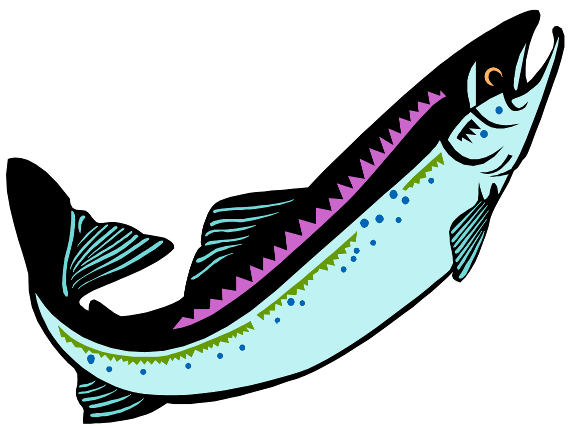
Monitoring the Effectiveness of Culvert Fish Passage Restoration

Final Report



Prepared for:

California Department of Fish and Game
Salmon and Steelhead Trout Restoration Account Agreement No. P0210566

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March 2005

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ACKNOWLEDGMENTS

Contributors to this report, in addition to the author, include Jared Gerstein and Susan Kocher. A great deal of direction and guidance came from the *California Salmonid Stream Habitat Restoration Manual, Part IX: Fish Passage Evaluation at Stream Crossings* by Michael Love and Ross Taylor (Flosi et al. 2002). George Robison was a peer reviewer.

This report should be cited as:

Stockard, W. and R. R. Harris. 2005. *Monitoring the Effectiveness of Culvert Fish Passage Restoration.* Center for Forestry, University of California, Berkeley. 25 pp.

INTRODUCTION

For salmonid species, migration is fundamental for supporting reproduction, feeding and access to cover and thermal refuges. Dams, channelization, installation of culverts and reductions in stream flow have all created barriers to migration. Removing migration barriers is intended to improve accessibility to habitat for both adult and juvenile anadromous fish.

Figure 1. Adult Salmon Attempting to Enter a Culvert With a Leap Height Barrier. *Source*: USDA Forest Service.

Lack of accessibility to habitat can cause a wide range of detrimental impacts, including:

- Loss of range for juvenile anadromous and resident fish
- Overcrowding in areas below barriers, increased competition for spawning sites, and increased risk of predation and poaching
- Reduced health and reproduction due to exertion from negotiating areas of impaired passage
- Loss of nutrients from the carcasses of anadromous spawning adults
- Reduced ability for juveniles to find cool refugia during summer low flows
- Loss of resident fish after extreme flood events that evacuate fish from the reach to which fish cannot return
- Loss of genetic diversity of fish with a wide range of swimming speeds and strength.

This report describes procedures for monitoring the effectiveness of fish passage restoration projects involving culverts. All references in this report to fish passage restoration pertain to projects at culverts. Most fish passage projects in coastal California are concerned with either replacing or retrofitting culverts. Other important fish passage problems such as poorly functioning fish screens, man-made ponds, reservoirs, side-channel gravel pits or channel diversions are not considered here.

Figure 2. Passage Impaired by Sediment and Debris. *Source*: USDA Forest Service

The objective of monitoring fish passage restoration effectiveness is to determine whether and for how long they the treatment has improved up and downstream habitat connectivity for targeted species of salmon and trout. This requires evaluating any structures as well as channel conditions above and below the project area. Effectiveness monitoring should only be conducted on projects that have met design specifications. Compliance with design, i.e., implementation monitoring, should have been assessed prior to effectiveness monitoring.

This report is intended for use as a guide to develop specific monitoring plans for fish passage improvement projects at culverts. Those plans may apply to single projects or may sample multiple projects in order to determine general effectiveness of practices. The target audience for this report is DFG and other professionals who are trained and experienced in hydrology and stream geomorphology.

RESTORATION OBJECTIVES

Many different approaches are used to improve fish passage at culverts. The main physical impediments to passage are insufficient jump pool depth, excessive jump heights, high flow velocities for extended distances, lack of resting habitat, and insufficient water depth during low flows. Low water depth may also be an issue during higher, migration-level flows through wide, flat-bottom box culverts.

Figure 3. Leap Height and Low Water Depth Presenting a Potential Migration Barrier at a Box Culvert. *Source*: USDA Forest Service

The objectives for restoring fish passage for juvenile and adult salmonids are to promote migration and increase accessibility to available habitat by:

- Increasing pool depth before jumps to allow fish to accelerate for a leap attempt
- Reducing jump heights to within the range of jumping ability
- Reducing stream velocities to within salmonid swimming abilities
- Increasing flow capacity to accommodate 100-year flood events and associated debris in order to prevent future obstructions
- Maintaining or restoring bedload transport by preventing sediment buildup at the inlet or outlet
- Focusing low flows so that they are similar in depth to the natural channel

Figure 4. Baffles in a Modified Culvert Providing Velocity Refugia.
Source: USDA Forest Service

Currently, DFG provides criteria and design options for fish passage restoration in "Culvert Criteria for Fish Passage" (Flosi et al. 2002). There are three design options based on "hydraulic," "active channel," and "stream simulation" criteria.
There is the fourth option of an individually approved engineering design. Because there are so many potential treatments, effectiveness monitoring must focus on a few parameters that all have in common. Consequently, the focus of this method is on measurements of physical channel conditions. Ultimately, the primary indicator that a project or group of projects is effective is an increase in the number of fish of the targeted species and life stages migrating through the project site. Methods for quantitative biological monitoring are provided in validation monitoring protocols currently under development at Humboldt State University (Collins 2003).

EFFECTIVENESS MONITORING QUESTIONS AND STUDY DESIGN

Questions about the effectiveness of fish passage restoration practices will generally be centered on either alternative practices (e.g., modifying culverts by adding baffles or jump pools versus increasing culvert size) or on the effects of environmental conditions on practices (e.g., effects of stream size or geology on culvert upgrading effectiveness). In some cases, particularly critical passage improvement projects may be subject to single project effectiveness monitoring. Otherwise, passage improvement effectiveness may be determined through studies involving sampling of multiple sites over time. The following is a list of potential questions that might be addressed:

- Is the project (or projects) still functioning as designed?
- Have channel or bank adjustments impaired the function of the passageway(s)?
- Did the project (or projects) have adverse effects on upstream or downstream habitat?
- Is upstream habitat still suitable for the targeted fish species and life stages?

Questions related to fish presence during migration periods are not addressed with this report and are properly addressed through biological monitoring.

Unlike other quantitative methods, a before-after-control-impact (BACI) approach is not recommended here. Evaluating fish passage projects does not require a comparison to pre-treatment and/or control conditions. Instead the emphasis is on comparing measured physical conditions and specific design and performance criteria. This analytic approach has weaker inferential power than the BACI approach but can accommodate evaluation of some explanatory variables for determination of effectiveness.

Table 1 presents monitoring questions, appropriate parameters, effectiveness criteria, and field methods. For each parameter, specific numerical effectiveness criteria must be determined depending on the project design and the swimming abilities of the targeted species and life stage, both of which may vary from site to site.

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

MONITORING QUESTION	EFFECTIVENESS CRITERIA[1]	PARAMETERS	FIELD METHODS
1. Is the project still functioning as designed?		Fish passage restoration project is within DFG passage guidelines.	
a. Is there still a sufficient jump pool depth for targeted species and life stages?	Residual pool depth at downstream outlet (if culvert outlet is perched or has entry leap).	If there is a jump, pool depth is appropriate for leap height. (Not required for no entry leap)	Field Method 1: Thalweg Profile Through Culverts plus water depths
b. Are leap heights still within jumping ability for targeted species and life stages?	Leap height (residual pool water surface elevation to passage outlet.)	Leap height is below critical heights for targeted species and life stage. (Not applicable for no entry leap.)	Field Method 1: Thalweg Profile Through Culverts.
c. Is stream velocity in critical flow areas still within the swimming ability of the target species and life stages?	Stream velocity	Stream velocity is equal to or less than swimming ability of target species and lifestage.	Field Method 3: Stream Velocity/Discharge Measurements[1]
d. Is upstream inlet of the passage area/ structure still at grade or below the channel bed?	Bed elevation at inlet and inlet elevation	Difference between natural channel bed and inlet is 0.	Field Method 1: Thalweg Profile Through Culverts
e. Is the passage area/ structure still at grade?	Slope	Passage structure is at specific designed slope or the slope relative to the natural channel.	Field Method 1: Thalweg Profile Through Culverts
f. Can sediment bed load still pass through the restored area?	Slope (top riffle to opening), active channel width, hydraulic capacity	Passage inlet shows no signs of clogging or deposition.	Field Method 1: Thalweg Profile Through Culverts, Field Method 2: Cross-section Surveys

[1] Additional evaluation of velocity may be performed using modeling software such as FishXing.

MONITORING QUESTION	EFFECTIVENESS CRITERIA1	PARAMETERS	FIELD METHODS
g. Can the structure pass 100-year flows and debris?	Hydraulic capacity	Passage passes 100-year flows and watershed products.[2]	Field Method 2: Cross-section Surveys
h. Does the passage project shows signs of imminent failure?	Structural integrity	Structure shows no signs of collapsing.	Field Method 1: Thalweg Profile Through Culverts, Field Method 2: Cross-section Surveys
2 Have channel or bank adjustments impaired the function of the passageway?	Slope, head-cutting, sediment deposition	Channel adjustments have not impaired passage or habitat values.	Field Method 1: Thalweg Profile Through Culverts
3. Did the project have adverse effects on upstream or downstream habitat?	Bank erosion, channel incision / head-cutting, debris accumulation or sediment deposition.	Passage project has not adversely affected up and downstream habitat.	Field Method 1: Thalweg Profile Through Culverts. Field Method 2: Cross-section Surveys
4. Is upstream habitat still suitable for the targeted fish species and life stages?	Habitat types and quality in upstream reaches.	Area is still suitable for targeted species and life stages.	Habitat Monitoring See *Monitoring the Effectiveness of Instream Habitat Restoration*

Effectiveness at creating access to upstream habitat for targeted species and life stages depends on a combination of parameters. Where one or more parameters fail to meet design requirements, the project may remain a complete, partial, or temporal barrier. Partial barriers are impassable at all flows to *some* species during some or all life stages. For example, a partial barrier may be passable for adults, but not juvenile salmonids. Temporal barriers limit access at specified flow regimes. Both partial and temporal barriers may result in under-utilization of upstream habitat (Flosi et al. 2002). The critical limiting parameters for fish passage may vary by species, life stage and local contributing biological and physical factors.

There may be instances of disagreement between biological evaluations of effectiveness and evaluations of effectiveness based on physical habitat parameters. For example, biological monitoring may show that there is no increase, or a decrease in presence of fish above the project, while the passage structure still meets its design criteria. In such cases, additional investigation should be conducted to identify if local fish populations have migration needs not met within the design criteria, or if other factors are preventing passage. If the passage restoration fails to meet design thresholds, yet fish abundance has increased above the structure, then the monitoring data may be useful in understanding local biological trends relative to physical constraints.

Also, fish abundance must be understood in a broader watershed context, beyond individual passage projects. Land use changes such as urbanization, or natural events such as forest fires may impact project effectiveness and should be considered.

[2] For some projects, such as in urban areas, passage of 100 year debris flows may be waived as a requirement. In such cases, monitoring the capacity for passing debris and watershed products should continue, but may not be factored into final evaluations of effectiveness.

The timing and intensity of monitoring should be determined within specific study plans for any application of these field methods. After project completion, effectiveness monitoring should occur after one or more winters and following major stressing events. Generally, pre-project, as built, and post-implementation project data should be available before effectiveness monitoring is initiated. For specific critical projects, with fish passage improvements in particularly important locations, monitoring intensity and frequency may be higher to allow for adaptive management. Also, timing may be determined by site and species specific factors for monitoring during migration flows.

For accessibility and safety, monitoring should be performed during low flow conditions. More intensive sampling may include observations during higher migration and spawning flows to evaluate passage capacity and velocities through the passage area. Visits during migration-level flows may also permit the observation of fish movement/behavior through the crossing, as well as an assessment of the crossing's ability to pass storm flow and other watershed products (large woody debris [LWD] and bedload). Although flow capacity and velocity should have already been evaluated in the design, implementation, and post-implementation monitoring phases of the project, changes in the watershed (e.g., wildfire, urbanization, intensive timber harvesting) may cause design specifications to be exceeded. Attendant changes in channel morphology and passage characteristics may warrant re-measurement of velocities through the site.

DATA QUALITY

It is assumed that studies using these methods will be conducted by agency staff, or experienced consultants or practitioners who are trained in the design and evaluation of fish passage projects. Data quality objectives are inherent to the field methods presented here. Additional data quality objectives should be described within specific study designs. Generally, measurements taken during surveys should be accurate to 0.01 feet. Quality control will be achieved through a combination of: 1) initial training, 2) error checking in the field, 3) repeat surveys by independent surveyors, and 4) follow-up training.

FIELD METHODS

The first step in effectiveness monitoring is to gather previously collected project data. This includes data on location, pre-project conditions, design specifications, as built conditions and implementation monitoring. Pre-project data should include details on project location, channel slope and channel cross-sections. Design specifications, "as built" specifications, and post-implementation monitoring data should include flow, sediment, and debris capacity, headwater depth to capacity ratio, and channel slope and cross-sections.

Delineation of the Study Area

Whether measuring structures or channel conditions the study area should include both the discrete project area and the stream reaches above and below it. Stream reach study area locations are to be documented according to methods found in *Documenting Salmonid Habitat Restoration Project Locations.*

Field Method 1, described below, pertains to measurement of thalweg profiles. To determine slope and other channel characteristics, the thalweg profile should extend a minimum of twenty channel widths above and below the passage restoration. This length must include the tailwater control above the first resting pool upstream of the passage project and the downstream tailwater control (Figure 5). It is also important to include the construction disturbance zone to capture any bank and channel effects resulting from any restoration practices, such as use of heavy machinery in the channel. Permanent cross-sections should be located at the passage inlet, outlet, and downstream tailwater control. Cross-sections at the inlet and outlet will provide measurements of bank and channel conditions that influence flow through the passageway.

Field Method 1: Thalweg Profile Through Culverts

Thalweg profiles are used to assess changes in the slope and condition of the channel bed and passageway. The thalweg profile measures the elevation of the channel bed or passageway below, through, and above the project area relative to a benchmark. These data allow monitoring of change in slope and morphology of the channel or passageway, facilitating interpretation of channel incision and sediment deposition over time. Also, while performing the longitudinal profile, observations of obstructions within the passageway may indicate a need to establish cross-sections to measure reduction in hydraulic capacity. Parameters that are derived from the thalweg profile include residual pool depth, leap height, channel and passageway slope, and bed elevation at the inlet.

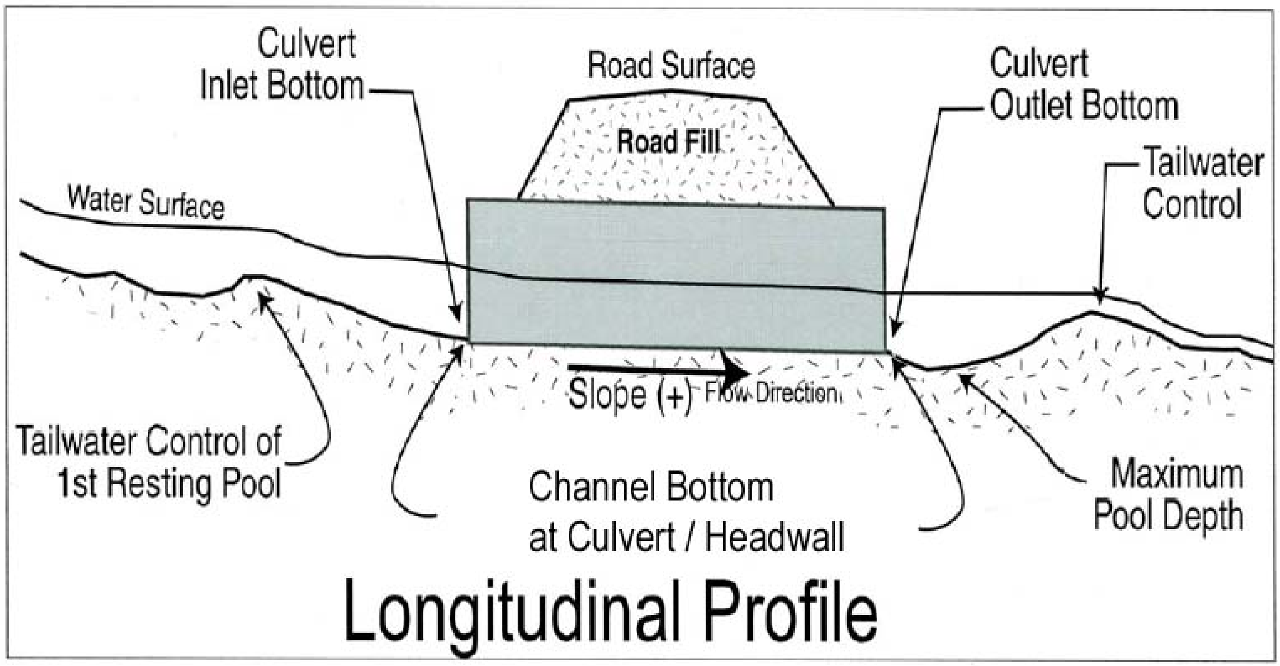


Figure 5. Longitudinal Survey Points at the Passage Structure.

Individual study objectives should determine the degree to which effects such as deposition or incision in the channel will impact project effectiveness. A certain amount of incision or deposition may be beneficial to a project. For example, during a culvert replacement project, it may not be possible to remove all of the sediment that had been stored upstream of an undersized crossing. Part of the restoration design may include increasing the hydraulic capacity of a new crossing which might induce a small amount of upstream incision through the stored fill, gradually returning the stream to natural stream grade. Therefore, the amount of allowable incision or deposition should be specified in the project design and within any monitoring study design.

Determination of Profile Length
To determine slope, the thalweg profile should extend at least twenty active channel widths above and below the passage restoration. The twenty channel widths minimum is commonly used in surveying thalweg profiles in order to capture the natural variability of the channel (Harrelson et al. 1994, Ramos 1996). The profile length may need to be longer if the passage restoration is likely to cause adjustments to the channel, such as large differences between the pre- and post-project channel slope or hydraulic capacity. The profile length must include the tailwater control above the first resting pool upstream from the passage project and the downstream tailwater control. Profile length may be adapted to fit the specific site conditions and monitoring question to be addressed. For example, on channels with highly erodible beds where adjustments may be significant, profiles may be extended to grade control points such as upstream or downstream crossings, rock outcrops or debris jams.

Field Sampling Method
For an overview of surveying procedures and concepts see Harrelson et al. (1994) and Ramos (1996). Also, read Part IX of the Restoration Manual, Fish Passage Evaluation at Stream Crossings (Flosi et al. 2002).

- Before leaving for the field, gather all previous location, project, and surveying benchmark and elevation data. In the field, relocate any previously monumented surveying benchmarks to establish the reference elevation.
- To determine the extent of the survey reach, use a surveyor's tape to measure a minimum of five upstream active channel widths. These measurements should be taken in runs where channel width and bank stability are more uniform rather than in pools or riffles. Taking width measurements in pools or in wider areas of the channel can cause an over-estimate of average channel width. Calculate the average channel width. The minimum length of the thalweg profile should extend at least 20 channel widths or 100 feet (which ever is greater) above and below the passage restoration. A longer profile may be required where channel stability is of greater concern.
- Set benchmarks in a safe place on the bank to mark the upper and lower limits of the profile. Benchmarks should be placed by pounding 3 foot x 3/8 inch length of rebar at least 2 feet into the ground with a cap or placing a 10 inch nail approximately 8 inches deep into the base of a stable tree. Take detailed notes on all benchmark locations and mark them with brightly colored flagging (see *Documenting Salmonid Habitat Restoration Project Locations*).
- To begin the survey, set up the total station or autolevel in a location that is safe from traffic, and has the best unobstructed view of benchmarks and as much of the upper and lower reaches of the channel as possible. This will reduce the sources for error and the number of turning points required to complete the survey.
- Starting from the upstream end of the thalweg profile, take measurements at frequent intervals, at least every ten to twenty feet. Be sure to take channel measurements at the top and bottom of changes in slope, such as head-cuts, and natural or man-made grade controls. Readings should also be taken at the start and end of riffles and runs, and the start, end, and bottom of pools. Multiple readings may be necessary to determine the deepest part of pools.
- Be sure to characterize the upstream tailwater control above the passageway, if any. The upstream tailwater control is the first pool tail-out or riffle crest upstream from the passageway (Figure 5).
- If the passageway is not sufficiently sized to walk through, pass the surveyor's tape through the passageway. Measure the bed and invert at the passageway inlet and outlet to calculate

slope. Look through the passageway to see if there is any structural damage, and measure any gradient breaks or bends in the passageway.

At the outlet, measure the passageway invert and the channel bed, including the outlet pool, pool tail-out, and tailwater control, if any. Proceed downstream surveying the thalweg profile. The tailwater control can be identified in the field as:

- A pool tail-out below the crossing outlet
- A natural or man-made weir or grade control structure
- Cross-section location within five feet of the outlet, if there is no flow impeding structure

Surveying with a total station, although more costly in terms of the required equipment and training, greatly increases speed and accuracy by reducing the error and time inherent in using a tape, auto-level, and stadia rod. Benchmarks and cross-sections can be relocated with more accuracy, even when monuments have been lost. Time is also saved during data entry and analysis. For all surveying, establishment of well-documented, easily discoverable benchmarks and orientation points (for total stations) is critical.

Data Analysis
For thalweg profiles, bed elevation is the response variable and is used to calculate the following measurements:

- Upstream, passageway, and downstream slope
- Bed elevations upstream from passage and at passage inlet
- Outlet jump height (Residual Outlet Drop)
- Changes in tailwater control elevations

Evaluating Changes in Slope. Several design approaches are based on specific criteria regarding a natural channel slope and the slope of the passageway itself. In the active channel design, for example, culverts are placed at 0 grade. In the stream simulation approach, culverts are placed at the same slope as the natural stream gradient, as long as the natural slope is less than six percent (DFG 2002). Furthermore, culverts with grade greater than three percent must include some form of grade control structure, with specific limits. For these and similar design criteria, slope should be calculated as:

*Slope (percent) = (Difference in elevation / horizontal length) *100*

As previously noted, individual study objectives should determine the degree to which deposition or incision in the channel will impact project effectiveness. Channel adjustments in excess of those prescribed in the design cause detrimental impacts on upstream habitat quality, such as a migrating head-cut.

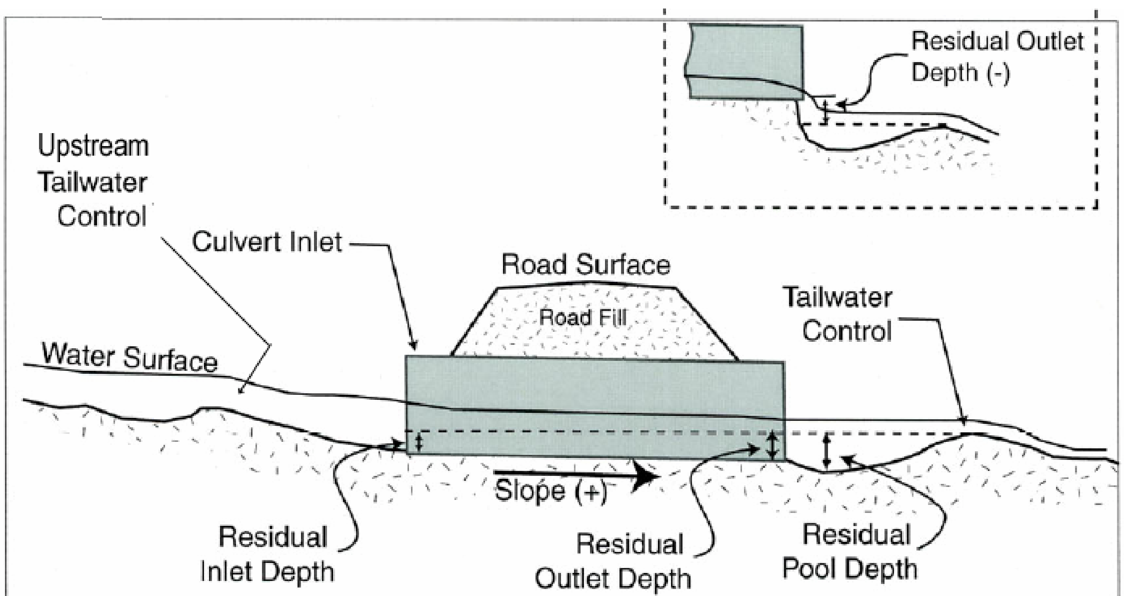
Evaluating Channel Changes .When a passage structure fails to pass the full range of flows, ponding and subsequent debris and sediment buildup may occur upstream. Depending on the passage design, bed elevations can be compared with design criteria to evaluate channel slope, inlet transitions, and potential reduction in passage capacity due to debris or velocity barriers at the culvert inlet. If survey data show increased or decreased bed elevation at the inlet, determine whether or not these changes are beneficial or detrimental to the restoration objectives, including flow capacity. Actual passageway capacity cannot be characterized by longitudinal profile surveys alone. Cross-section surveys at the inlet and possibly within the passageway itself would be required.

Evaluating Outlet Jump Height. Changes in downstream flows can cause changes in the channel bed below the passage. These in turn can affect the flow conditions for fish. Longitudinal profile elevation data should be used to reevaluate jump pool depth and the inlet jump height below restored passage structures (Figure 6). Calculate jump heights, or residual outlet drops as follows:

$$\textit{Residual outlet depth} = \textit{Elevation}_{\textit{Tailwater Control}} - \textit{Elevation}_{\textit{Outlet}}$$

Calculate jump pool depth as residual pool depth as follows:

$$\textit{Residual pool depth} = \textit{Elevation}_{\textit{Tailwater Control}} - \textit{Elevation}_{\textit{Pool Bottom}}$$



Residual Pool Depth = (Elev $_{\text{Tailwater Control}}$ - Elev $_{\text{Pool Bottom}}$)

Residual Outlet Depth = (Elev $_{\text{Tailwater Control}}$ - Elev $_{\text{Culvert Outlet}}$) (If Residual Outlet Depth is less than zero it is referred to as the Residual Outlet Drop)

Residual Inlet Depth = (Elev $_{\text{Tailwater Control}}$ - Elev $_{\text{Culvert Inlet}}$)

Figure 6. Calculations Obtained from Longitudinal Profiles Through Passage Structures
Source: Flosi et al. 2002.

Instructions for Completing the Longitudinal Profile 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/Road 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) **Drainage Name—**Enter the name of the main drainage basin that the stream is a tributary to.
7) **Crew—**Enter the names of the crew member operating each survey instrument using the following format: *last name, first initial*.
8) **Description of Survey-** Describe the type of survey being conducted, long profiles are typically numbered as LP1, LP2, etc. Also record where in the project area the survey is occurring. This may be an abbreviated description as all reference points, project locations, benchmarks, etc. should be separately described and mapped using the methods and data forms contained in *Documenting Salmonid Habitat Restoration Project Locations*.
9) **Measurement Units-** record the units of measurements used in the survey. 'Feet and tenths' and 'meters' are the most common units.
10) **Station Number—**Enter the distance from the beginning point of the survey to the point where the elevation measurement is recorded. Benchmarks (BM) and Turning Points (TP) are recorded here as well. Longitudinal surveys may start at a benchmark, reference point, monumented cross section, or other permanent feature. Locations of survey end points are recorded using methods described in *Documenting Salmonid Habitat Restoration Project Locations.*
11) **Offset –** is the perpendicular distance between the long profile tape and the thalweg. Offset is only recorded when plotting thalweg locations along a long profile survey.
12) **(+) BS—Back Sight** is a rod reading taken on point of known elevation, this reading is entered as a positive value.
13) **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.
14) **(-) 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.
15) **Elevation—**is the actual elevation of the point in question, calculated from HI, BS, or FS readings.
16) **Comments-** are used to describe points where elevation measurements were recorded. Common notations include: LEW (left edge of water), REW (right edge of water), CLP (center line of profile), etc. See Harrelson et al. (1994) for list of common survey notes.

LONGITUDINAL PROFILE FIELD DATA COLLECTION FORM **Page ___ of ___**

Contract #: **Contract name:**

Stream/Road: **Date:**

Drainage:

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

Description of Survey (i.e. stream reach, cross section number, gully number, etc.
Refer to location protocol for overview of site and descriptions of points**):**

Measurement Units:____________

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

Field Method 2: Cross-Section Surveys

Cross-sections are used to assess changes in the condition of the channel bed and banks at particular locations, and to make inferences about channel form, stability, and passage capacity. A channel cross-section measures the elevation of the channel bed across the entire channel or structure width.

A minimum of three cross-sections should be measured at each passage project location. Permanent cross-sections should be located at the passage inlet, outlet, and downstream tailwater control (Figure 7). The cross-section at the passage inlet and outlet will measure channel scour, sediment deposition, bank conditions, the alignment of the passage restoration with the channel, as well as changes in the capacity of the passage structure. Additional cross-sections may be measured within a passage structure to characterize obstructions that limit capacity. The cross-section at the downstream tailwater control will measure any changes to hydraulic control for the water surface at the outlet as a result of aggradation or incision of the channel.

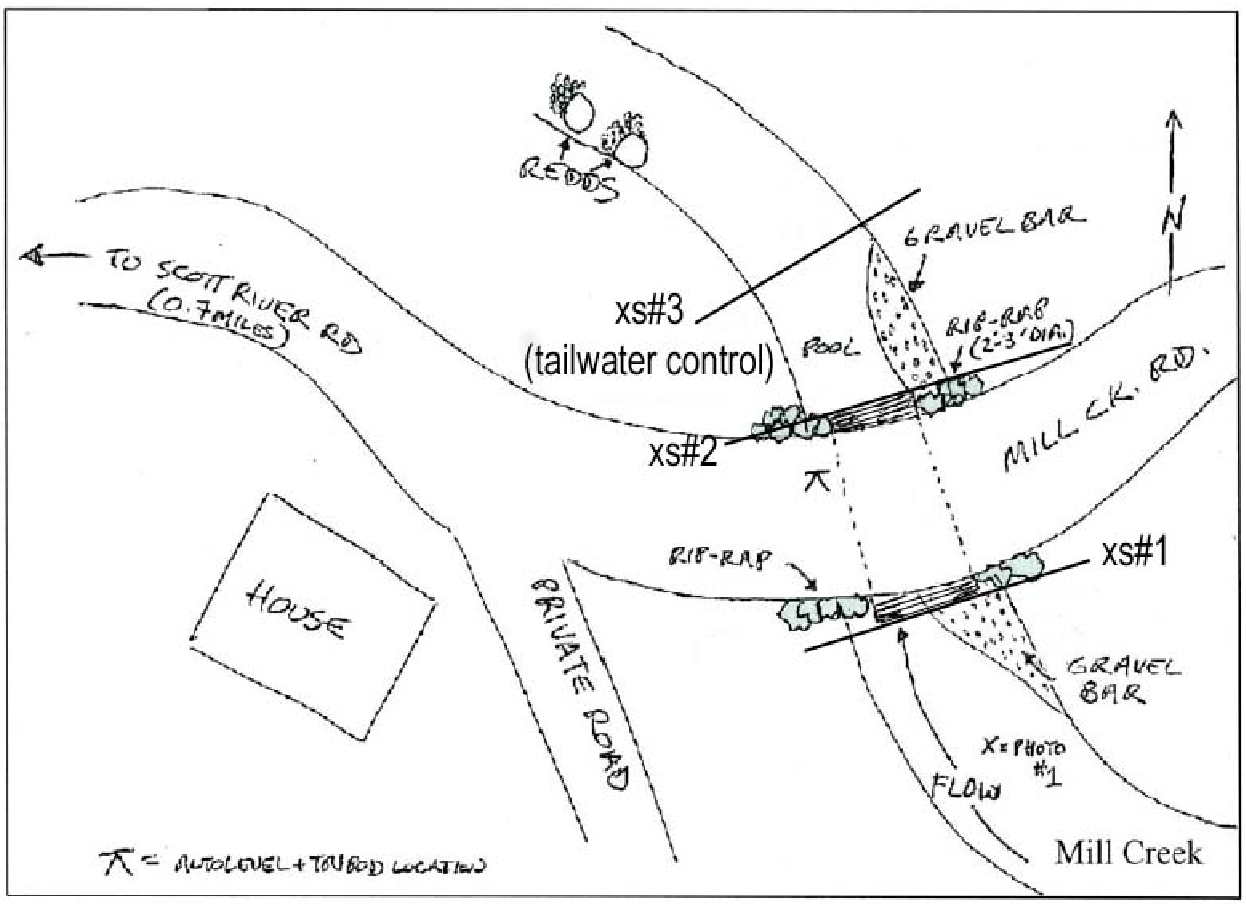


Figure 7. Sketch Map Example of Restoration Site and Cross Section Locations.
Source: Adapted from Flosi et al. 2002.

Cross-section surveys may be conducted during thalweg profile surveys if careful attention is paid to maintaining clear notes on how and where surveys begin and end. The procedure described for locating permanent benchmarks and endpoints should be used for every cross-section installed, including recording bearing and distance between endpoints (see *Monitoring Effectiveness of Instream Habitat Restoration, Field Method 3: Channel Dimensions*).

The technique for surveying cross-sections is similar to the method for longitudinal profiles except measurement points are spaced more closely. The precision of a cross-section is directly related to the number of elevation measurements taken. 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. Usually, measurement points are predefined by an interval (e.g., every two feet) with additional points at every significant break in slope (e.g., top and bottom of banks, terrace edges, toe of slope, thalweg). Measurements may need to be closely spaced (at two-foot intervals or less, depending on channel size) in the active channel to ensure locating the thalweg. The precision of measurement required will depend on the complexity of the channel but the principle objective should be to obtain the data points required for analysis.

The elevation and station at the left and right edges of water are recorded. Noting the location of "bankfull discharge elevation" may be helpful for some analyses (such as width/depth ratios), but is difficult to repeat between visits or observers. Indicators used to determine bankfull elevation are described in Harrelson et al. (1994) and in *Monitoring Effectiveness of Instream Habitat Restoration*. Observations along the channel margins such as vegetation lines, active channel boundary, and water's edge may be helpful.

Field Sampling Method
For a general overview of surveying procedures and concepts see *Monitoring Effectiveness of Instream Habitat Restoration* and Harrelson et al. (1994).

- Monument the right and left bank beginning points of each cross-section with permanent markers referenced to permanent bench marks (see *Documenting Salmonid Habitat Restoration Project Locations*). In order to preserve endpoint benchmarks, place them outside of the channel, several feet beyond what might be considered "top of bank."
- Begin at permanent endpoints on the floodplain, at least five feet from the channel edge, and take elevation readings at regular intervals all the way across the channel. Spacing between readings may be every two feet.
- If there is a visible obstruction within a wadeable crossing that may be reducing capacity, create a cross-section within the structure so that it passes through the obstruction. This may be a debris jam or sediment wedge. Note the location of the cross-section and obstruction relative to the passage inlet and the station in long profile.
- Be sure to collect data at the top of endpoint markers, the ground at endpoints, the tops of banks, breaks in slope, the toe of each bank, vegetation lines, the water edge, the thalweg elevation, the bed at structure inlets and outlet, and note when in line with the edges of structure inlets and outlets.
- Measure the elevation of the bed at intersections with the thalweg profile.
- Take notes on the depth of stream water in pools and riffle crests.

Data Analysis
At the most basic level, successive cross-section surveys are simply overlain and observations of changes are made: including changes in depth as a result of scour or fill. This type of comparison works well for fish passage projects. Bed elevation is the response variable, especially in critical locations, such as the upstream inlet, the outlet, and the downstream tailwater control.

Upstream Inlet. Evaluate vertical and lateral scour and deposition. The bed may have aggraded with sediment, reducing passage capacity, or it may have eroded creating a perched inlet. Lateral scour and erosion may also have implications for reduction in capacity, perching, and alignment between the structure and the channel.

If survey data show increased bed elevation at the inlet, determine whether or not it can still pass design flows and associated watershed products. Often a design may specify an inlet capacity sufficient to pass flows at a specific percent or ratio of the structure's capacity as a headwater to depth ratio (HW/D). For example, a headwater depth ratio $HW/D \leq 0.67$, may be specified in the design. Where specified in the design, reevaluate the cross section data of the passage to yield the HW/D ratio and compare it to the design specifications.

Downstream Outlet. Evaluate vertical and lateral scour and deposition. The bed may have aggraded with sediment, reducing passage capacity, or it may have eroded creating a perched outlet. Lateral erosion may also have implications for structural stability.

Tailwater Control. Evaluate vertical and lateral scour and deposition. Changes in the tail water control may worsen or improve passage conditions relating to the residual pool depth and entry into the passageway.

Instructions for Completing the Channel Dimensions 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/Road 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) **Drainage Name—**Enter the name of the main drainage basin that the stream is a tributary to.
7) **Crew—**Enter the names of the crew member operating each survey instrument using the following format: *last name, first initial*.
8) **Description of Survey-** Describe the type of survey being conducted, typically 'long profile' or 'cross section'. Also record where in the project area the survey is occurring. This may be an abbreviated description as all reference points, project locations, benchmarks, etc. should be separately described and mapped using the methods and data forms contained in *Documenting Salmonid Habitat Restoration Project Locations*.
9) **Measurement Units-** record the units of measurements used in the survey. 'Feet and tenths' and 'meters' are the most common units.
10) **Station Number—**Enter the distance from the beginning point of the survey to the point where the elevation measurement is recorded. Benchmarks (BM) and Turning Points (TP) are recorded here as well. All cross sections start at 0 on the left bank side and end at the right bank end point. Longitudinal surveys may start at a benchmark, reference point, monumented cross section, or other permanent feature. Locations of survey end points are recorded using methods described in *Documenting Salmonid Habitat Restoration Project Locations.*
11) **Offset –** is the perpendicular distance between the long profile tape and the thalweg. Offset is only recorded when plotting thalweg locations along a long profile survey.
12) **(+) BS—Back Sight** is a rod reading taken on point of known elevation, this reading is entered as a positive value.
13) **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.
14) **(-) 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.
15) **Elevation—**is the actual elevation of the point in question, calculated from HI, BS, or FS readings.
16) **Comments-** are used to describe points where elevation measurements were recorded. Common notations include: LEW (left edge of water), REW (right edge of water), CLP (center line of profile), etc. See Harrelson et al. (1994) for list of common survey notes.

CHANNEL DIMENSIONS FORM

Page ___ of ___

Contract #: **Contract name:**

Stream/Road: **Date:**

Drainage:

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

Description of Survey (i.e. stream reach, cross section number, gully number, etc. Refer to location protocol for overview of site and descriptions of points**):**

Measurement Units:____________

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

Field Method 3: Stream Velocity/Discharge Measurements

Reducing velocities during migration flows is often the objective in fish passage restoration projects, especially those projects following hydraulic design guidelines (DFG 2002). The goal of this field method is to quantify an average velocity and high velocities through a passage area between resting habitats. These velocities would be compared with the swimming abilities of the targeted species and life stages. If the passage has a natural bed, and the channel is unconfined, such as with a bridge, velocity may not be of concern.

Average velocities do not accurately represent the slower velocities that fish take advantage of at the flow margins. Consequently, the field method presented here has limitations. Alternatives to this field method may include using use of modeling software and field survey data to model migration flow velocities (Flosi et al. 2002).

Velocity measurements should be taken during ordinary migration flows for the targeted population. Consult local fisheries biologists for migration flow information or for using annual exceedance flows to estimate migration flows.

Figure 8. Conducting Velocity Measurements on a Cross Section in a Natural Bottom Culvert. *Source:* George Robison

Do not enter the channel or structures during dangerous flow conditions.

The equipment required for this field method includes:

- Stream wading equipment and clothing
- Surveying equipment
- 50 foot surveyors tape
- Flow meter (such as a USGS Price Type AA or “mini”), spare parts and batteries (if required)
- Graduated wading rod
- Data forms

Field Sampling Method

The general procedure for monitoring stream velocities is the same as that for discharge, except that points of high velocity along the length of project passageway are the targeted areas for measurement. Measurements are taken at temporary cross-sections at various stations along the longitudinal profile.

- First, determine the length of the channel where measurements are to be taken. This may be between resting habitat, such as pools or where the channel widens, such as at the inlet or outlet of the passage.
- Then, determine the number of cross-sections where velocity will be measured. Critical measurements include just inside the inlet and outlet of the passageway. If the passage is large enough and wadeable, the number of cross-sections is determined by the culvert length. One cross-section at the inlet, outlet, and center of the passage is the minimum. The more readings taken along the length of the culvert, the more detailed will be the definition of the longitudinal variation in velocity. If the passage is not wadeable, take readings by extending the wading rod into the passage inlet and outlet.
- At each cross-section, determine the number of measuring stations. With a surveyors tape, measure the wetted width, and then, divide by 25 (for wider streams), or less for smaller streams. Try to capture variations in the changes of flow over the cross-section. Record the interval distance. From the left bank, measure one interval distance. This will be the first "cell" where velocity will be measured. Take a velocity reading at the midpoint of each cell, at 0.6 of the depth. If the cell is deeper then 0.75 meters, take readings at 0.8 and 0.2 of the depth.
- Record the readings and move on to take readings at the midpoints of the remaining cells (Figure 9).

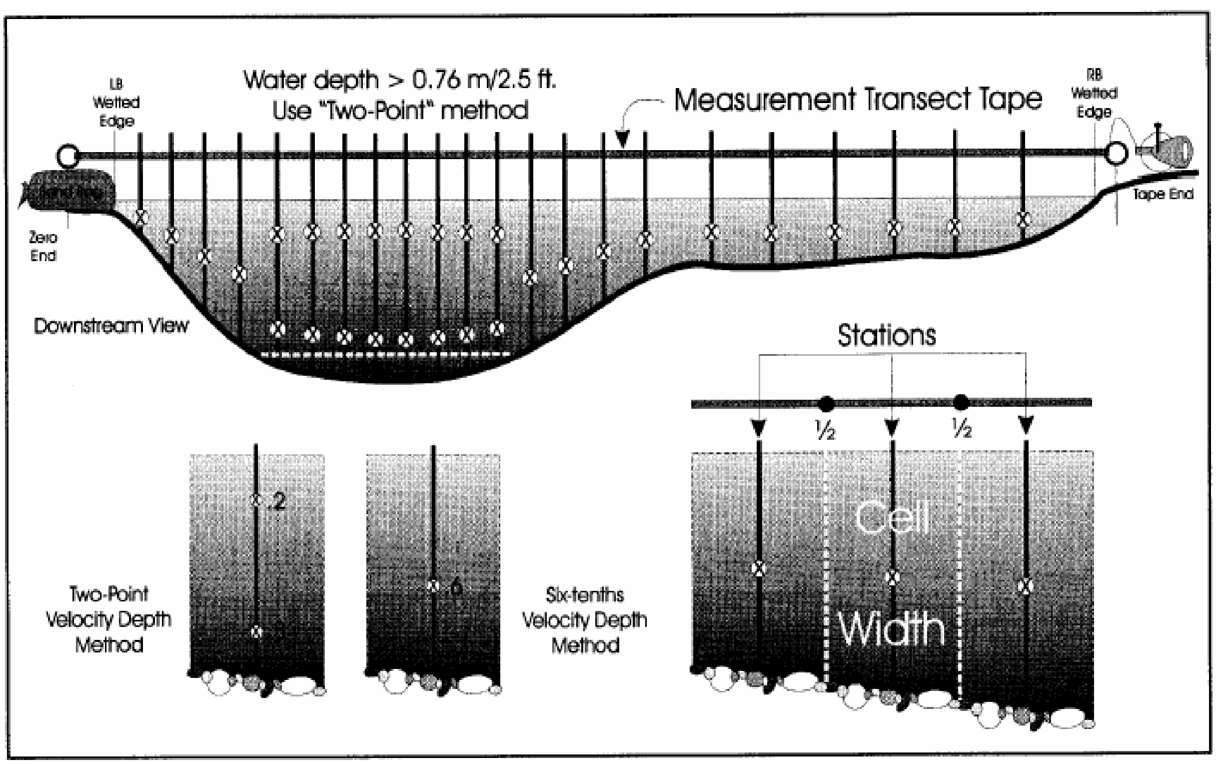


Figure 9. Stream Water Velocity Measurement Locations.
Source: Adapted from Pleus 1999.

Data Analysis
For each velocity cross-section, calculate the average velocity and note the high and low velocities.

Average Velocity = Sum Of Each Cell Velocity ÷ Number Of Cells.

Using longitudinal profile horizontal stationing, plot the high, low, and average velocities. Display this data on a graph with the longitudinal profile. High, low, and average velocities can then be compared to the swimming abilities of the targeted species and life stages to evaluate the passage restoration performance. A velocity profile may also be plotted on cross-sections, as in Figure 10.

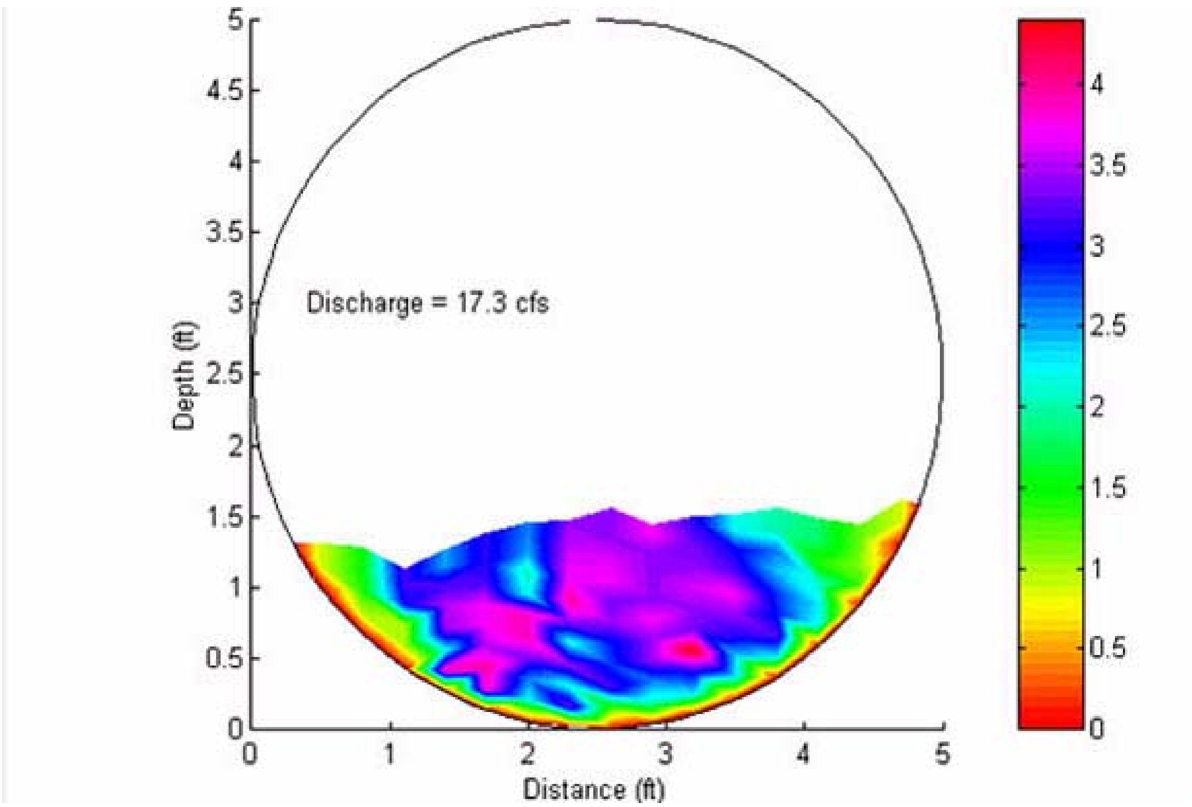


Figure 10. Distribution of Water Velocities Inside a Culvert at a Cross Section.
Source: USDA Forest Service.

Instructions for Completing the Stream Velocity Profile 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 and name 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 survey crew in the following format: *last name, first initial*.
7) **Transect # & Length—**Enter the transect # and total length of the completed cross-section.
8) **Unit of measure—**Circle the unit of measure: meters, feet/tenths, feet/inches.

Velocity Data—Section 2

9) **Station number—**Enter the cross section station number where velocity is being measured.
10) **Tape Distance—**Enter location on the surveying tape where velocity is being measured.
11) **Width #1—**Subtract the tape distance of the current reading from the tape distance of the last reading, and divide by two. *Subtract* that difference from the station of the current reading.
12) **Width #2—**Subtract the tape distance of the current reading from the tape distance of the last reading, and divide by two. *Add* that difference to the station of the current reading
13) **Cell Width—**Add Width #1 and Width #2.
14) **Station Depth—**Enter the depth the cell.
15) **Velocity #1 and #2—**Enter the velocity measurement(s), (#1 for 0.2 and 0.6 depth measurements, and if depth is greater than 2.5 feet, #2 for 0.8 depth measurements).
16) **Discharge—(Optional)** This step is not required for a velocity profile. To calculate discharge multiply cell width by cell depth, then again by the velocity.
17) **Comments—**Enter the long profile stationing and any comments.
18) **Width—**Enter the wetted width of the stream.
19) **Average Depth—**Sum the depths of each station, and calculate the average.
20) **Area—**Multiply the Width by the Average Depth.
21) **Average Velocity—**Sum and average the velocities from all stations.
22) **Highest Velocity—**Enter the highest velocity measured at a single station.
23) **Lowest Velocity—**Enter the lowest velocity measured at a single station.
24) **(Optional)** Enter the Average discharge for the cross-section by multiplying the area by the average velocity.

STREAM VELOCITY PROFILE DATA COLLECTION FORM Page ____of_____

Contract #:___________________________ **Contract name:**____________________________

Stream/Road:____ **Date:** _____________

Drainage:____

Crew____

Transect # ____________________ **Transect Length**________________

Unit of Measure: (Feet/tenths, Meters) ___________________

Description of Survey (i.e. stream reach, cross section number, gully number, etc.

Refer to location protocol for overview of site and descriptions of points**):**

Lb edge:		Rb edge:		Length:		Station Interval:			
	a	b	c	d=b+c	e	f	g	h=(f + g)/2	q'=dxexh
Sta #	**Tape Distance**	**Width #1**	**Width #2**	**Cell Width**	**Sta Depth**	**Velocity #1**	**Velocity #2**	**Station Velocity**	**Discharge**
									-

Comments:____

____

____

Summary:

Width(ft):____________

Average Depth (ft):_____________ Width:_________ x Ave Depth:_________ = Area:_________

Average Velocity (ft/s):_______

Highest velocity:_________

Lowest Velocity:_________ Area:_________ x Ave Velocity:________ = cfs:_______

STREAM VELOCITY PROFILE DATA COLLECTION FORM Page_1__ of __1___

Contract #:_P0000_ **Contract Name:** ______________________________

Stream/Road:______________________________ **Date:** ______________________________

Drainage: ____

Crew-Level: __Jill, J (wading rod), John,G (notes)_ **Recorder:** ______________________________

Transect #:_1____ Transect length:__16 feet____

Unit of Measure: *(Feet/tenths, Meters)*

Description of Survey (i.e. stream reach, cross section number, gully number, etc.

Refer to location protocol for overview of site and descriptions of points**):**

Lb edge:	1.40	Rb edge:	13.80	Length:	12.40	Station Interval:		0.50	
	a	b	c	d=b+c	e	f	g	h=(f + g)/2	q'=dxexh
Sta #	**Tape Distance**	**Width #1**	**Width #2**	**Cell Width**	**Sta Depth**	**Velocity #1**	**Velocity #2**	**Station Velocity**	**Discharge**
Lb edge	1.4								
1	1.9	0.50	0.25	0.7	0.4	0.220		0.220	
2	2.4	0.25	0.25	0.5	0.3	0.215		0.215	
3	2.9	0.25	0.25	0.5	0.6	0.235		0.235	
4	3.4	0.25	0.25	0.5	0.6	0.220		0.220	-
5	3.9	0.25	0.25	0.5	0.4	0.300		0.300	
6	4.4	0.25	0.25	0.5	0.4	0.335		0.335	
7	4.9	0.25	0.25	0.5	0.3	0.300		0.300	
8	5.4	0.25	0.25	0.5	0.6	0.250		0.250	
9	5.9	0.25	0.25	0.5	0.7	0.250		0.250	
10	6.4	0.25	0.25	0.5	0.8	0.300		0.300	
11	6.9	0.25	0.25	0.5	0.9	0.400		0.400	
12	7.4	0.25	0.25	0.5	0.8	0.500		0.500	
13	7.8	0.25	0.25	0.5	0.9	0.400		0.400	
14	8.3	0.25	0.25	0.5	1.1	0.300		0.300	
15	8.8	0.25	0.25	0.5	1	0.540		0.540	
16	9.3	0.25	0.25	0.5	1	0.500		0.500	
17	9.8	0.25	0.25	0.5	1.2	0.550		0.550	
18	10.3	0.25	0.25	0.5	1.2	0.550		0.550	
19	10.8	0.25	0.25	0.5	0.7	0.400		0.400	
20	11.3	0.25	0.25	0.5	0.6	0.350		0.350	
21	11.8	0.25	0.25	0.5	0.5	0.400		0.400	
22	12.3	0.25	0.25	0.5	0.3	0.200		0.200	
23	12.8	0.25	0.25	0.5	0.3	0.150		0.150	
24	13.3	0.25	0.25	0.5	0.2	0.100		0.100	
Rb edge	13.8	0.25	0.5	0.744					

Comments:____

Summary:

Width(ft):_______16

Average Depth (ft):___*0.658333*

Average Velocity (ft/s):_*0.33*__

Highest velocity:__*0.55*___

Lowest Velocity:__*0.1*____

Width:__*16*_____ x Ave Depth:__*0.66*___ = Area:_*10.56*___

Area:__*10.56*__ x Ave Velocity:_*0.33*__ = cfs:__*3.5*_

Field Method 4: Habitat Typing

Habitat typing is used to characterize the quality of upstream habitat made accessible by the passage improvement. Sequential habitat typing may be used to determine if any changes have occurred due to the project e.g., upstream deposition or scouring. It should be done using the method provided in *Monitoring Effectiveness of Instream Habitat Restoration*.

HISTORY OF REPORT DEVELOPMENT AND REVISION

This report was initially developed in January 2004 and greatly benefited from review by Ross Taylor. Velocity profile methods were adapted from Pleus (1999). Field-testing was conducted during summer 2004. The report was subsequently revised into its present form based on field testing and peer review.

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