PACFISH/INFISH (2004).

Control (untreated) stream reaches, if possible, should be located upstream of the treated area, or at least in the vicinity. Control reaches should be environmentally and ecologically comparable to the reaches that will be treated.

Field Method 1: Line Intercept Transects Along Banks

Longitudinal transects are used to assess changes in bank stability and cover, riparian connectivity, vegetation structure and species composition at or near the bankfull boundaries of the channel. They are used where one or both sides of the stream will be treated as a whole or where there are multiple treatments located along one or both banks. Data recorded are: 1) cover by species and height class and, 2) stability of banks. These data allow calculation of percent vegetation cover on each bank by species, percent barren ground, percent unstable banks and percent of streambank length occupied by restoration treatments. This method is not suitable for detecting changes in channel geometry (e.g. width/depth ratios), bank retreat or advance of streambanks or accumulating/trapping sediment at restoration sites (Field Method 2).

Picture at right illustrates stable banks, patchy riparian vegetation cover in the 3-15 foot height class and complete vegetation cover in the 0-3 foot height class.

Determination of Sample Size

The entire length of stream within the study area and a similar length of control reach are measured. In a study assessing effectiveness of practices across many sites or regions, the combined data for all transects in each study area would be a sample and an estimate of the mean difference in condition before and after treatment on treated and control sites can be made. A paired single-sided t-test will be used for statistical comparison.

The required sample size for a study of bank stabilization treatments should be determined during the preparation of a monitoring study plan. The measurement of difference methodology is statistically powerful such that a relatively small sample will be sufficient to detect differences. Ten treatment/control pairs for each kind of treatment should be sufficient to detect relatively large target differences, e.g., increasing vegetation cover by 50 percent or more.

Field Method

- Describe and/or monument the starting point for the transect. Multiple monuments may be needed to ensure relocating the point in the future. Distance from a bridge, road, parking lot, or other landscape feature is useful in referencing the starting point. Tie this point into other monitoring activities if possible. It is essential that the starting point be identifiable in the future
- From the starting point, establish the line intercept transect through the permanent riparian vegetation closest to the channel bankfull line (this is a modified version of the "green line" method described by Winward (2000)). The line intercept may be at, below or above bankfull depending on the location of permanent vegetation at that particular site. If no vegetation is present, the transect should follow the bankfull elevation.
- Walk along the channel bank and record interception of the line (in feet and/or inches, to the nearest 0.5 foot) by each shrub or tree species (or genus if species is not identifiable) within three height class categories (< 3 feet), 3 to 15 feet and >15 feet). Record interception by herbaceous cover (if >10 percent; barren otherwise), litter, rock or restoration structures where vegetation is not present. It may be necessary to repeat the line more than once to accurately measure vegetation in each height class (see *Monitoring the Effectiveness of Riparian Vegetation Restoration* for more information on line intercept sampling).
- Along the same transect, record the stability class of the bank, as inferred from observing the bank toe to top. Note the beginning and end points of unstable banks by their distance from

the starting point of the transect and the streambank on which they occur (left or right). Also note whether banks are within proposed or existing treatment areas. Banks are classified using only two categories: "stable" or "unstable.[1]"

- Repeat surveys in 3-5 years (or more) depending on study plan objectives. Length of surveyed channel should be the same as the initial survey.

The determination of stability class is made at the time of assessment and should not attempt to anticipate effects. Unstable stream banks are identified by the following morphological features (from Overton et al. 1997):

- **breakdown** if clumps of bank are broken away and banks are unvegetated,
- **slumping** if banks have slipped down recently,
- **tension cracks or fracture** if a crack is visible on the bank, or
- **vertical and eroding** if the bank is mostly uncovered, in other words, less than 50 percent covered by perennial vegetation, roots, rocks of cobble size or larger, or logs of 0.1 meter in diameter or larger, and the bank angle is steeper than 80 degrees from the horizontal (Bauer and Burton 1993). Undercut banks are considered stable unless tension fractures show on the ground surface at the back of the undercut (USDA Forest Service 1992).
- Generally, banks with an angle >80 degrees from horizontal are considered unstable, 45-80 degrees may be at risk of instability and banks that are at an angle of less than 45 degrees (1:1) are stable (Overton et al. 1997, Bain and Stevenson 1999).
- Local conditions need to be considered, for example in some geologic settings vertical, unvegetated banks may be stable for decades. If the definition of stable versus unstable differs from the characteristics cited above provide the locally accurate definition and rationale and/or data.

Picture at right illustrates barren, raveling streambank with a steep angle.

[1] The use of fewer stability categories (2 rather than 5) reduces observer error compared to more complex systems (Archer et. al. 2004).

Picture at left illustrates steep bank angle but stable conditions due to high coarse content and scattered vegetation. No evidence of ravel, sloughing or scarp at top of bank.

Picture at right illustrates stable, vegetated bank in foreground with unstable eroding bank in background. Note scarp at top of bank, “floating” fenceposts and lack of vegetation on background banks.

Data Analysis

In a study of effectiveness, at least two parameters may be of interest: 1) total length of vegetated bank as a proportion of total bank length; and 2) total length of unstable banks as a proportion of total bank length.

Total length of vegetated bank as a proportion of total bank length is calculated as follows:

*Total length of sampled line with vegetation cover in height class A, B or C/Total length of sampled line * 100 = Percentage of reach with vegetated banks in height class A, B or C*

In cases where canopy overlap by different species occurs, it should be subtracted so that the maximum cover in any one layer cannot exceed 100 percent. As indicated, cover should be calculated separately for each height class. It may be expressed for one or both banks, as desired. Adding together the estimates for each canopy layer will produce a total cover measurement that may be up to 300 percent. Which data will be most important for analysis will depend on the objectives of the restoration and study design. For example, objectives may specify that one or another canopy class is targeted for increased cover.

Total length of unstable banks is calculated as follows:

*Total length of sampled line in all unstable bank classes/Total length of sampled line * 100 =Percentage of reach with unstable banks*

For each variable of interest the test of statistical significance, to see if treatment resulted in achieving target levels, will be a paired *t*-test.

Instructions for Completing the Bank Stability Line Intercept Transect Data Form

General Information- section 1

1) **Page ___ of ____—**Number the page. For example, if this is page 2 out of 3 total pages, enter: Page 2 of 3.
2) **Contract #—**Enter in the contract number assigned to this project by the Department of Fish and Game.
3) **Contract Name –** Enter the name of the contract.
4) **Stream Name—**Enter in the name of the stream or road. If unnamed, use named stream or road to which it is tributary.
5) **Date—**Enter the date: *mm/dd/yy*
6) **Crew—**Enter the names of the crew members collecting the data using the following format: *last name, first initial*.
7) **Drainage Name—**Enter the name of the main drainage basin that the stream is a tributary to.
8) **Transect #-** Enter the number of the transect for which data is being recorded.
9) **Transect Length**- Enter the total length of the completed transect.
10) **Start Point-** Describe the location at which the survey began, using permanent reference points.
11) **Streambank**- Circle the stream bank being surveyed, if applicable.
12) **Survey Direction**- Circle the direction of travel taken by surveyors during data collection, if applicable.

Bank Stability Data – section 2

13) **Bank Class Start Distance -** Enter the distance displayed on the tape at the location where the bank stability class begins.
14) **Bank Class End Distance -** Enter the distance displayed on the tape at the location where the bank stability class ends.
15) **Stability Class -** Enter the bank stability class found at that section of the line, based on four letter/digit codes defined for each survey area and study objectives. Classify banks according to the following codes:

    - STNT - stable bank, no treatment
    - STPT - stable bank, treatment area
    - UNPT - unstable bank, treatment area
    - UNNT - unstable bank, no treatment

Line Intercept Vegetation Data – section 3

16) **<3 Foot Height Class Start Distance -** Enter the distance displayed on the tape at the location where the vegetation/cover type begins.
17) **<3 Foot Height Class End Distance -** Enter the distance displayed on the tape at the location where the vegetation/cover type ends.
18) **Species -** Enter the species code (or genus if species cannot be identified) found at that section of the line, based on standard four letter/digit codes,(e.g. *Psuedotsuga menziesii* = PSME). Or, if unvegetated (<50 percent cover as intercepted by line transect), enter barren soil, wood, rock, restoration structure or other structure according to codes listed on the data form.
19) **3-15 Foot Height Class Start Distance -** Enter the distance displayed on the tape at the location where the vegetation begins.

20) **3-15 Foot Height Class End Distance -** Enter the distance displayed on the tape at the location where the vegetation ends.
21) **Species-** Enter the species code found at that section of the line.
22) **>15 Foot Height Class Start Distance -** Enter the distance displayed on the tape at the location where the vegetation begins.
23) **>15 Foot Height Class End Distance -** Enter the distance displayed on the tape at the location where the vegetation ends
24) **Species –** Enter the species code found at that section of the line.
25) **Comments –** Record relevant comments, including the location at which any associated monitoring transects or plots are taken.

BANK STABILITY LINE INTERCEPT FORM

Page ___ of ___

Contract #:___________________________ **Contract name:**____

Stream:________________________ **Date:** _____________ **Evaluation crew:**______________________________

Drainage:____

Transect #:________ **Transect length:**_________ **Start Point:**____

Streambank: (*Left* or *Right*) **Direction:** (*Upstream* or *Downstream*)

Bank class			0-3' height class			3-15' height class			>15' height class			Comments
Start	End	Stability	Start	End	Species	Start	End	Species	Start	End	Species	(Record location of other
Distance		Class	Distance			Distance			Distance			transects/plots)

Species Codes

				BRRS - Barren soil
				HERB = Herbaceous
				LITT = Litter
				REST = Restoration Structure
				WOOD = Wood
				ROCK = Rock
				OTST = Other structure

Stability Codes

STNT = stable bank, no treatment STPT = stable bank, treatment UNPT = unstable bank, treatment UNNT = unstable bank, no treatment

Field Method 2: Cross Section Surveys

Cross section surveys are standard methods for monitoring changes in channel and streambank dimensions (Simon and Castro 2003). Protocols for conducting these surveys using differential leveling are well established (Harrelson et al. 1994, Ramos 1996). Cross section surveys provide a sensitive means for monitoring changes in channel geometry. They are time consuming, and thus expensive to conduct. Investigators with limited experience in these techniques should consult Harrelson et al. (1994) and Ramos (1996) for further detail.

The surveyed area for studies of bank stabilization should extend across the channel to the low terrace or valley wall on either side (Simon and Castro 2003). This is particularly important in unconfined alluvial areas (a common location for stabilization projects) where channel migration or avulsion can result in movement of the channel across the floodplain. Cross sections that include the entire floodplain ensure that bank retreat will not end up outside the surveyed area.

Cross section surveys are recommended for bank stabilization projects with the following objectives:

- preventing bank retreat due to erosion
- decreasing bank angles
- changing width/depth ratios of the channel
- storing sediment at restoration sites
- preventing channel migration

Measuring a cross section on a small stream, which is also the upstream endpoint for a long profile survey, note tape measure running down stream.

Determination of Sample Size
As in field method 1, the sample size is the number of treated reaches evaluated under the BACI design. Two considerations affect the accuracy and precision of estimates obtained using cross sections. One is the number of measurement points required to obtain a “true” distribution of elevations on each cross section. The other is the number of cross sections that should be measured to constitute a valid sample for a reach.

The precision of a cross section is directly related to the number of elevation measurements taken along with the quality of the tools used to take the measurements. Harrelson et al. (1994) recommend a minimum of 20 points, with more needed on structurally complex channels. If the points are evenly spaced, the interval between them is calculated by dividing the total width of the cross section by 20. In addition to evenly spaced measurement points, all significant breaks in slope are recorded (top of bank, toe of bank, thalweg, etc.).

In studies evaluating the effectiveness of individual structures, the number of cross sections needed to provide a valid measure of width/depth ratio, bank angle or accumulation of sediment will depend on the size and variability of the treated area[2]. In cases of small treatments (<75 feet long), one cross section may be sufficient to detect changes. For larger treatment areas, it is recommended that at least three, placed at the downstream and upstream ends and middle of the treated area be used (Figure 4). The average bank angle, width/depth ratio or cross sectional area of the streambank (for studies of accumulation) may then be calculated. Generally, studies should avoid assessing effectiveness among treatments that vary significantly in size. Especially large treatments should be treated as reaches rather than sites.

For reach scale studies, the number of cross sections to measure in order to provide a valid sample of width/depth ratio and bank angle is based on the recommendation of Kaufmann et al. (1999). They recommend installing cross sections approximately four bankfull channel widths apart with a minimum of 11 per treated or control reach. The cross sections are placed systematically at the calculated interval with a random start (Figure 4). Average bank angle and width/depth ratios are calculated from the sampled transect measurements.

Field Method

Auto levels and total stations are standard tools for cross section surveys. A total station is the preferred tool because more survey points can be captured in a shorter time period, horizontal accuracy is improved over other methods and electronic data analysis and map production are faster and more accurate. Total stations require a greater initial investment in crew training and equipment costs compared to an auto level, however the increased efficiency reduces data collection and analysis costs—which tend to be greater over the long term. Specific field methods will depend on the monitoring objectives and tools available.

Cross section surveys rely on a set of benchmarks to which all other points in the survey are referenced to accurately measure bed elevations above sea level. Establishing durable benchmarks that can be relocated many years into the future is essential

[2] In order to calculate bank angle two key measurement points are needed: 1) top of bank and 2) toe of bank. Width/depth ratios are computed by dividing the average bankfull width by the average of the bankfull depth measurements as measured at the thalweg (Kauffman 1999).

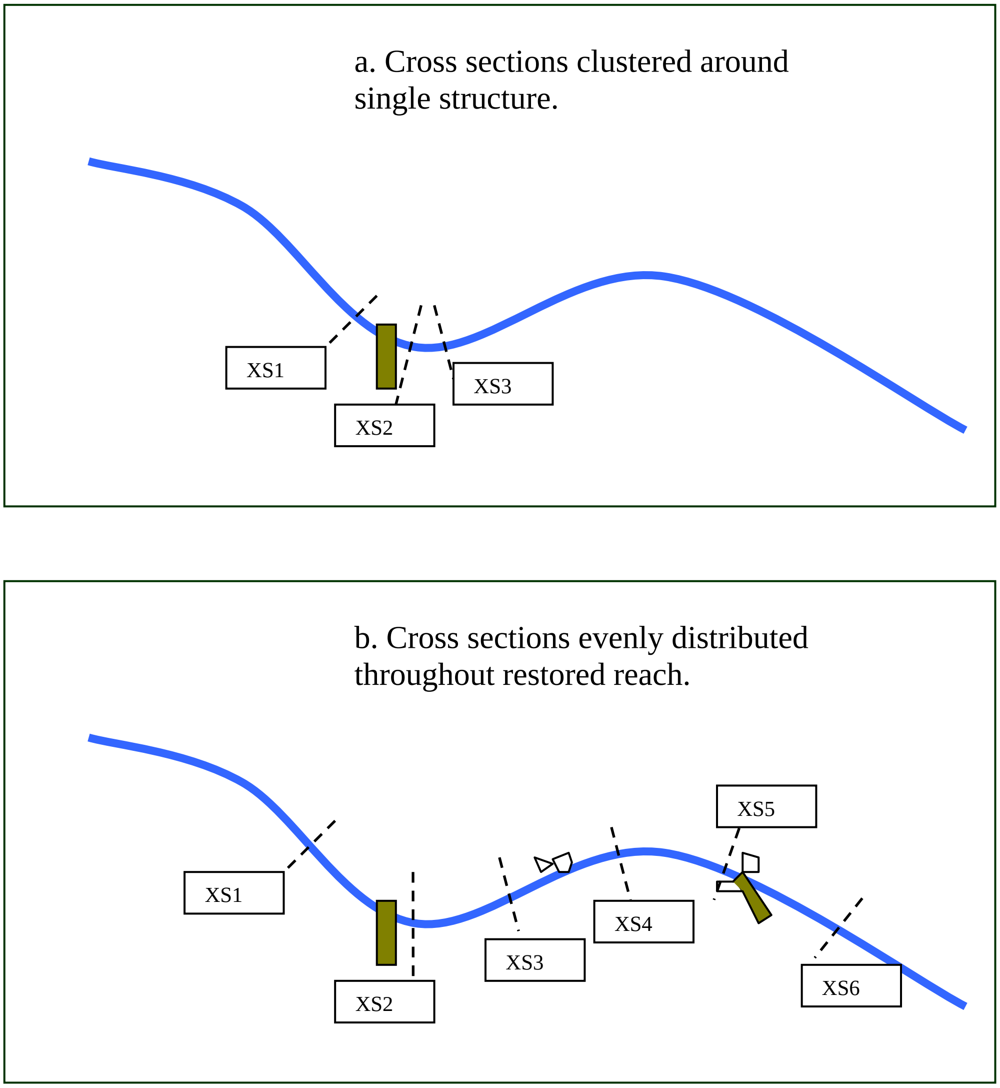

Figure 4. Cross Section Locations for Individual Structures and Stream Reaches.
Cross sections clustered around a single structure (a.) are intended to provide data about physical effects immediately adjacent to the restoration structure. Cross sections evenly distributed throughout the restored reach (b.) will provide data on the reach level average response to restoration structures.

- Locate two permanent benchmarks on the downstream end and one benchmark at the upstream end of the survey. Use existing permanent benchmarks to establish new ones, if available. If not, establish new benchmarks with an arbitrary elevation of 100 feet. Locate new benchmarks well out of the floodplain.
- Monument benchmarks using a method suitable for the survey tools in use. Construct cement monuments for total stations since they allow a tripod and instrument to set up directly over them. Dig a 1-2 foot deep hole, fill it with cement and place a galvanized carriage bolt into the wet cement so that it protrudes 1-2 inches. Spikes driven into trees and monuments on boulders may be suitable for auto level use.
- Describe the location of benchmarks and record these coordinates (see *Documenting Salmonid Habitat Restoration Project Locations*).

- After establishing benchmarks, establish cross section endpoints 'tied' to benchmarks by bearing and distance measurements. Cross section endpoints should be located well out of the floodplain in order avoid disturbance by high flows.
- Conduct the cross section survey. Record the bed and water elevation at each data point using standard differential leveling techniques.
- Record standard survey notes such as left and right edge of water, terrace and floodplain surfaces, bankfull discharge elevation and indicator, turning points, etc. which are described and defined in Harrelson et al. (1994).
- Depending on study objectives, optional data may be recorded at each point (or a sub-sample of points), including: substrate class (fines, sand, gravel, cobble, boulder, bedrock), vegetation type or species, canopy cover, presence of restoration structures and types, channel habitat type (pool, riffle, run), LWD categories by size, origin or species, and engineered structures such as culverts, bridges, etc.

A note page should describe the project name, purpose, survey party and definitions of all codes used in the survey. Additionally a map of all relevant points and features should be included. The map may be a site sketch, USGS topographic map of the site or aerial photograph.

Data Analysis

Cross section data may be plotted using standard engineering techniques or graphics programs to yield channel morphology parameters for each transect (Figure 5). Parameters that can be

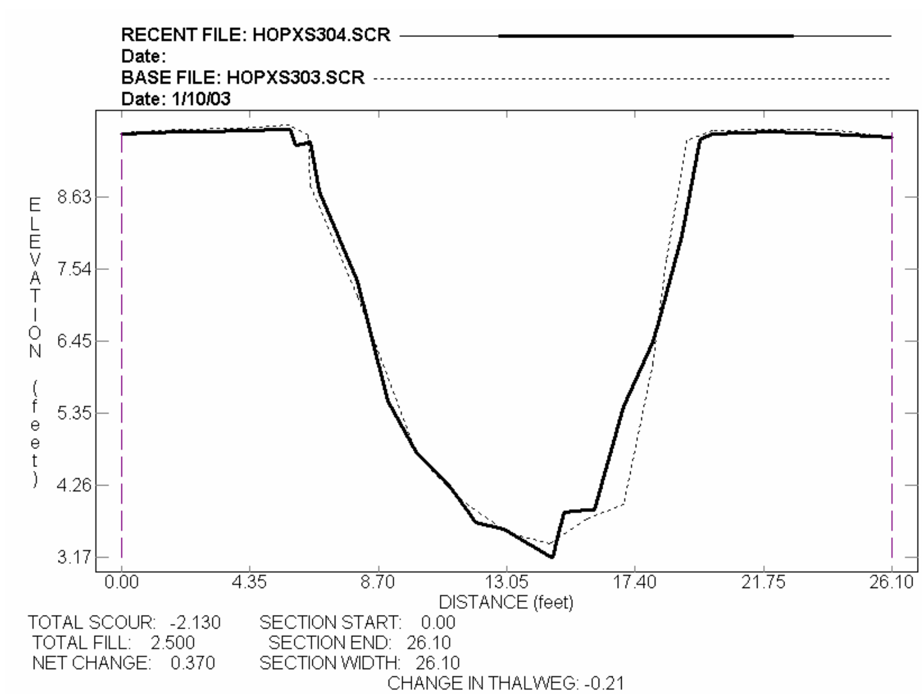

Figure 5. Example of Sequential Cross Sections.
Summary data calculated using a standard computer program indicate that the net change in the area of the cross section between the initial measurement in 2003 and remeasurement in 2004 was 0.370 square feet and the thalweg depth decreased by 0.21 feet. Data analyzed in WinScour (U.S. Dept. of Interior 1999).

derived from the data include: 1) bank angle (angle from toe to top of bank); 2) bankfull channel width; 3) channel depth at thalweg; and 4) width/depth ratio (bankfull channel width/thalweg depth). These in turn, are the data required to evaluate attainment of effectiveness criteria. At least two approaches may be used for data analysis. Cross sections at different locations and at different points in time can be overlain for graphical analysis. Differences in cross sectional area can be computed. The WinScour computer program is recommended to perform these calculations (U.S. Dept. of Interior 1999). Or, data from cross sections can be averaged to provide means and standard deviations for reach-scale parameters. For example, the average width/depth ratio may be compared between treated and control reaches. A similar approach could be used to evaluate changes in bank position (retreat) or channel width (narrowing or widening).

For analysis of changes in bank angle, another approach may be preferable. In this case, cumulative frequency distributions indicating what proportions of measured bank angles are in different stability classes may have more interpretive value. By convention, bank angles are computed as departures from horizontal (180 degrees) rather than vertical to accommodate undercut banks (Platts 1987). For banks that slope away from the channel, the bank angle is greater than 90 degrees from horizontal, so for example a 30 degree slope away from the channel would be reported as 180 degrees-30 degrees = 150 degrees. Generally, the following bank classification criteria may be used: < 90 degrees = undercut banks, 90-135 degrees = steeply sloping banks (potentially unstable) and >135 degrees = gently sloping banks (mostly stable)(Bain and Stevenson 1999). Frequency distributions can be compared statistically using methods such as Kolmogorov-Smirnoff tests. Which data will be most important for analysis will depend on the objectives of the restoration and study design. Effectiveness will be judged on whether a significant difference is found between control and treatment reaches before and after treatment.

Instructions for Completing the Cross Section Survey Data Form

General Information- section 1

1) **Page ___ of ____-** Number the page. For example, if this is page 2 out of 3 total pages, enter: Page 2 of 3.
2) **Contract # & Name-** Enter in the contract number assigned to this project by the Department of Fish and Game.
3) **Stream/Road Name-** Enter in the name of the stream. If unnamed, use named stream to which it is tributary.
4) **Date-** Enter the date: *mm/dd/yy*
5) **Drainage -** Enter the name of the main drainage basin that the stream is a tributary to.
6) **Crew-** Enter the names of the crew member operating each survey instrument the following format: *last name, first initial*.

Cross Section Data – section 2

7) **Station Number -** Enter the distance from the left cross section endpoint where the elevation measurement is recorded. All cross sections start at 0 on the left bank side and end at the right bank end point.
8) **(+) BS- Back Sight** is a rod reading taken on point of known elevation, this reading is entered as a positive value.
9) **(-) FS- Foresight** is a rod reading taken on any point to determine its elevation. The algebraic sign for the foresight is negative (-) since the FS is subtracted from the HI to find the ground elevation of the point in question.
10) **HI- Height of Instrument** is the elevation of the line of sight projected by the instrument. This is calculated by adding the rod reading from the backsight to the known (or assumed) elevation at that point, typically a benchmark.
11) **Elevation -** is the actual elevation of the point in question, calculated from HI, BS, or FS readings.

CROSS SECTION FORM Page ___ of ___

Contract #: **Contract name:**

Stream/Road: **Date:**

Drainage:

Crew: Level **Recorder** **Stadia Rod**

Description of Survey:

Measurement Units: **Total Survey Length:**

Station	(+)BS	HI	(-)FS	Elevation	Comments

HISTORY OF REPORT DEVELOPMENT AND REVISION

This report was initially developed on the basis of a literature review and consultation with the scientific community. Field-testing of this protocol was conducted in the summer and fall of 2004. The draft report was subsequently revised in June 2004 and subjected to peer review. The final report reflects changes made in response to peer reviewers.

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