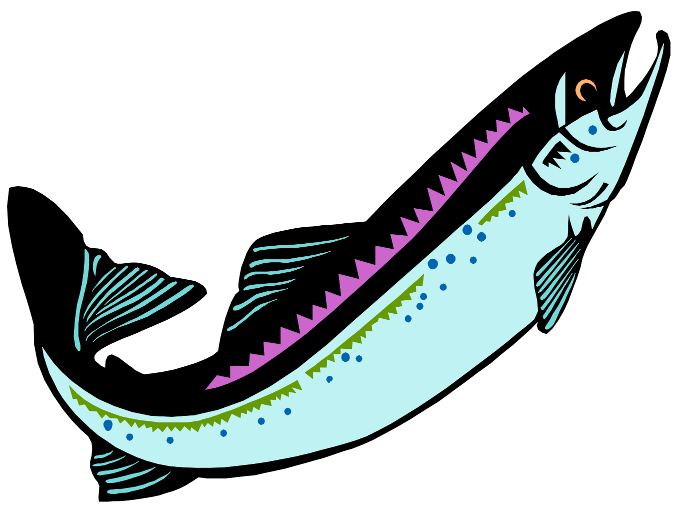
# Monitoring the Effectiveness of Instream Habitat Restoration

Final Report



*Prepared for:*

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

*Prepared by:*

**Center for Forestry, University of California, Berkeley**
**Richard R. Harris, Principal Investigator**

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## INTRODUCTION

The composition and distribution of physical habitat elements within the stream channel affect its suitability for salmonids. Habitat requirements vary among salmonid species and at different stages of their life cycles. The goal of instream habitat restoration is typically to create or enhance habitat elements thought to be deficient for targeted species and/or life stages, i.e., “limiting factors.” Lack of summer or winter rearing habitat, limited spawning sites and lack of hiding cover are limiting factors that are commonly cited in proposals for instream restoration.

Roni et al. (2004a) provides a comprehensive review of instream habitat improvement projects. On the California coast, most instream restoration includes construction or placement of boulder and/or large woody debris (LWD) structures within the stream channel. These projects may improve habitat and result in higher fish populations almost immediately (Hopelain unpublished, House and Boehne 1985, Olson and West 1990, Cedarholm et al. 1997, Solazzi et al. 2000, Roni and Quinn 2001). They also may be destroyed due to high streamflow events or improper placement (Ehlers 1956, Babcock 1986, Hamilton 1989, Frissell and Nawa 1992). If they survive, beneficial effects may decline over the long term (Thompson 2002). Questions that pertain to monitoring these projects include:

- Whether or not structures meet their objectives for creating physical habitat,
- If physical objectives are met, whether or not an appropriate biological response occurs, i.e., validation monitoring and,
- If physical and biological objectives are met, how long these effects persist.

This report provides guidance for monitoring the responses of physical habitat to instream structure placement and the longevity of those responses at the site and/or reach level. Methods for evaluating biological responses are available elsewhere (Collins 2003). The report is intended for use in developing monitoring study plans. Those plans may pertain to the performance of a single project or the performance of instream habitat restoration practices in general. Users are expected to have education and experience in stream sampling.

Many stream condition inventory techniques exist (Johnson et al. 2001) and were reviewed during the development of this report. In addition, many professionals experienced with the various methods were consulted for advice. The methods presented in this report have been adapted for specific application to restoration effectiveness monitoring on the California coast. Study designs based on this report may be used to determine the effectiveness of specific project designs in different geomorphic or regional settings; or to compare the effectiveness of different designs in achieving similar objectives.

## RESTORATION OBJECTIVES

This report applies to projects involving the placement of habitat forming elements such as logs, rootwads or boulders within the bankfull channel in various configurations.

The general objectives for these projects include:

- Increasing hiding cover, habitat complexity, and instream habitat types
- Increasing quality or quantity of spawning and rearing habitat
- Altering stream channel geometry

If the primary objective is to alter instream substrate conditions, either quantity or quality of spawning gravels or fine sediment loads, *Monitoring the Effectiveness of Instream Substrate Restoration* should be consulted.

## EFFECTIVENESS MONITORING QUESTIONS AND STUDY DESIGN

This report will be used to develop monitoring plans for single projects that are particularly critical or for more generalized studies of instream structure effectiveness. The following core questions may be used as the basis for prioritizing future studies:

- At the site level, has the structure 1) created the desired habitat type; 2) increased pool depth; 3) increased hiding cover; and/or 4) created velocity refugia?
- At the stream reach level, have the structures 1) increased the frequency or area of desired habitat types; 2) increased the abundance of LWD or other structural components; 3) increased channel complexity; 4) decreased width/depth ratios; and/or 5) increased sinuousity?

Table 1 indicates the parameters, effectiveness criteria and field methods that may 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 should be defined in project contracts and/or within study plans for effectiveness monitoring. No guidance is provided here for studies addressing unintended consequences of restoration (positive or negative), although the field methods presented here would be suitable for that purpose.

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

| Monitoring Question | Parameters | Effectiveness Criteria | Field Methods |
|---|---|---|---|
| *At the **site level**, has the installed structure:* | | | |
| 1) created the desired habitat type? | Habitat types | Habitat has changed to the desired type e.g., changed from "run" to "pool" | Habitat monitoring (field method 1) |
| 2) increased pool depth? | Residual pool depth adjacent to structure | Residual pool depth has increased by >1.5 feet | Habitat monitoring (field method 1) –or- channel dimensions (field method 3) |
| 3) increased hiding cover? | Shelter rating= (shelter value)*(percent unit covered) | Shelter rating > 80 (existing DFG standard) | Habitat monitoring (field method 1) |
| 4) remained intact and functional? | Presence/absence and structure condition | Present and good or better condition | Habitat monitoring (field method 1) |
| 5) created velocity refugia or winter rearing habitat? | Slow water habitat abundance at specified flows (dam pools, slack water) | Increase in slow water habitat area of >50 percent | Habitat monitoring, winter habitat section (field method 1) |
| *At the **reach level** have the installed structures:* | | | |
| 1) increased the frequency or area of desired habitat types? | Habitat types | Change in frequency or area of habitat types >50 percent | Habitat monitoring (field method 1) |
| 2) increased the abundance of LWD? | LWD counts and volumes | Increase of >25 percent in volume or piece count per 100 feet of channel | Large woody debris survey (field method 2) |
| 3) increased channel complexity? | Standard deviation of residual water depths | Significantly different than control reach(es) | Channel dimensions (field method 3) |
| 4) decreased average width/depth ratio? | Width/depth ratio | Decrease of >25 percent | Channel dimensions (field method 3) |
| 5) increased sinuosity? | Sinuosity | Sinuosity increases significantly as compared to control reach(es)d | Channel dimensions (field method 3) |

To conduct effectiveness monitoring, projects must have clear, measurable objectives for performance and lifespan (Roni et al. 2004b). These must be defined at the appropriate scale, i.e., site or stream reach. Project objectives should be documented in contracts for ready reference. An example of a clear measurable objective is, "installation of 10 boulder weirs within the 800 foot long project reach is expected to result in the creation of four pools in addition to the three currently in the reach and increase reach level average residual pool depth by one foot. These changes may take 1-2 years to occur and will persist at least until 2015."

There are three alternative study designs for evaluating these effects: 1) retrospective, 2) before-after, and 3) before-after-control impact (BACI).[1]

The BACI design is recommended for general studies of instream structures in which several to many projects are sampled. It permits control over and knowledge of the primary confounding factors in most monitoring studies: pre-treatment conditions and natural variability (Stewart-

[1] See Sit and Taylor (1998) or Roni et al. (2004b) for complete treatments of alternative methods.

Oaten et al. 1986, Sit and Taylor 1998, Crawford and Johnson 2003). This feature of the BACI design facilitates detection of smaller changes than would be possible with other study designs. The main drawback of the BACI design is that results may take years to manifest, since it is a prospective design that draws conclusions based upon future performance of structures.

For studies of restoration structure durability, where a BACI design may take 10-20 years to yield results, a retrospective study design will be more efficient and is recommended (Smith 1998). Restoration structures have been designed and installed under DFG guidance for at least twenty years. These projects represent a potential source of information on structure longevity under different geomorphic conditions. Retrospective studies of instream structures have been used with some success in Oregon and Washington (Frissell and Nawa 1992, Smith 1998, Roni and Quinn 2001). Retrospective studies generally require large sample sizes to compensate for the lack of pre-treatment data (Hicks et al. 1991, Roni and Quinn 2001). Nevertheless, they can provide useful information with only 1-2 years of study. Results gained from the less robust retrospective type study designs can be used to develop or refine study plans for prospective, BACI type study designs.

For either BACI or retrospective studies, the use of control reaches is required (Jacobsen and Thom 2001, Jacobsen and Jones 2004, Roni et al. 2004b). Control reaches/sites should be located immediately upstream (preferably) or downstream of the treated site within a reach of the same channel type. If suitable controls cannot be located on the same tributary as the treatments, then a control should be established on a nearby tributary with the same channel type as the treated area.

Figure 1 shows treatment (red) and control (blue) reaches on Mill Creek, Del Norte County. Comparable reaches are located on the larger main stem (Site 1). On smaller streams (Site 2), treatment and control reaches are established on adjacent tributaries to pair comparable channel types. Variables such as gradient, bankfull width, habitat type distribution and substrate composition should be very similar within treatment/control pairs.

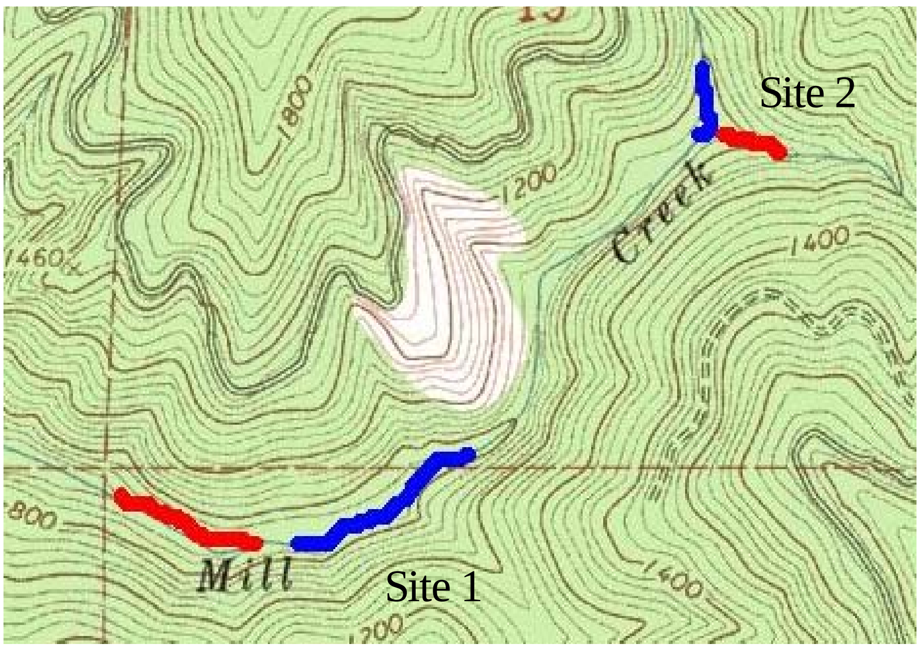



**Figure 1.** Example of Spatial Arrangement for Treatment and Control Stream Reaches.

The timing of restoration monitoring should be tied to project objectives. This requires that project objectives include reference to when and how restoration projects are intended to function. Physical responses (or indications of failure) are usually apparent after the first high flow season. Full response by the stream channel to instream structure placement may take 3-4 years, or at least several high flow events (Reeves et al. 1997; Roni and Quinn 2001). As a general rule, instream habitat restoration projects and controls should be monitored before treatment, after one high flow season and at future times dictated by a study design. In Oregon, these projects are monitored at five-year intervals (Jacobsen and Jones 2004).

Restoration projects intended to provide summer rearing habitat may need to be sampled multiple times over the summer season to determine if habitat remains functional and available as water levels drop or dry up entirely.

**Figure 2.** Summer Instream Habitat Data Collection.
Isolated pools and long dry reaches between restoration structures on June 27, 2002, at McDowell Creek, Hopland, CA.

For winter rearing habitat projects, sampling should occur during flows that are appropriate to evaluate the stated objectives of the project. These may be peak flows, bankfull flows or a wide range of winter flows.

**Figure 3.** Instream Habitat Restoration Structure During Winter Flows.
High flows going over boulder weir structures on December 23, 2002, at Bull Creek, CA.

To minimize variability in data collection procedures, sequential monitoring should occur during the same season and/or flow conditions.

## DATA QUALITY

This report and field methods are intended for use by agency staff, experienced consultants or practitioners who are trained in stream sampling methods. Data quality objectives are 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. This may not be feasible for all studies or parameters (Archer et al. 2004). Consequently, goals for change detection must be realistic and allow for both observer and natural variability. Bias will be minimized through the use of standards and training. 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

### Field Method 1: Habitat Type Monitoring

Habitat type monitoring includes a suite of basic channel morphology metrics capable of detecting gross changes associated with instream habitat restoration activities. The method presented here is based on existing DFG Habitat Inventory procedures (Flosi et al. 1998), but it is intended to produce more consistent and reliable data by eliminating parameters that typically lead to inconclusive results or are especially prone to error or subjectivity. It is compatible with the data needs of the validation monitoring methods for estimating fish abundance (Collins 2003).

This method will not detect subtle changes in channel characteristics. If the expected change of habitat unit area or frequency is less than 50 percent, detection is uncertain due to observer error and flow dependency inherent to the habitat typing methodology (Azuma and Fuller 1995, Roper and Scarnecchia 1995, Kaufmann et al. 1999, Archer et al. 2004). Habitat typing is best suited to detecting fundamental changes in habitat types, such as from fast water to slow water or riffles to pools (DFG Level I or II).

Generally, instream restoration projects are intended to produce changes exceeding 50 percent in a single habitat type's abundance or area at the reach level (Roni et al. 2004a). Variability related to flow can be minimized by conducting repeat surveys at similar times and/or flows in subsequent years. If the goal of the monitoring study is to evaluate summer rearing habitat quality, conditions should be evaluated throughout the low-flow season (i.e., monthly from May-September) to track actual useable habitat as flows drop to zero in some cases.

In the case where the restoration structures are intended to improve winter rearing habitat (i.e., create areas of lower flow velocities), habitat typing should be done at the prescribed design flows to determine the area of suitable rearing habitat before and after treatment at treated and control reaches.

*Determination of Sample Size*

Habitat typing is essentially a survey rather than a sampling procedure. In evaluating effectiveness at the stream reach scale, each treated and control reach is surveyed in its entirety. Each reach is, therefore, a sampling unit. In evaluating effectiveness at the site scale (e.g., studies of individual structure effects on immediately adjacent habitat units) the habitat unit(s) potentially affected by the structure is surveyed. The monitoring objective and study design will determine which scale is appropriate.

As with other methods, the sample sizes needed to address specific questions will depend on study objectives. In some cases, an estimate of variance of the parameter or variables of interest from the region where the study will be conducted may be necessary to calculate the appropriate number of treated sites and controls to sample (Archer et al. 2004). The variance of a particular parameter or variable of interest can be estimated from historical data or a pilot study. The threshold difference necessary to determine effectiveness needs to be established for each parameter. For example, if a 20 percent increase in the average shelter ratings within a reach is the treatment objective, then this value is the threshold for paired testing. The sample size is the number of similar sites or reaches and controls measured before and after treatment. This will likely be limited by available funding. Projects implemented in different years can be included in the same analysis to achieve the desired sample size.

*Delineating Study Areas*

Effectiveness monitoring can be focused on single structures or whole reaches influenced by restoration activities. Reaches are defined as the distance between the upstream and downstream extents of the restoration work, plus two habitat units on either end to capture all influences from restoration activities. The length of the control reach(es) should be the same as the corresponding treatment reach(es).

At the site level, defining the area of influence of a restoration structure is more subjective. Generally, it should include the habitat units immediately upstream and downstream of the structure. Complication can arise in places with a high density of structures due to interactions between structures. In those instances, evaluation at the reach scale is more appropriate and those sites would be excluded from studies assessing individual structures.

*Field Sampling Method*

Delineating habitat types involves walking up the channel and classifying each habitat unit as it is encountered (Flosi et al. 1998). Using the fewest number of habitat classes possible increases accuracy and repeatability between observers (Azuma and Fuller 1995, Roper and Scarnecchia 1995, Ramos 1996). Therefore Level III habitat typing (Flosi et al. 1998) is recommended because it is much simpler than Level IV yet it is still suitable for both summer and winter habitat surveys (Figure 4).

Level II habitat typing may be used when the additional precision of Level III is not required, for example in validation monitoring or summer only monitoring. Graphics and descriptions of all habitat types are included in Flosi et al. (1998).

An important component of monitoring changes due to instream projects is the ability to relocate structures and habitat units during future surveys. A string box (a.k.a. hip chain) is used to record the location of every habitat feature and structure observed along the stream relative to the starting point of the survey. The string box is not reset to zero at each habitat unit break, instead, the total distance from the start point to the upstream end of each habitat unit or restoration structure is recorded. Lengths of each habitat unit are calculated after data entry by subtracting

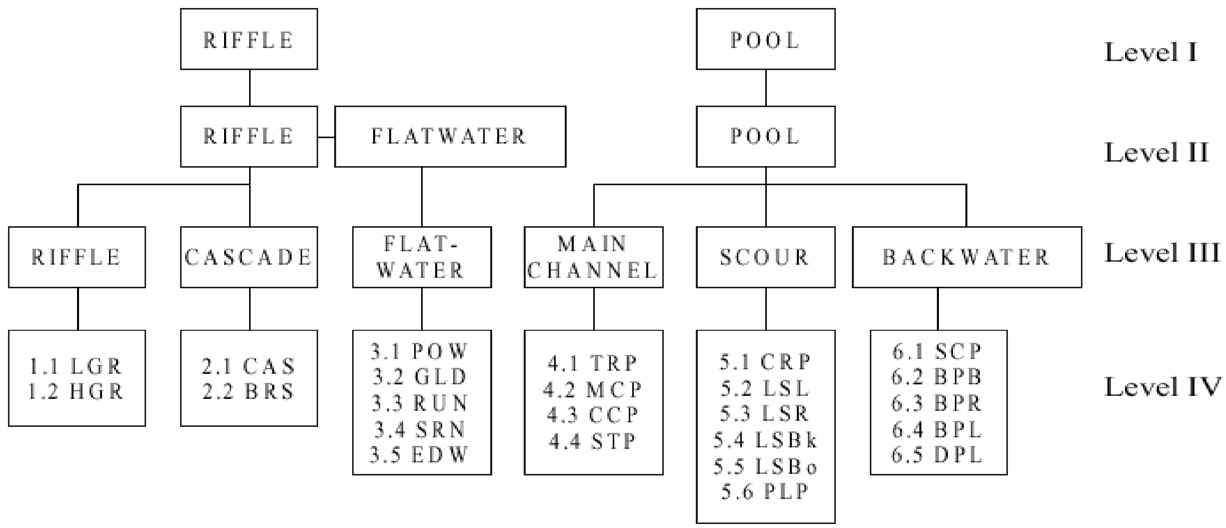



**Figure 4.** Dendrogram of Habitat Type Classifications Used by DFG.
*Source*: Flosi et al. 1998.

the distance of one unit from the preceding unit. This method facilitates relocating habitat units, restoration structures, and other notable features to within 20-100 feet depending on length of the survey reach and the number of obstructions in the channel.

*Information Needed Before Surveying.* Locations and descriptions of all installed or proposed structures should be presented to the monitoring survey team prior to the initial survey (pre-treatment). A site sketch map with distances between structures and an accompanying summary report of the design and intended function of each structure should be included in the "packet" presented to the monitoring team. Proposed locations of all structures should already be flagged along the stream and each structure should have a unique ID number assigned to it. Numbering should be sequential from downstream to upstream.

*Conducting the Stream Survey.* The timing of the survey depends on the restoration objectives i.e., to create summer or winter rearing habitat. Summer rearing habitat studies should be conducted at low flows. Winter rearing habitat studies should be conducted at design flows. These may either be winter "base flows" or "flood flows" (Solazzi et al. 2000, Jacobsen and Thom 2001, Jacobsen and Jones 2004). At such times, "backwater pools," side channels, dam pools and alcoves provide suitable velocity refugia (Morgan and Hinojosa 1996) although portions of any habitat may contain slack water and its occurrence should be noted.

Each stream survey should begin at an easy to locate, permanent landmark on the downstream end of the surveyed reach. Bridges, roads, parking lots, power lines, and tributary junctions (in non-alluvial settings) can be used as the starting point. A photograph and detailed description of the starting point, along with explicit directions for getting there should accompany the data sheet. If no permanent landmark is convenient, a permanent point can be established. Surveys should begin and end two habitat units beyond the extent of the restoration project, in order to capture all potential influences of the structures.

- Tie off the string from a string box (hipchain) at the beginning point of the survey and set the counter to zero.
- Proceed up the thalweg of the channel recording habitat units and associated data. Record the location of habitat unit breaks at the upstream end of each unit, landmarks, and restoration structures at the distance indicated on the string box counter. Record structure type using the numeric DFG structure type codes (Flosi et al. 1998 section VIII, pages 18-20). Do not reset the string box to zero at each habitat unit break.
- Split stream survey reaches into sub-sections at unmistakable permanent landmarks such as bridges, electric transmission lines, or occupied buildings. Describe and photograph these features and their distance from the last permanent reference point. Reset the string box to zero for the new section. Breaking the survey into sub-sections decreases the cumulative error associated with stringbox surveys over long reaches.

*Habitat Monitoring Parameters.* The parameters measured during the habitat monitoring survey are described below:

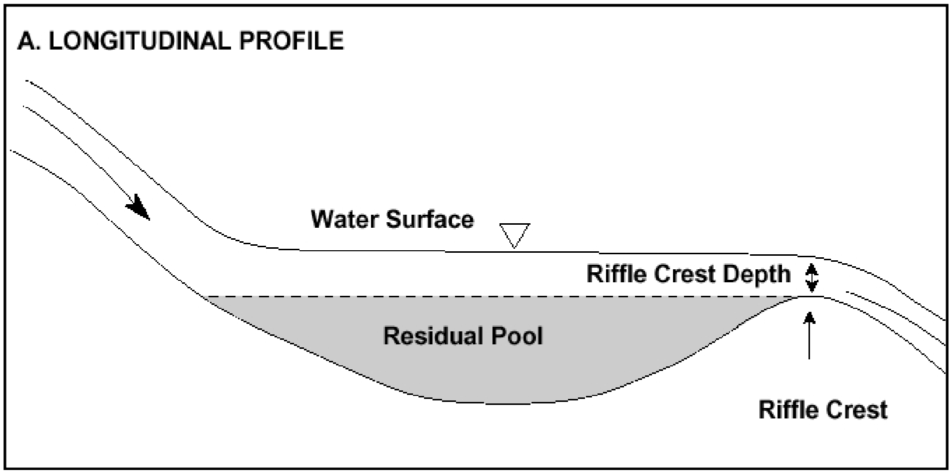
Habitat units are recorded as riffle, cascade, flatwater, or pool type (main channel, scour or backwater) (DFG Level III). Dry areas are noted as a separate habitat type. Side channels are noted where they enter the main channel using the distance displayed on the hipchain. If a study of winter rearing habitat or if the side channels were subjected to restoration treatment, side channels should be surveyed in their entirety. If not, then no further data are recorded on the side channel. Notes on the field form should make it clear which channel was surveyed as the "main channel" and which was called the "side channel." The distance at the upstream end of each habitat unit and width at 1/3 and 2/3 of the length of each unit are recorded. Individual habitat units must be as long as the channel is wide to be recorded. For winter habitat typing width of stream channels may have to be measured using a range finder if wading across the channel is not possible.

Restoration structure location is recorded. The location point is the edge of the structure farthest upstream. Each structure is classified using structure type codes from the DFG Manual (section VIII, pages 18-20).

Restoration structure condition is recorded using a subjective rating system of Failed to Excellent.

Structure problems if any, are recorded using a set of descriptive codes.

Maximum depth of water is recorded for all habitat units. A maximum depth measurement is also recorded within the estimated zone of influence of each in-channel restoration structure, both before and after installation. The measurement should be taken in the area that is (or will be) influenced by the structure. Pool tail crest depth is also measured in order to calculate residual pool depth (Lisle 1987).




Residual pool depth is calculated by subtracting the water depth at the riffle crest from the maximum depth recorded within the pool (Figure 5).

**Figure 5.** Measuring Residual Pool Depth.
*Source:* Hilton and Lisle 1993.

Pool-forming elements are recorded for each pool encountered. Pool forming elements include large woody debris (LWD), rootwad, boulders, bedrock, live trees, and stream confluences. Pool forming elements will be designated as natural, restoration related or unknown. Record the structure ID number for those contributing to pool formation.

Boulder weir identified as the pool forming element for the scour pool downstream of the structure.

Shelter rating is recorded for pools and flatwater units for a target fish three inches in length. The "Shelter Value" and "Percent Unit Covered" estimates are recorded using current DFG habitat typing methods (Flosi et al. 1998). Then, the code for the first and second most dominant cover elements along with the percent of the total cover contributed by each are recorded. For winter habitat typing it may not be possible to accurately estimate cover due to high turbidity levels, however presence of LWD and an estimate of the percent coverage of the habitat unit should be made where possible even if shelter values or the presence of other cover elements cannot be determined. LWD is an important component of winter rearing habitat suitability.

*Data Analysis*
A number of parameters can be calculated from the habitat monitoring data. These parameters may be evaluated by their relative change after treatment as compared to changes observed in control reaches or sites during the same time period. Some of these values may also be compared to regional “reference values,” in the event that these become available.

- Frequency of each habitat type at the reach scale
- Area of each habitat type at the reach scale
- Number of pools created by restoration structures, which may be expressed as percent of total within the reach
- Residual pool depth within specific habitat units or associated with particular restoration structures
- Average residual pool depth for the reach or group of sites
- Frequency of “primary pools” within the reach based on residual pool depth (defined as >2.5 feet deep in first and second order streams, >3 feet deep in third order or larger streams)
- Shelter rating for specific habitat units or associated with particular restoration structures
- Reach level average shelter ratings
- Changes in dominant cover elements, either in rank or percentage especially within habitat units with restoration structures
- Presence/absence of individual restoration structures and condition
- Number of structures within each structure condition class

Habitat typing data may also be used in conjunction with biological monitoring to determine habitat suitability or use by salmonids.

For evaluation of effectiveness in relation to velocity refugia or winter rearing habitat, the following parameters may be used:

- Increased frequency or area of backwater pool habitat types, especially in side channels (alcoves)
- Increased area of slack water across all habitat types, in square feet or as a percentage of total area
- Increased maximum pool depth and number of primary pools
- Increased LWD frequency and volume
- Increased percent hiding cover and shelter value
- Increased LWD frequency and volume
- Increased percent hiding cover and shelter value or LWD cover

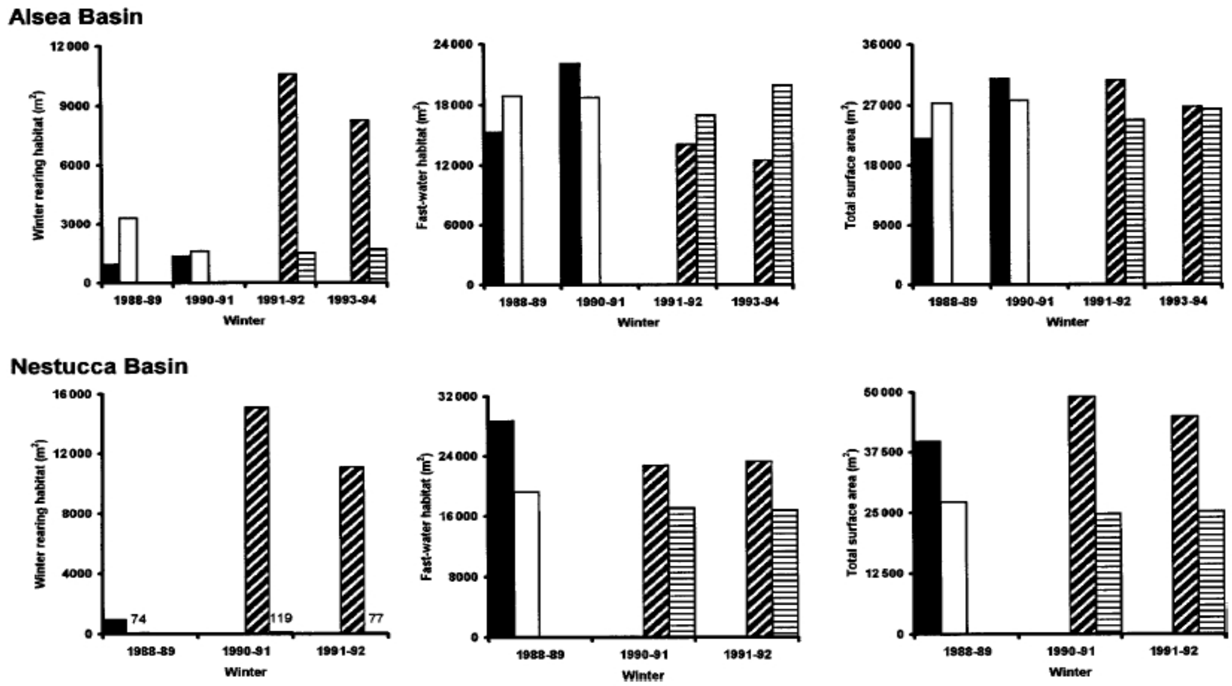



**Figure 6.** Example of Winter Habitat Type Data Collected.
This figure shows the surface area of winter rearing, fast-water, and total habitat in the treatment and reference streams in the Alsea and Nestucca basins, before and after treatment. Solid bars show treatment reaches before restoration; open bars show reference reaches before restoration; diagonally hatched bars show treatment reaches after restoration; horizontally hatched bars show reference reaches after restoration. *Source*: Solazzi et al. 2000.

**Instructions for Habitat Typing 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. If unnamed, use named stream to which it is tributary.
5) **Date—**Enter the date: *mm/dd/yy*
6) **Evaluation Crew—**Enter the names of the survey crew in 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.

**Habitat Unit Data—Section 2**

**Data recorded for all habitat units.**

8) **Habitat Unit Number—**Enter the habitat unit number. Record the habitat unit numbers in sequence from downstream to upstream, beginning with "001" at the survey start.
9) **Habitat Unit Type—**Determine the type of habitat unit and enter the appropriate habitat type code. For Level II habitat types use the following codes: Pool = PP, Riffle = RF, Flatwater =FW, Dry =DR. For Level III habitat types use the following codes: Main Channel Pool=MP, Scour Pool=SP, Backwater Pool=BP, Flatwater=FW, Riffle=RF, Cascade=CA, Dry=DR.
10) **Main or Side Channel—**Record whether the habitat unit occurs within the main channel or in side channel using M or S, respectively.
11) **End Distance—**Record the distance as displayed by the running total on the string box at the upstream end of each habitat unit.
12) **Max Depth of Water—**Enter the measured maximum depth for each habitat unit in feet.
13) **Width @ 1/3—**Record the wetted width of the channel at 1/3 of the distance from the downstream end of the habitat unit to the upstream end. For example, a 30-foot-long habitat unit would have width recorded at 10 feet from the downstream end.
14) **Width @ 2/3—**Record the wetted width of the channel at 2/3 of the distance from the downstream end of the habitat unit to the upstream end. For example a 30-foot-long habitat unit would have width recorded at 20 feet from the downstream end.
15) **% Slackwater (winter only)—**Habitat surveys conducted during the winter with the objective of recording the quantity of habitat suitable for velocity refugia for juvenile and adult salmonids will include an estimate of the percentage of the surface area of each habitat unit that appears to have slackwater suitable for resting.

**Data recorded for pool and flatwater habitat units only.**

16) **Shelter Value—**Enter the number code (0-3) that corresponds to the dominant structural shelter type that exists in the unit (Part III- Instream Shelter Complexity).
17) **Percent Unit Covered—**Enter the percentage of the unit occupied by the structural shelter.
18) **1st element—**Enter the two-letter code for the most extensive cover type in the unit. Refer to the attached code sheet for categories and codes.
19) **% of total 1—**Enter the percentage of the total cover contributed by element 1.

20) **2$^{nd}$ element—**Enter the two- letter code for the second most extensive cover type in the unit. Refer to the attached code sheet for categories and codes.
21) **% of total 2—**Enter the percentage of the total cover contributed by element 2.

**Data recorded for pool habitat units only.**

22) **Pool Former—**Enter the geomorphic element which caused the pool to form in its current location using the following codes:
    - BE = Bedrock
    - BO = Boulder
    - LS = Lateral Scour
    - LT = Live Tree
    - LW = Large Woody Debris
    - RW = Rootwad
    - UN = Unknown
23) **Origin of Former** (Natural or Structure **#**)—Where it is possible to identify the pool forming element, record whether the element is natural using an '**N'** or due to restoration. If a restoration structure caused the formation of the pool record the structure ID number.
24) **Depth Tail Crest—**Enter the depth of water at the deepest part of the pool tail crest. For pools where the water level is below the pool tail crest (i.e. not flowing) *and* a restoration structure is present, calculate residual pool depth by subtracting the elevation at the pool tail crest from the elevation at the deepest part of the pool using a stadia rod and a hand level, record this number in the comments section.

**Restoration Structure Data**

25) **Structure Number**—If numbers were assigned to the structures in the design drawings, use these. If structures were not pre-numbered, assign numbers to each structure in sequence, beginning with "R001" at the first structure encountered at the downstream end of the survey reach. All restoration structure numbers should begin with an "R" to avoid confusion with habitat unit numbering.
26) **Structure Type-** Determine the type of restoration structure, referring to project description if available. The codes for each type of restoration structure are found in section VIII, pages 18-20 in the DFG Manual.
27) **Structure Condition-** Record condition of the structure:
    - **EX = EXCELLENT** The structure is intact and structurally sound,
    - **GD = GOOD** The structure is intact and generally sound but some wear or undermining is evident. Pieces may have shifted slightly, erosion cloth is visible, one or two anchor pins or cables are loose, but the structure is intact,
    - **FR = FAIR** The structure position or condition has been altered significantly (50% intact),
    - **PR = POOR** The structure is visible but has suffered significant movement or damage (25% intact),
    - **FD = FAILED** The structure is not visible or remnants are not in any form of designed configuration.
28) **Structure Problem—**If there are no problems record **NON**, otherwise record problems using the following categories:
    - **ANC** = Anchoring problems
    - **BUR** = Buried
    - **CBL** = Cable problems
    - **SHF** = Shifting

**STR** = Stranding
**MIS**= Missing
**UND** = Undermining
**OTH** = other, specify in Comments section.

29) **Upstream End Distance—**Enter the distance from the start point of the stream section shown on the string box where the upstream most point of the restoration structure occurs.
30) **Max Depth of Water—**Enter the maximum depth water observed within the influence zone of each restoration structure, in feet. If the restoration structure has not yet been built, record the max depth of water within the area likely to be influenced by the structure.
31) **Shelter % unit covered by structure—**Enter the percent of the total areal coverage of stream shelter contributed by the restoration structure.
32) **Slackwater % created by structure—**Enter the percent of the total area of slackwater within the habitat unit that the restoration structure is causing.
33) **Comments—**Add comments that are important to each habitat unit or restoration structure. For restoration structures comment on: whether or not the structure appears to be accomplishing the intended function, notes on condition of structures including any repairs that need to be made, and describe any unintended side effects of structures if apparent, etc.

## HABITAT MONITORING FORM

Page ___ of ___

**Contract #:**________________________ **Contract name:**________________________

**Stream:**________________________ **Date:** ____________ **Evaluation crew:**__________

**Drainage:**________________________________________

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| All Habitat units | **Habitat Unit Number** | | | | | | | | | | |
| | Habitat Unit Type | | | | | | | | | | |
| | **M**ain or **S**ide channel | | | | | | | | | | |
| | End Distance | | | | | | | | | | |
| | Max Depth of Water | | | | | | | | | | |
| | Width @ 1/3 | | | | | | | | | | |
| | Width @ 2/3 | | | | | | | | | | |
| | % Slackwater (winter only) | | | | | | | | | | |
| Pool and Flatwater Units | Shelter Value | | | | | | | | | | |
| | % Unit Covered | | | | | | | | | | |
| | 1st element | | | | | | | | | | |
| | % of total 1 | | | | | | | | | | |
| | 2nd element | | | | | | | | | | |
| | % of total 2 | | | | | | | | | | |
| Pool Data | Pool Former (element) | | | | | | | | | | |
| | Origin of Former (**N**atural or structure #) | | | | | | | | | | |
| | Depth Tail Crest | | | | | | | | | | |
| Restoration Structure Data | **Habitat Unit Number** | | | | | | | | | | |
| | Structure Number | | | | | | | | | | |
| | Structure Type | | | | | | | | | | |
| | Structure Condition | | | | | | | | | | |
| | Structure Problem | | | | | | | | | | |
| | Upstream End Distance | | | | | | | | | | |
| | Max Depth of Water | | | | | | | | | | |
| | Shelter- % unit covered by structure | | | | | | | | | | |
| | Slackwater- % created by structure (winter) | | | | | | | | | | |
| Comments | | | | | | | | | | | |

| Cover elements | code |
|---|---|
| Aqua Veg | AV |
| Bedrock Ledges | BE |
| Boulders | BO |
| Bubble Curtain | BC |
| LWD (> 12") | LW |
| Root Mass | RM |
| SWD (<12") | SW |
| Terr Veg | TV |
| Undercut Bank | UB |

| Pool Former | code |
|---|---|
| Bedrock | BE |
| Boulder | BO |
| Lateral scour | LS |
| Live Tree | LT |
| LWD | LW |
| Multiple | MU |
| Rootwad | RW |
| Unknown | UN |

| Level III Habitat Types | code |
|---|---|
| Main Channel Pool | MP |
| Scour Pool | SP |
| Backwater Pool | BP |
| Flatwater | FW |
| Riffle | RF |
| Cascade | CA |
| Dry | DR |

**Field Method 2: Large Woody Debris Assessment**

Placement of large woody debris (LWD) may have several effects on channel morphology. Most of these are likely to be beneficial to fish habitat and include:

- Increased frequency and volume of LWD in the channel
- Increased complexity and quantity of hiding cover
- Formation of pools, either scour or backwater type depending on LWD configuration
- Increased local water depths
- Recruitment of additional LWD to the restoration site via bank erosion and/or interception of mobile LWD
- Functioning as a “key piece” in the formation of LWD jams

The existing DFG LWD survey method (Flosi et al. 1998) is not adequate for quantifying all of these potential effects. Consequently, Field Method 2 was adapted from the LWD survey method used by the Oregon Department of Fish and Wildlife (ODFW) (Moore 2002). Some key characteristics of Field Method 2 are:

- Pieces are tallied by habitat unit.
- The configuration of each piece is noted (piece, accumulation or jam).
- Debris type is noted, i.e., whether natural or part of a restoration structure.
- Diameters are estimated at the midpoint.
- Minimum size of LWD is 0.5 foot diameter by 10 feet length.
- Live pieces of LWD are counted.
- Recruitment mechanism information is recorded for each piece.
- Functionality of placed LWD in the formation of jams is recorded.

LWD surveys should be conducted simultaneously with habitat monitoring (Field Method 1) to determine how LWD affects instream parameters such as habitat unit frequency and area, pool depth, shelter rating, structure condition, etc.

The combined data sets will be sufficient to answer basic questions about LWD restoration structure function and physical habitat condition. Cedarholm et al. (1997) used a similar approach, along with biological monitoring (fish counts) to document improvements in physical habitat and increased salmonid populations due to large woody debris additions in Washington.

Questions regarding winter habitat availability, spawning habitat, channel dimensions, in-channel sediment storage and substrate composition may be addressed by simultaneously using other field methods (see *Monitoring Effectiveness of Instream Substrate Restoration*). As with other methods, concurrent validation monitoring may be used to evaluate the biological response to restoration activities.

Alternate methods not included here may be needed to answer some questions regarding large woody debris processes or characteristics such as:

- LWD effects on water velocity or residence time of water in each habitat unit
- Source distances for LWD pieces recruited to survey reaches
- Interactions and movement of LWD between the active channel and floodplain
- Comparison of specific attributes of structure types and construction methods
- Transport distance of installed LWD
- Effects of orientation within the channel on LWD performance
- Overall LWD budget of watersheds
- Patterns of LWD function and recruitment as influenced by geology, channel type or other abiotic factors
- Fine scale differentiation of the portion of each piece of wood within the bankfull channel
- Residence time or age of LWD in the channel

A number of studies have been done on these subjects. See Lassettre and Harris (2001) for a review of the literature on the ecologic and geomorphic functions of LWD.

*Determination of Sample Size*
This field method is a survey, similar to Field Method 1 and the same sampling considerations apply.

*Field Sampling Method*
The large woody debris monitoring should be conducted along with habitat monitoring. Instructions in Field Method 1 for defining sample reaches, starting locations and use of string boxes to record distance apply to this method as well.

Record the location of each piece of wood by identifying the habitat unit number where it was observed. The habitat unit number is the "primary key" between the two data sets that facilitates combining the data during analysis. Assign LWD pieces or jams to the habitat unit where primary effects are observed, i.e., pool scour, shelter increases, etc. If effects are not apparent, assign the piece or jam to the habitat unit where the majority of its volume appears to be located.

The standard definition for minimum LWD piece size in the scientific literature is 10 cm diameter by 1 or 2 meters long (Schuett-Hames et al. 1999, Lassettre and Harris 2001, Martin 2001). The current minimum piece size used by DFG is 1-foot diameter by 6 feet long (approximately 30 cm x 1.8 m). LWD pieces in the 10-30 cm diameter class typically represent a large percentage of the piece count but a relatively low percentage of the volume in LWD surveys (J. Opperman personal communication). Small pieces may not contribute much to function in the channel. The method described here uses the minimum piece size defined by ODFW (Moore 2002), which is 15 cm diameter by 3 m long. Root wads with cut ends may be less than 3 m long. Since DFG uses the imperial measurement system, the definition of minimum piece size will be 6 inches in diameter at the large end by 10 feet in length.

A common metric for evaluating the quantity of wood in the channel is volume. The standard method for calculating wood volume is multiplying the length of the piece by the cross sectional area of the piece at the midpoint (Schuett-Hames et al. 1999, Martin 2001). To facilitate volume calculations, each piece of LWD counted should be placed into a diameter size class based on its midpoint diameter. The diameter classes are in even increments as follows:  0.5-1 foot, 1-2 feet, 2-3 feet, 3-4 feet, etc.

Any piece of dead wood in the survey that is within, partially within or suspended over the bankfull channel[1] zone should be included (zones 1, 2 and 3 of Schuett-Hames et al. 1999, Figure 7).

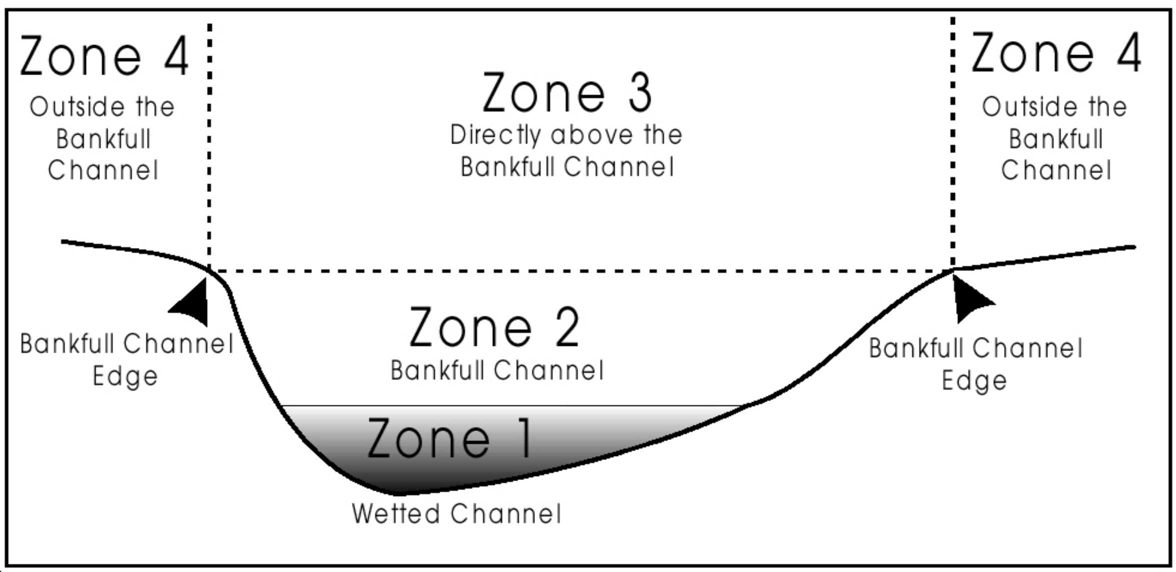



**Figure 7.** Zones Used to Define the Location of LWD.
*Source*: Schuett-Hames, et al. 1999.

LWD pieces that have at least 0.5 feet of their total length in zones 1, 2 or 3 are recorded. The total length of each piece is recorded, even if it extends into zone 4. Live LWD pieces (branches or trees) must extend into zone 1 or 2 to be recorded.

Also count live pieces of wood (trees, branches) if they are parallel to and extend into the active or bankfull zone (zones 1 and 2), but not if they are suspended entirely over the channel (zone 3) (Opperman *in press*). The count of live LWD typically excludes leaning trees, because they are above the bankfull channel. Include the entire length of each piece of wood, even the portion that extends outside of the zones described above. Tally each piece of wood into the appropriate length class. Dimensions of each LWD piece (diameter and length) should be measured at the beginning of each day for calibration and estimated thereafter.

In addition to habitat unit location and dimensions, record the following characteristics for each piece of wood:

[1] See the Channel Dimensions Field Method 3 (Page 27) for discussion of bankfull width and relevant indicators.

- Configuration: Single piece, accumulation (2-9 pieces) or jam (10 pieces or more). Assign a unique number beginning with 1 to each jam or accumulation as it is encountered. All pieces within jams or accumulations are identified by that unique number. Record the approximate length, width and height of the entire jam in the comments section in order to calculate jam volume.

**Figure 8.** Example of LWD Accumulation in Old-Growth Redwood Forest.
All pieces in the picture would be measured because each extends into or over the bankfull channel width, zones 1-3.

- Type: Natural piece with broken ends or whole trees, logging related piece with cut ends, restoration structure piece (may or may not still be in original location), piece with a root wad attached or live piece.
- Location: Side of channel, mid channel, island in the channel, spanning the channel within the bankfull zone or suspended over the channel.
- Recruitment mechanism: The way in which LWD pieces have been recruited to their current locations can be divided into the following categories: 1) installed as part of a restoration project, 2) originally installed as a restoration project, but has since moved off site, 3) new pieces of LWD recruited to the channel via bank erosion or landslides caused by installation of LWD structures, 4) LWD intercepted during transport by restoration structures, 5) natural recruitment mechanisms such as windthrow, mortality, landslides, exhumed from alluvial material and bank erosion, or 6) recruitment process unknown.

**Figure 9.** Example of LWD Recruitment.
The recruitment mechanism shown in this photo is bank erosion. If the recruitment mechanism is not obvious, as in this case, record "unknown."

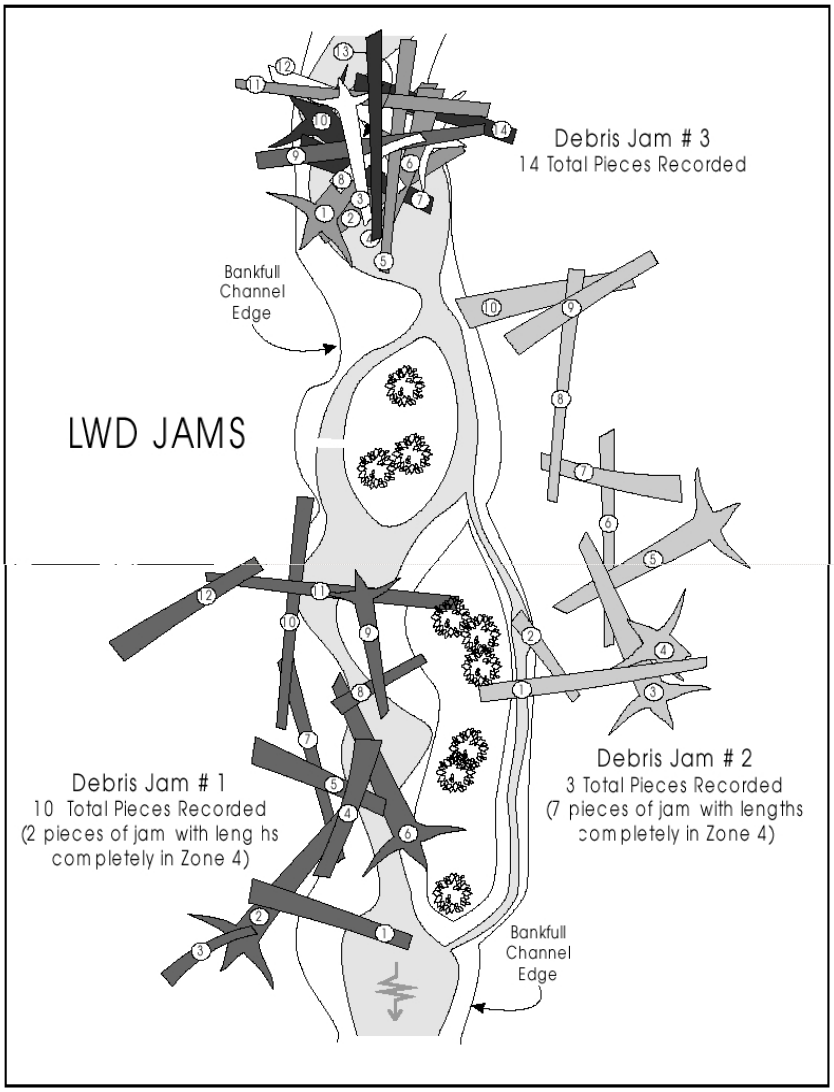
- Key piece function: Note whether the piece is currently trapping other pieces within a jam or is providing the key stability to the jam. It is especially important to note when restoration structures or pieces are functioning as key pieces.

The log in the center of this photo, placed by restoration, is a key piece of LWD. It is functioning as a key piece and has intercepted floating LWD to form a logjam. Stream flow is from right to left.

**Figure 10.** Example of a Key Piece of LWD.

- Species Class: Hardwood or conifer; four letter species codes may also be entered if relevant to the study question.

Multiple lines on the data sheet may be used for habitat units with many pieces of wood. Large debris jams may also require multiple lines on the data sheet. In cases where multiple lines are used for the same habitat unit or debris jam, simply repeat the ID number for the habitat unit and/or jam on each line. Conversely a single line of the data sheet can be used for multiple pieces of wood that have the same characteristics (type, location, etc.) and diameter class but differ only by length class or have multiple pieces in the same length class.




For log jams, record LWD pieces extending into zones 1, 2 or 3. Do not count pieces completely in zone 4. Also record the overall dimensions of the jam (Length x Width x Height). Be sure to record which individual piece or pieces are serving as the key pieces in stabilizing or forming the jam.

**Figure 11**. Counting LWD Pieces in a Log Jam.
*Source:* Schuett-Hames et al. 1999.

*Data Analysis*
There are a number of relevant parameters that can be calculated from the large woody debris inventory and simultaneous habitat monitoring data. All parameters should be evaluated in light of the pre-treatment data collected in the control and treated reaches using the BACI design.

Significant increases in the following parameters relative to the change observed in the control reaches are indicators of effectiveness:

- Frequency or volume of LWD pieces and/or jams
- Frequency or area of summer or winter pool habitat
- Individual or reach level average residual pool depths
- Average diameter, length or volume of individual pieces
- Shelter ratings and number of habitat units with LWD as the first or second most dominant element of instream shelter
- Frequency of pool habitat units formed by LWD from restoration structures
- Frequency or volume of LWD pieces recruited by the restoration structure after installation.
- Frequency of debris jams or accumulations that have restoration structure pieces functioning as "key pieces"

Volume and piece counts should be calculated per 100 feet of stream reach to facilitate comparison between stream reaches of different lengths, i.e., cubic feet of LWD/100 feet stream length or pieces/100 feet.

| Location | % pool habitat | %riffle habitat | % flatwater habitat | % of pools formed by restoration | average wetted width (feet) | average residual pool depth (feet) | average shelter rating | volume of LWD (cu. Ft./ 100 ft.) | pieces of LWD per 100 ft. | number of jams or accumulations/ 100 feet |
|---|---|---|---|---|---|---|---|---|---|---|
| Bull Creek | 16 | 52 | 32 | 100 | 35 | 2.7 | 23 | 33 | 1 | 0 |
| Squaw Creek | 44 | 34 | 22 | 20 | 16 | 1.5 | 49 | 656 | 7 | 0.8 |

**Figure 12**. Example of LWD Inventory Data.
Data were collected on two nearby stream reaches in Humboldt Redwoods State Park that have received restoration treatments. Bull Creek is a fourth order tributary draining largely cutover land, Squaw Creek is a second order stream draining mostly undisturbed old growth land.

For each parameter some threshold of increase or decrease must be established as a basis for statistical testing within a BACI design. Again, as in Field Method 1, the sample size is the number of projects evaluated under the BACI design and projects implemented in different years may be used to achieve the appropriate number of sample projects for analysis. Either historical data or pilot study data can be used to estimate variance of a particular parameter of interest. Archer et.al. (2004) includes tables of required sample sizes to detect changes in LWD loading (and other parameters) ranging from 5 to 50 percent. Although the data were not collected on local streams the methods used to construct the tables are relevant and the tables may serve as examples.

**Instructions for Large Woody Debris Inventory 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. If unnamed, use named stream to which it is tributary.
5) **Date—**Enter the date: *mm/dd/yy*
6) **Evaluation Crew—**Enter the names of the survey crew in 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.

**LWD Inventory Data**

8) **Habitat Unit Number.** Enter the habitat unit number where the majority of the LWD volume is located.
9) **Debris Configuration.**
   - **S** Single piece.
   - **A** Accumulation. Two to nine pieces.
   - **J** Jam. Ten pieces or more.
10) **Jam or Accumulation ID number.** Number sequentially as encountered, starting at 01.
11) **Debris Type.**
    - **NT** **N**atural. Broken ends or whole tree.
    - **CE** **C**ut end.
    - **AT** **A**rtificial. Is or was part of man-made structure
    - **RN** **R**oot wad attached to **N**atural bole.
    - **RC** **R**oot wad with opposite end **C**ut.
    - **LV** **L**ive tree or root.
12) **Debris Location.**
    - **S** **S**ide of the channel.
    - **M** **M**id-channel
    - **I** **I**sland. At upstream end of mid-channel island.
    - **F** **F**ull channel. Completely across channel within active channel. Pieces may be above the wetted channel at the time of the survey. When part of a jam, include all pieces regardless if they are touching the water, piled up, or submerged.
    - **O** **O**ver channel. Suspended over the active channel with the ends above the active channel. Include debris with suspended bole but with branches in water.
13) **Recruitment Mechanism.**
    - **PR** Placed in channel by Restoration
    - **DR** Dislocated Restoration piece, moved from original location
    - **BR** Bank erosion, due to Restoration
    - **IR** Intercepted floating LWD by Restoration structure
    - **LR** Landslide due to Restoration structure
    - **BN** Bank Erosion, Natural
    - **LN** Landslide, Natural
    - **WN** Windthrow, Natural

**MR** Mortality, Natural
**EN** Exhumed from alluvium, Natural
**UK** Unknown

14) **Key Piece.** Record "Y" if the piece is currently trapping other LWD pieces or if the piece is providing key stability to the jam or accumulation—if not record "N."
15) **Species Class.** Determine if LWD piece is hardwood or conifer, record "H1" or "C."' Four letter species codes may also be used if desired, e.g., PSME, ARME, etc.
16) **Diameter Class.** Estimate diameter at mid-point along LWD piece, or for rootwads at 4.5 feet above the base of the stem (dbh). Diameter classes are in 1-foot increments starting at <1 foot. For LWD greater than 11 feet in diameter, record the diameter in the comments section.
17) **Length Classes.** Count and tally the number of pieces within each length class. Root wad less than ten feet long (usually with a cut end) is a special case. For trees >80 feet long, record actual length in comments section.
18) **Comments/ Jam Dimensions (ft)**. Note any other information or assessments of the source, influence, or character of the woody debris.

When estimating very large amounts of wood in debris jams, visually group it into length and diameter classes then count and tally onto the data sheet. Assign each jam to only one habitat unit number. Indicate in the note column if the jam spans more than one habitat unit. Do not try to evaluate one piece at a time. Record and tally all countable pieces. Record the approximate length, width and height of the entire jam (feet) in the comments section, in order to calculate overall jam volume.

## LWD INVENTORY FORM

**Page ___ of ___**

**Contract #:__________________________ Contract name:___________________________**

**Stream:_________________________ Date: _____________ Evaluation crew:__________**

**Drainage:__________________________________________**

| | Debris Characteristics | | | | | | | Diam. | Length class (feet) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hab Unit Number | Config | Jam or Accum # | Type | Locat | Recruit Mech | Key P | Species Class | DBH Class | RW<10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | 80+ | Comments/ Jam Dimensions (ft.) |
| | | | | | | | | | | | | | | | | | | |
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**Field Method 3: Channel Dimensions**

Thalweg (long) profile and cross section surveys are standard methods for monitoring changes in channel dimensions. Methods for conducting these surveys using differential leveling are well established (Harrelson et al. 1994, Ramos 1996). Channel dimension surveys provide a more sensitive, less subjective method of monitoring changes in channel bank and bed form as compared to habitat typing methods (Field Method 1). They are recommended for monitoring studies evaluating restoration projects with the following objectives:

- Increase channel bed complexity
- Decrease width/depth ratios
- Decrease channel width
- Store sediment in the channel or recruit gravels
- Prevent/encourage incision of the channel
- Increase sinuosity
- Reduce sediment delivery to the channel

Given the wide variety of potential monitoring objectives, it is not possible to specify a single survey methodology. The location, length, quantity, spacing between measurements, tools used and crew size will be determined by the question(s) posed in the study design and available budget. A general description of recommended procedures is presented below. Investigators with limited experience in these techniques should consult Harrelson et al. (1994) and Ramos (1996) for further detail.

For monitoring restoration activities intended to decrease the quantity of sediment delivered to the stream channel, surveys should take place in the first response reach downstream from the restoration activities (Montgomery and Buffington 1993). Response reaches are typically less than two percent gradient and function as temporary storage sites for sediment being transported down the channel. It may be necessary to monitor more than one response reach depending on study objectives.

*Determination of Sample Size*

For each parameter to be measured and assessed some threshold of increase or decrease (quantitative objective) needs to be established as a basis for statistical testing within a BACI design. For example, if instream projects are intended to increase residual pool depths by a given amount such as 1.5 feet, that would be the threshold for evaluation. As in Field Method 1 the sample size is the number of projects evaluated under the BACI design and projects implemented in different years may be used to achieve the appropriate number of sampled projects and controls for analysis. Either historical data or pilot study data can be used to estimate variance of a particular parameter of interest (Archer et al. 2004).

Given that each site or stream reach is a sample, the user must determine the number of individual measurements necessary to produce a suitable sample unit. This is akin to setting the transect length or plot size to capture enough of the variation so the each sample unit is an estimate of the population. There are three calculations that may need to be completed to determine the number of measurements required for channel dimension surveys. The first is the number of individual measurement points needed for each long profile or cross section survey. This is equivalent to the spacing between points for surveys using equally spaced elevation measurements. Guidelines for measurement spacing for long profiles and cross section surveys are given below.

The second calculation may be for the number of individual long profiles or cross section surveys needed to answer a specific study question. The size of the channel, dimensions of the restoration project, variability between samples and desired precision will influence how many samples are required.

The third calculation that may be required would be for the number of individual features that need to be sampled, e.g., pools in a reach. In this case the first two (above) calculations would be completed in order to determine how to space measurement points across these features, then a third calculation would be required to determine how many features would need to be measured to answer the question of interest.

*Field Sampling Methods*

Specific sampling methods will depend on the study design and available tools and crew. Auto levels and total stations are standard tools for channel dimension 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 (including digital elevation models) 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.

All channel dimension surveys begin with a set of benchmarks to which all other points in the survey are referenced. Establishing durable benchmarks that can be reliably relocated many years into the future is essential. Before establishing new benchmarks, the location of existing permanent benchmarks should be determined. If existing benchmarks are reasonably close by, they should be used to establish the new benchmarks so that the channel dimension surveys can be done with actual elevations above sea level. If no existing benchmarks are available, establish a new benchmark with an arbitrary elevation; usually 100 feet is used. New permanent benchmarks should be located well out of the floodplain (e.g., on the hillside), so they will not be disturbed during high flows. Permanent cross section endpoint markers should also be located as far out of the floodplain as possible, ideally above any evidence of sediment or debris deposition, damaged vegetation from floating debris or other indicators of high flows.

The type of benchmark established depends on the tools used for the survey. Harrelson et al. (1994) describe four common benchmark types; however, only benchmarks that allow a tripod and instrument to be set up directly above are suitable for total stations. Therefore, spikes driven into trees and monuments on boulders are not suitable. Constructed cement monuments are recommended because they are suitable for both total stations and auto levels. Construction involves digging a 1-2 foot deep hole, filling it with cement and placing a galvanized carriage bolt into the wet cement so that it protrudes 1-2 inches (Harrelson et al. 1994). Two to three permanent benchmarks should be established within the project area, typically two on the downstream end and one at the upstream end of the survey. Benchmarks and cross section endpoints should have 6-10' long, white, PVC tubing placed over them to protrude above the shrub layer of vegetation. Describe the location of benchmarks and record these coordinates using *Documenting Salmonid Habitat Restoration Project Locations*.

After permanent benchmarks are established, surveys can be conducted. In addition to long profiles and cross sections, surveys of specific features may also be conducted such as, gravel or sediment accumulations in relation to restoration structures, LWD or restoration structure locations, engineered features such as culverts or bridges, etc. The type of survey conducted should be directly linked to the question driving the study design.

Questions specific to each monitoring study may require collection of descriptive information at each, or a subset, of survey point(s).  Standard survey notes include codes for location of specific features such as left and right edge of water, terrace and floodplain surfaces, bankfull elevation, turning points, etc., which are described and defined in Harrelson et al. (1994). Beyond these standard notes it may be useful to note the following characteristics at measurement points, depending on study objectives:

- Substrate class—fines, sand, gravel, cobble, boulder, bedrock
- Vegetation type or species
- Presence of restoration structures and types
- Channel habitat type—pool, riffle, run, etc.
- LWD categories by size, origin or species
- Engineered structures such as culverts, bridges, etc.

As described in Harrelson et al. (1994), a note page should be used to record 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 (see *Documenting Salmonid Habitat Restoration Project Locations*).

All surveys should "close the loop" following standard survey procedures (Harrelson et al. 1994). The acceptable error for "closing the loop" is 0.02 feet. Temporary turning points may be needed for long surveys or areas with poor visibility.

*Channel Dimension Survey 1: Longitudinal Profile Surveys.* Longitudinal profile surveys are used to characterize the distribution of bed elevations along the stream channel. The survey should follow the deepest part of the channel, known as the thalweg. Typically, longitudinal profile surveys extend at least 20 times the bankfull width of the channel (Harrelson et al. 1994). The specific monitoring question will determine the length of survey. For long restoration projects (> 1 mile), especially if restoration structures are infrequent within the reach, it may not be feasible or useful to survey the entire restored reach.

The upstream and downstream extents of the longitudinal profile survey will be denoted with permanent markers (typically cross section endpoints), which are referenced to the permanent bench marks; both well out of the floodplain.

Methods for setting up the longitudinal profile survey will vary depending on the tools used. If using an auto level, a tape measure will be strung down the channel thalweg to locate long profile stations, usually starting at the upstream end (Harrelson et al. 1994). First, pound a stake into the streambed at the starting point. Attach a tape measure (300 feet+) to the thalweg stake and unwind the tape along the thalweg. Pound additional stakes into the streambed at intervals sufficient to allow the tape to remain suspended over the wetted channel width as the tape is strung from stake to stake. The bearing and distance between each stake will be recorded as the survey proceeds downstream. This procedure will be repeated for as many tape lengths as necessary to complete the longitudinal channel survey.

In Figure 13, the solid line is the tape measure staked down the channel. The dashed line is the channel thalweg where elevation measurements are recorded. The perpendicular lines between the tape and the thalweg represent the offset distance recorded as left or right of the tape measure when facing downstream.

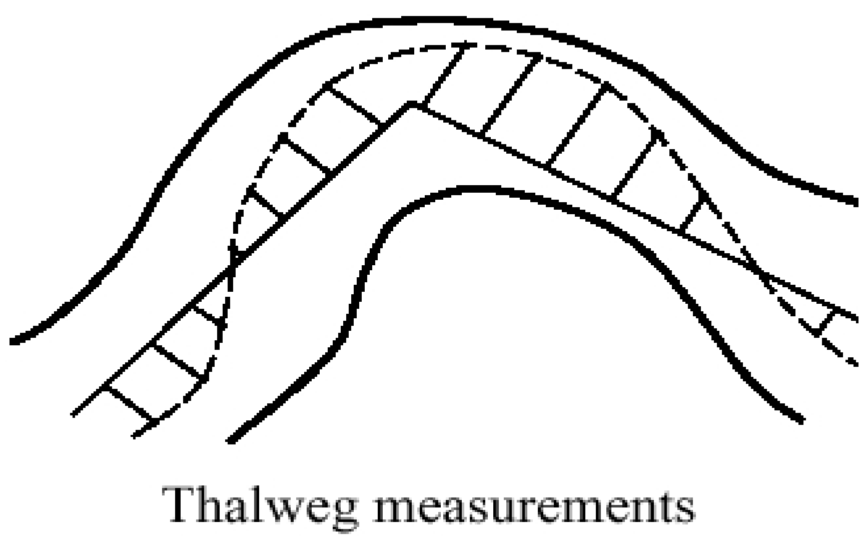


**Figure 13.** Tape Layout for Long Profile Survey Using an Auto Level. *Source:* Taylor 1999.

After setting up the stakes and tape measure down the channel thalweg, elevation data may be collected using standard differential leveling techniques (Harrelson et al. 1994). If using an auto level, the person holding the stadia rod will call out to the person recording the data the distance along the tape measure (long station) for each place the rod is positioned along with any other survey notes (tributary junctions, structure locations, habitat unit breaks, etc.) necessary to answer the monitoring question. If the study design requires information related to the thalweg position within the channel or sinuosity, then the "offset" from the tape measure to the rod location in the thalweg should also be recorded. Offset is the perpendicular distance between the thalweg and the tape measure at each point where elevation is recorded; offset will be noted as "left" or "right" of the tape measure facing downstream.

If using a total station, the tape measure, stakes in the channel bed and offset measurements are not required as total stations determine exact coordinates of each point in all planes (X, Y and Z). Thus the rod operator is only required to call out relevant comments if required for each survey point. It may be desirable to retain even spacing between survey points in which case it is best to have two rod operators with a fixed length of rope or tape between them moving up the channel in a "leap frog" manner (Simpson Resource Company 2004).

Whether using a total station or auto level, it is recommended to use a fixed spacing between survey points in addition to capturing grade breaks. Current DFG methodology employs a standard spacing of five feet between sample points on long profile surveys (B. Collins personal communication) which may not be appropriate for all surveys. For example, on large low gradient river systems, it is not uncommon to have 100 feet between long profile stations; conversely on small streams or gullies 0.5 or 1 foot spacing may be necessary to obtain enough sample points to accurately capture channel dimensions. An initial assessment (sample size calculation) may be required to determine appropriate spacing between sample points.

In addition to equally spaced stations (e.g., every five feet), the elevation and location of significant grade breaks should be measured as they are encountered. The elevations of riffle crests and maximum pool depths are particularly important for calculations of residual water depths. Recording elevation data at a fixed interval, as well as recording grade breaks and other relevant points effectively creates two data sets that may be analyzed individually or aggregated, depending on the question.

*Data Analysis Methods for Longitudinal Profiles.* There are many ways to analyze longitudinal profile survey data depending on the question being asked. At the most basic level, successive surveys are simply overlain and observations of changes are made: including changes in depth at specific points, spacing between features, scour or fill, etc. This type of comparison works best for individual features of interest, such as pool depth below a restoration structure (Figure 14).

For analyses of longitudinal profiles for entire reaches, an objective method of determining whether or not complexity has increased is required. Lisle (1987, 1995) developed a method for analyzing longitudinal profile data that produces an objective metric describing channel bed complexity. Residual water depth is an adaptation of the concept of residual pool depth that can be applied to the entire longitudinal profile, rather then being confined to areas subjectively defined as pools, as is done in habitat typing. Based on this concept, Madej (1999) developed a computer program called Longpro (available from DFG; B. Collins personal communication) to plot the profiles; convert the surveys into standardized data sets, calculate the distribution, mean and standard deviation of residual water depths; and compute the percentage of channel length occupied by riffles.

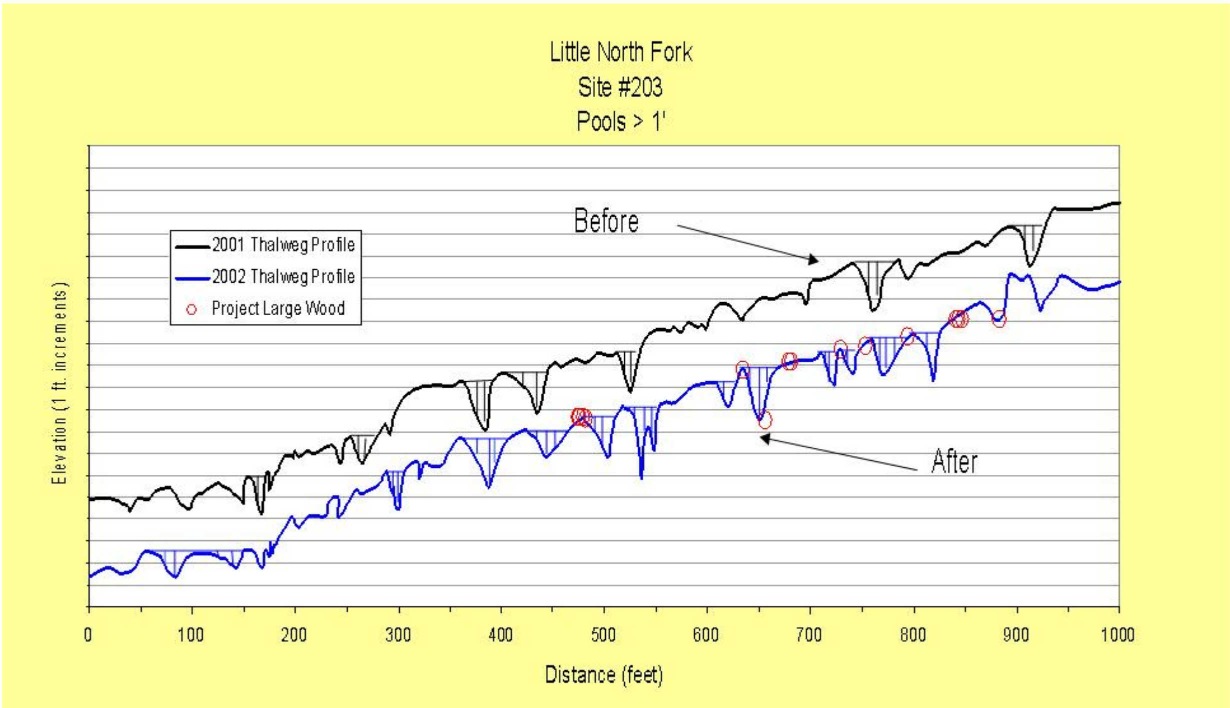


**Figure 14.** Longitudinal Profile Monitoring Data from the Gualala River Watershed.
LWD structures are associated with an increase in the quantity and depth of pools. *Source:* GRWC 2004.

After processing the data in Longpro, it is possible to test for statistically significant changes in bed complexity over time. Mean, median, and maximum residual water depths may be compared using Student's *t*, Mann-Whitney or ANOVA statistical tests. Comparisons of the entire distribution of residual water depths may be made using the Kolmogorov-Smirnov test (Madej 1999). Increases in mean, median or maximum residual water depths are indicative of increased deep water habitat availability, such as pools. Increases in the variance or standard deviation of residual water depths may be interpreted as increases in channel bed complexity (Madej 1999).

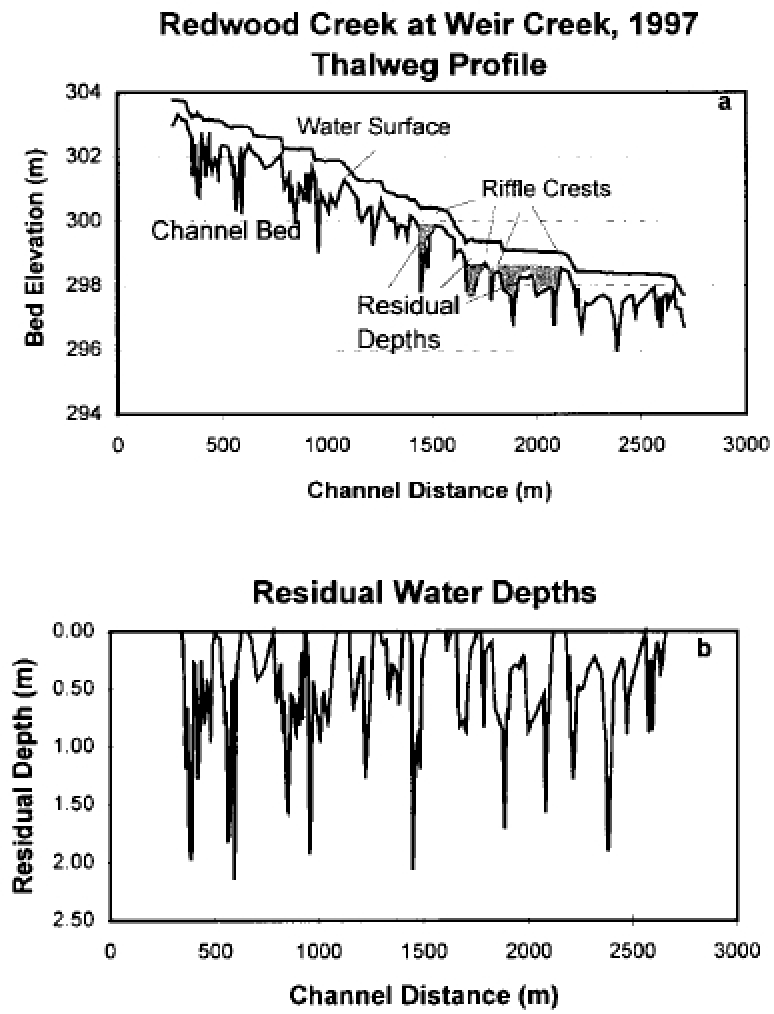


**Figure 15.** Processed Data From a Longitudinal Profile.
LongPro generates a new data set of residual water depths along the length of the channel (below). These new data can then be compared between time periods and/or stream reaches for differences in the distribution of values. *Source:* Madej 1999.

Another approach used to calculate the complexity of the channel bed involves plotting the long profile data and then fitting a regression line to the data (Ramos 1996, McBain and Trush 2004). The least squares regression analysis of the long profile data can be accomplished in most spreadsheet or data analysis programs, such as Excel, SAS, NCSS, etc. The complexity of the bed is then analyzed by examining: 1) the equation of the regression line, 2) the $R^2$ value, and 3) regression residuals. Decreases in the $R^2$ value and increases in the range of the residuals are indicative of increasing bed complexity.

Figure 16 shows box and whisker plots of regression residuals from longitudinal profile survey data using the analysis technique of McBain and Trush (2004). The increasing range of residuals from 2000 to 2003 indicates that bed complexity is increasing in the reach where restoration structures are located.

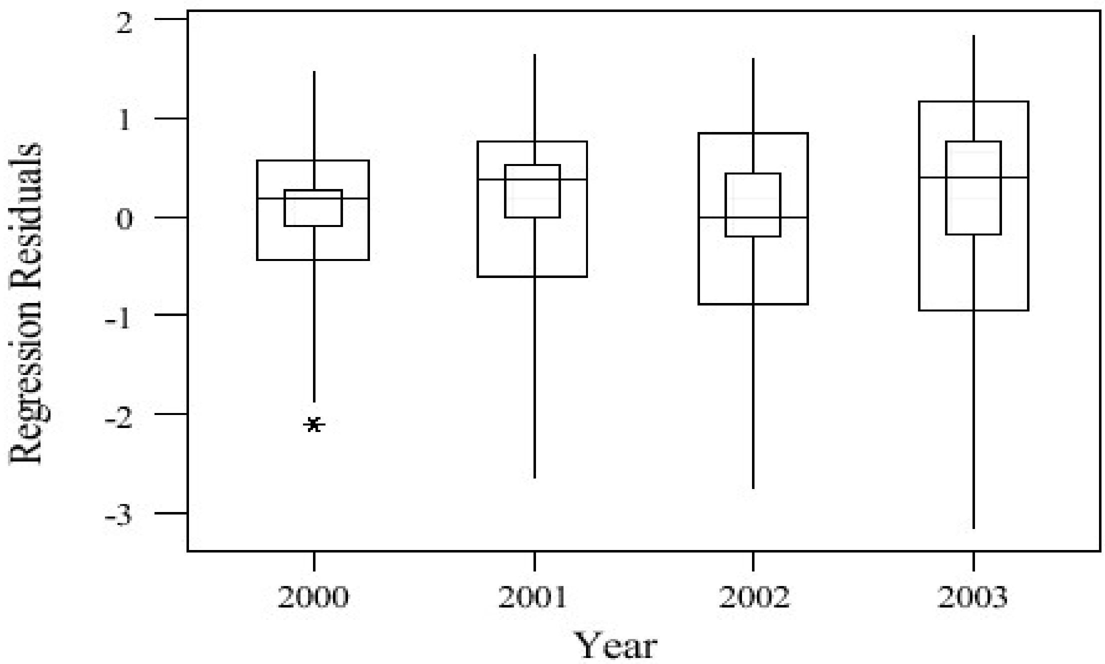


**Figure 16.** An Example of Analysis of Longitudinal Profile Data.
*Source:* McBain and Trush 2004.

The regression analysis method is simpler than using Longpro to analyze data prior to statistical analysis. The disadvantage is that each regression equation is unique to the data set from which it was generated and has no direct relationship to physical processes; while residual water depths (Madej 1999) are interpretable on their own and comparable between streams.

*Channel Dimension Survey 2: Cross Section Surveys*. Cross section surveys are very similar to longitudinal profile surveys. The procedure described above for locating permanent benchmarks and endpoints should be used for every cross section installed. Bearing and distance between cross section endpoints and to permanent benchmarks should be recorded for each cross section. The technique for surveying cross sections is similar to the method for long profiles except measurement points are spaced more closely and there is no need to record offset. Two feet between measurement points plus all grade breaks is recommended (B. Collins personal communication). At least 20 measurements are recommended to accurately describe the channel but more may be required on wider or more complex channels (Harrelson et al. 1994).

The most difficult aspect of installing cross sections is determining how many are required and where they should be located in order to answer the question posed in the study design. There are three basic configurations: 1) single cross sections, 2) equally spaced cross sections within a reach or 3) clusters of cross sections located in a particular habitat unit type, geomorphic feature, restoration structure or other stream feature. Examples of the various cross section configurations include:

- Determining discharge: A single cross section would be required to calculate the stream channel area for making a discharge measurement. Typically, a relatively straight and stable area of the channel would be selected.

- Changes in reach level width/depth ratios: This would require systematic placement of cross sections throughout the reach, based on a random start point. A sample size calculation should be used to determine the required number of cross sections, which will determine spacing between transects. For stream reaches approximately 40 bankfull widths in length, Kaufmann et al. (1999) recommended installing 11 cross sections, each approximately 4 channel widths apart. The spacing. may be used as a first approximation.
- Potential bank failures or channel widening due to installation of restoration structures: Monitoring these events could be accomplished by installing clusters of cross sections in areas likely to be affected by the structure. These areas are likely to be dynamic portions of the channel rather than a stable area like those used for discharge or hydraulic modeling. The general locations of *upstream, downstream* and *through the structure* itself would likely capture potential effects. How far upstream and downstream and how many cross sections to install will depend on the dimensions of the structure and the channel.

There is no single best location for cross section installations and the placement of cross sections will directly influence the results obtained. For example, pool units can be expected to respond more dramatically to changes in sediment supply than riffle units. An investigator seeking the maximum potential response to changes in sediment supply may choose to install clusters of cross sections in pool units. Characterizing the average response of an entire reach may be done by systematically placing cross sections throughout the reach across all habitat types.

Another issue the investigator must address during the study design phase is the potential for changes in site or reach level conditions over the length of the study period. The longer the study period the greater potential there is for changes in conditions. The lateral and longitudinal locations of habitat units, restoration structures, streambanks and the channel thalweg may change dramatically over several years. This is particularly true in low gradient, unconfined, alluvial settings where many restoration activities occur.

Permanent cross sections may be become useless for their original purpose if the stream channel changes position radically. In settings where large changes in channel location or form are likely to occur it may be necessary to extend cross sections across the entire floodplain to the first low terrace or valley wall (Simon and Castro 2004). Another option is to use a total station to gather a large number of points longitudinally and laterally throughout the study area and generate a digital elevation model (DEM). Synthetic cross sections could then be derived from the DEM. The synthetic cross sections will be less precise than surveyed permanent cross sections, but they will be available for any location within the surveyed and modeled area (J. Bair personal communication).

Survey notes recorded at cross sections are described in Harrelson et al. (1994) and should always include the elevation and station at the left and right edge of water. The location of the estimated “bankfull discharge elevation” should also be recorded in order to calculate width/depth ratios (Dunne and Leopold 1978). See Table 2 below for indicators of bankfull width elevation.

**Table 2.** Bankfull Width Indicators in the Stream Channel.

| |
|---|
| **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.

*Data Analysis Methods for Cross Sections.* There are many ways to analyze cross section survey data depending on the question being asked. At the most basic level, successive surveys are simply overlain and observations of changes are made: including changes in depth at specific points, spacing between features, scour or fill, etc. This type of comparison works best for individual features of interest, such as pool depth below a restoration structure (Figure 17).

Although bankfull discharge elevation and width/depth ratios are useful and commonly reported parameters, they should not be relied on exclusively. Width/depth ratio should be calculated by dividing the bankfull width measurement by the average of the bankfull depth measurements (Archer et. al. 2004). Bankfull discharge elevation is a subjective estimate that is difficult to repeat between visits or observers. This subjectivity makes it difficult to discern real changes from measurement error. Changes in cross sectional area, scour, fill and thalweg depth relative to permanent benchmarks are less subjective. These last values are automatically calculated using the Winscour program developed by Mary Ann Madej at Redwood National Park. The program is available from DFG (B. Collins personal communication).

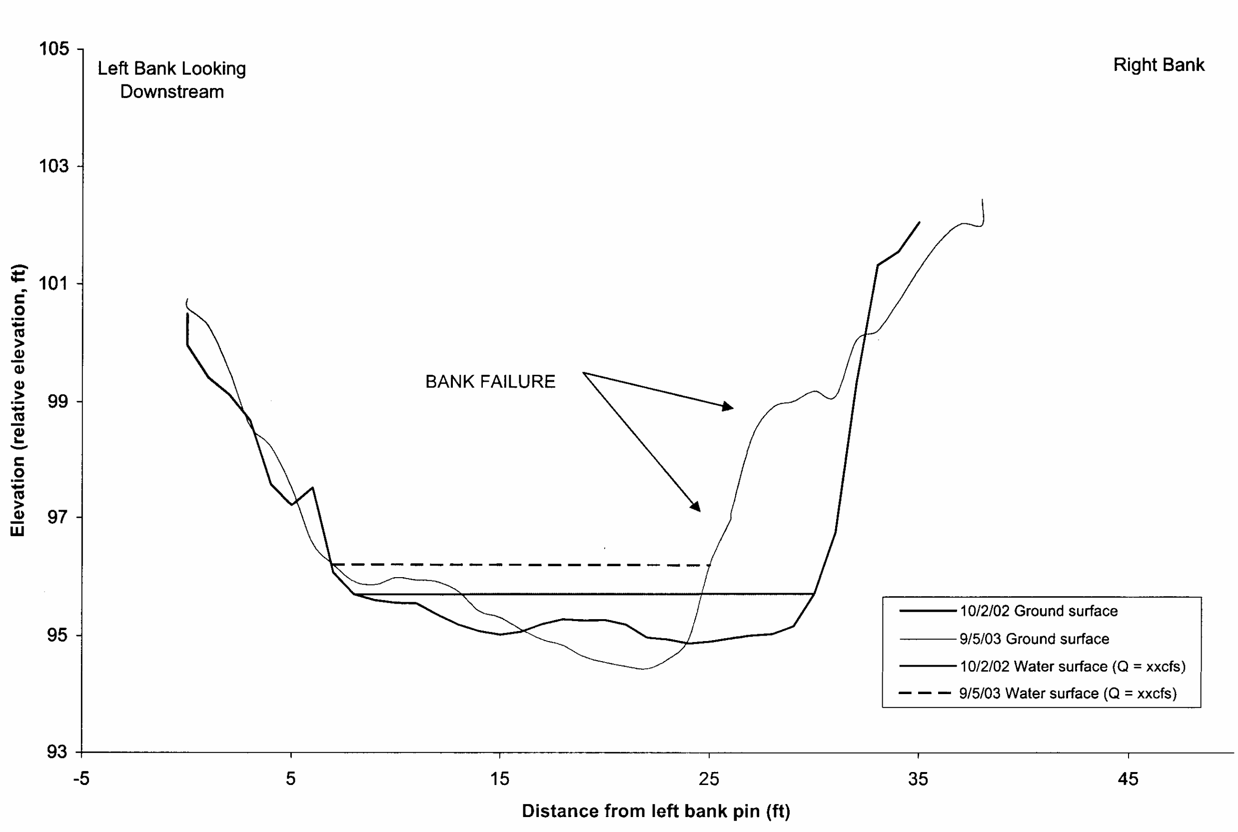


**Figure 17**. Sequential Cross Section Surveys From 2002 and 2003 in a Restored Reach on Lower Freshwater Creek, CA.

In this cross section a stream bank failure deposited material into the bankfull channel width on the right bank, resulting in a narrower and slightly deeper channel. *Source:* McBain and Trush 2004.

**Instructions for 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 Name—**Enter in the name of the stream. If unnamed, use named stream 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 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.

**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 |
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## LITERATURE CITED


Archer, E.K., B.R. Roper, R.C. Henderson, N. Bouwes, S.C. Mellison and J. Kershner. 2004. *Testing Common Stream Sampling Methods for Broad-Scale, Long-Term Monitoring.* Gen. Tech. Rep. RMRS-GTR-122. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain research Station. 15 p.

AREMP/PACFISH/INFISH. 2004. *Effectiveness Monitoring for Streams and Riparian Areas Within the Pacific Northwest: Stream Channel Methods for Core Attributes*. Unpublished report.

Azuma, D. and D. Fuller. 1995. *Repeatability of a Stream Habitat Classification System and its Use for Monitoring*. Unpublished. USDI Bureau of Land Management. Arcata, CA.

Babcock, W.H. 1986. *Tenmile Creek: A Study of Stream Relocation*. Water Resources Bulletin 22:405-415.

Bair, J. 2004. *Personal communication*. McBain and Trush, P.O. Box 663, Arcata, CA, 95518.

Bell, E., W.G. Duffy and T.D. Roelofs. 2001. *Fidelity and Survival of Juvenile Coho Salmon in Response to a Flood*. Transactions of the American Fisheries Society 130:450-458.

Bell, E. 2004. *Personal communication*. Stillwater Sciences, Arcata CA.

Cedarholm, C.J., R.E. Bilby, P.A. Bisson, T.W. Bumstead, B.R. Fransen, W.J. Scarlett and J.W. Ward. 1997. *Response of Juvenile Coho Salmon and Steelhead to Placement of Large Woody Debris in a Coastal Washington Stream*. North American Journal of Fisheries Management. 17:947-963.

Collins, B.W. (editor). 2003. *Interim Effectiveness and Validation Monitoring Protocols. California Coastal Salmonid Restoration Monitoring and Evaluation Program.* California Department of Fish and Game. Fortuna, CA. 320 p.

Collins, B. 2003-2004. *Personal communication*. California Department of Fish and Game, Northern California & North Coast Region, Coastal Restoration Monitoring & Evaluation, Fortuna, California. bcollins@dfg.ca.gov

Crawford, B.A. and L.E. Johnson. 2003. *Protocol for Monitoring Effectiveness of Fish Passage Projects (Culverts, Bridges, Fishways, Logjams, Dam Removal, Debris Removal).* Washington Salmon Recovery Board. 27 pages.

Dunne, T. and L.B. Leopold. 1978. *Water In Environmental Planning*. W.H. Freeman, New York.

Ehlers, R. 1956. *An Evaluation of Stream Improvement Devices Constructed Eighteen Years Ago*. California Department of Fish and Game 42:203-217

Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey and B. Collins. 1998. *California Salmonid Stream Habitat Restoration Manual, Third Edition*. State of California, The Resources

Agency, California Department of Fish and Game, Inland Fisheries Division. Sacramento, CA.

Frissell, C.A. and R.K. Nawa. 1992. *Incidence and Causes of Physical Failure of Artificial Habitat Structures in Streams of Western Oregon and Washington*. North American Journal of Fisheries Management 12:182-197.

Hamilton, J.B. 1989. *Response of Juvenile Steelhead to Instream Deflectors in a High Gradient Stream*. Pages 149-158 in R.E. Gresswell, B.A. Barton, and J.L. Kershner (eds.), *Practical Approaches to Riparian Resource Management: An Educational Workshop*. US Bureau of Land Management, Billings, Montana 193 pp.

Harrelson, C. C., Rawlins, C.L., and J.P. Potyondy. 1994. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique*. Fort Collins, Colorado, United State Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. GTR-RM-245. 61 pages.

Harris, R.R., S.D. Kocher, J. Gerstein, F. Kearns, D. Lindquist, D. Lewis, J. LeBlanc, W. Weaver, and N.M. Kelly. 2002. *Monitoring Fish Habitat Restoration Projects, Draft Final Report to the Department of Fish and Game.* Center for Forestry and Center for the Assessment and Monitoring of Forest Environmental Resources, University of California, Berkeley, 213 p.

Hicks, B. J., J. D. Hall, P. A. Bisson and J. R. Sedell. 1991. *Responses of Salmonids to Habitat Changes*. pp. 483-518. in W. R. Meehan, editor. *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. American Fisheries Society Special Publication 19.

Hopelain, J. unpublished. *Evaluation of Salmonid Habitat Restoration Structures in Northwestern California Streams Conducted During 1993 and 1995*. California Department of Fish and Game, Inland Fisheries Division.

House, R.A., and P.L. Boehne. 1985. *Evaluation of Instream Enhancement Structures for Salmonid Spawning and Rearing in a Coastal Oregon Stream*. North American Journal of Fisheries Management 5:283-295.

Jacobsen, Paul and B. Thom. 2001. *1998-2000 Habitat Restoration Effectiveness Monitoring for the Western Oregon Stream Project*. Oregon Department of Fish and Wildlife, Portland, Oregon. Monitoring Program Report Number OPSW-ODFW-2001-07. 25 pages.

Jacobsen, P.S and K.K. Jones. 2004. *2000-2002 Effectiveness Monitoring for the Western Oregon Stream Restoration Program*. Monitoring Program Report No. OPSW-ODFW-2003-07, Oregon Department of Fish and Wildlife, Salem, Oregon.

Johnson, D.H., N. Pittman, E. Wilder, J. Silver, R.W. Plotnikoff, B.C. Mason, K.K. Jones, P. Roger, T. O'Neil, A. Thomas and C. Barrett. 2001. *Inventory and Monitoring of Salmon Habitat in the Pacific Northwest, Directory and Synthesis of Protocols for*

*Management/Research and Volunteers in Washington, Oregon, Idaho, Montana and British Columbia*. Washington Department of Fish and Wildlife, Olympia, Washington. 212 pages.

Kaufmann, P., P. Levine, E. G. Robison, C. Seeliger, and D. Peck. 1999. *Quantifying Physical Habitat in Wadeable Streams*. EPA/620/R-99/003. U.S. Environmental Protection Agency, Washington, D.C.

Lassettre, N.S. and R.R. Harris. 2001. *The Geomorphic and Ecological Influence of Large Woody Debris in Streams and Rivers*. Report prepared for the California Department of Forest and Fire Protection, Fire and Resource Assessment Program. California Department of Forestry and Fire Protection, Sacramento, CA. 69 pp.

Lisle, T.E. 1987. *Using 'Residual Depths' to Monitor Pool Depths Independently of Discharge.* USDA Pacific Southwest Forest and Range Experiment Station Research Note PSW-394, 4 pp.

Lisle, T.E. 1995. *Effects of Coarse Woody Debris and its Removal on a Channel Affected by the 1980 Eruption of Mount St. Helens, Washington*. Water Resources Research. 31(7):1797-1808.

MacDonald, L.H., A. Smart, and R.C. Wissmar. 1991. *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*. Seattle Washington, U.S. Environmental Protection Agency, Water Division, EPA/910/9-91-001. 166 pages.

Madej, M.A. 1999. *Temporal and Spatial Variability in Thalweg Profiles of a Gravel-Bed Rive*r. Earth Surface Processes and Landforms. 24:1153-1169.

Martin, D.J. 2001. *The Influence of Geomorphic Factors and Geographic Region on Large Woody Debris Loading and Fish Habitat in Alaska Coastal Streams*. North American Journal of Fisheries Management 21:429-440.

McBain, S. and B. Trush. 2004. *Lower Freshwater Creek Cover Enhancement Longitudinal Profile Monitoring*. Unpublished. Prepared for Coastal Stream Restoration Group and California Department of Fish and Game. P.O. Box 663, Arcata, CA, 95518.

Montgomery, D.R. and J.M. Buffington. 1993. *Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition*. Report TFW-SH10-93-002 prepared for the SHAMW committee of the Washington State Timber/Fish/Wildlife Agreement, 107 pp.

Moore, K., K. Jones and J. Dambacher. 2002. *Methods for Stream Habitat Surveys Aquatic Inventories Project*. Oregon Department of Fish and Wildlife, Aquatic Inventories Project, Natural Production Program, Corvallis, OR.

Morgan, A. and F. Hinojosa. 1996. *Winter Habitat Utilization by Juvenile Salmonids, A Literature Review*. Northwest Indian Fisheries Commission. TFW-AM9-96-004. http://www.nwifc.wa.gov/TFW/documents/report5.htm

Olson, A.D. and J.R. West. 1990. *Evaluation of Instream Fish Habitat Restoration Structures in Klamath River Tributaries.* USDA Forest Service. Klamath National Forest, Yreka, California. Annual report.

Opperman, J. in press. *Large Woody Debris, Riparian Vegetation and Land Management in California's Hardwood Dominated Watersheds*. Submitted to Environmental Management.

Opperman, J. 2004. *Personal Communication*. Department of Environmental Science, Policy, and Management, University of California, Berkeley. jjopperman@ucdavis.edu.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for Evaluating Stream, Riparian and Biotic Conditions*. USDA Forest Service, General Technical Report INT-183, 71 p.

Ramos, C. 1996. *Quantification of Stream Channel Morphological Features: Recommended Procedures for Use in Watershed Analysis and TFW Ambient Monitoring*. Northwest Indian Fisheries Commission. TFW-AM9-96-006.

Reeves, G.H., D.B. Hohler, B.E. Hansen, F.H. Everest, J.R. Sedell, T.L. Hickman, and D. Shively. 1997. *Fish Habitat Restoration In The Pacific Northwest: Fish Creek Of Oregon*. In: *Watershed Restoration: Principles and Practices.* Edited by J.E. Williams, C.A. Wood, and M.P. Dombeck. American Fisheries Society, Bethesda, MD. pp 335-359.

Roni, P. and T. Quinn. 2001. *Density and Size of Juvenile Salmonids in Response to Placement of Large Woody Debris in Western Oregon and Washington Streams*. Can. J. Fish. Aquat. Sci. 58:282-292.

Roni, P., A.H. Fayram and M.A. Miller. 2004a. *Monitoring and Evaluating Instream Habitat Enhancement.* In: Roni. P. editor. *Monitoring Stream and Watershed Restoration.* American Fisheries Society. Alpharetta, GA. 328 pp.

Roni, P., M.C. Lierman, C. Jordan and E.A. Steel. 2004b. *Steps for Designing a Monitoring and Evaluation Program for Aquatic Restoration*. In: Roni. P. editor. *Monitoring Stream and Watershed Restoration*. American Fisheries Society. Alpharetta, GA. 328 pp.

Roper, B.R. and D.L. Scarnecchia. 1995. *Observer Variability in Classifying Habitat Types in Stream Surveys*. North American Journal of Fisheries Management, 15:49-53.

Schuett-Hames, D. A.E. Plues, J. Ward, M.Fox, and J. Light. 1999. *TFW Monitoring Program Method Manual for the Large Woody Debris Survey*. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish and Wildlife Agreement. TFW-AM9-99-004. DNR #106. March.

Simon, A and J. Castro. 2003. *Measurement and Analysis of Alluvial Channel Form*. In: Kondolf, M. and H. Piegay., *eds. Tools in Fluvial Geomorphology*. John Wiley and Sons. England.

Simpson Resource Company. 2004. *Class I Channel Monitoring Protocol*. In: *Simpson's Draft Habitat Conservation Plan*. February 5, 2004.

Sit, V. and B. Taylor (editors). 1998. *Statistical Methods for Adaptive Management Studies.* Research  Branch, B.C. Min. For., Res. Br., Victoria, BC, Land Manage. Handb. No. 42.

Smith, G. John. 1998. Retrospective Studies. In: Sit, V. and B. Taylor (editors). 1998. Statistical Methods for Adaptive Management Studies. Res. Br., B.C. Min. For., Res. Br., Victoria, BC, Land Manage. Handb. No. 42.

Solazzi, M.F., Nickelson, T.E., Johnson, S.L. and Rodgers, J.D. 2000. *Effects of Increasing Winter Rearing Habitat on Abundance of Salmonids In Two Coastal Oregon Streams*. Can. J. Fish. Aquat. Sci. 57:906-914.

Stewart-Oaten, A., Murdoch, W.W., and Parker, K.R. 1986. *Environmental Impact Assessment: "Pseudoreplication" in Time*? Ecology 67:929-940.

Tschaplinski, P.J. and G.F. Hartman. 1983. Winter Distribution of Juvenile Coho Salmon (Oncorhynchus kisutch) Before and After Logging in Carnation Creek, British Columbia, and Some Implications for Overwinter Survival. Can. J. Fish. Aquat. Sci. 40: 452-461.

Thompson, D.M. 2002. *Long-Term Effect of Instream Habitat-Improvement Structures on Channel Morphology Along the Blackledge and Salmon Rivers, Connecticut, USA.* Environmental Management, Vol. 29, no 1, pp 250-265.

U.S. Department of Interior. 1999. *WinScour, Scour and Fill for Windows*. National Biological Service, Redwood National Park. Arcata, CA.

U.S. Geological Survey. 1999. *LongPro, Long Profile for Windows Version 2.0.* Biological Resources Division, Redwood Field Station. Arcata, CA.

## FIGURES CITED

Gualala River Watershed Council. 2004. *Monitoring Watershed Scale*. PowerPoint presentation. G.R.W.C  P.O. Box 1269, Gualala, CA 95445.

Hilton, S. and T. Lisle. 1993. *Measuring the Fraction of Pool Volume Filled With Fine Sediment.* Res. Note. PSW-RN-414. Albany, CA. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.

Taylor, R.N. 1999. *Using Stream Geomorphic Characteristics as a Long-term Monitoring Tool to Assess Watershed Function.* Proceedings of a Workshop Co-Sponsored by Fish, Farm, Forests, and Farms Communities Forum; Simpson Timber Company; National Marine Fisheries Service; Environmental Protection Agency; Forest Science Project; and the Americorp Watershed Stewards Program. Humboldt State University, Founder's Hall, Room 118 March 18 & 19, 1999.

McDavitt, B. 2002. photograph of Bull Creek at high flows. O'Connor Environmental Inc. Healdsburg, CA.

## ADDITIONAL REFERENCES


Bain, M.B., and N.J. Stevenson, editors, 1999. *Aquatic Habitat Assessment: Common Methods.* American Fisheries Society, Bethesda, Maryland.

Bisson, P.A., Nielson, J.L., Palmason, R.A. and Grove, L.E. 1982. . *A System of Naming Habitat Types in Small Streams, With Examples of Habitat Utilization by Salmonids During Low Stream Flow*. In: Armantrout, N.B. ed. 1982. *Acquisition and utilization of aquatic habitat inventory information.* American Fisheries Society, Bethesda, Md. Pp. 62-73.

Nickelson, T.E., Rodgers, J.D., Johnson, S.L. and Solazzi, M.F. 1992. *Seasonal Changes in Habitat Use by Juvenile Coho Salmon (Onchorynchus Kisutch) in Oregon Coastal Streams.* Can. J. Fish. Aquat. Sci. 49:90-794.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for Evaluating Stream, Riparian and Biotic Conditions*. Gen. Tech. Rep. INT-138. U.S. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 70 p.