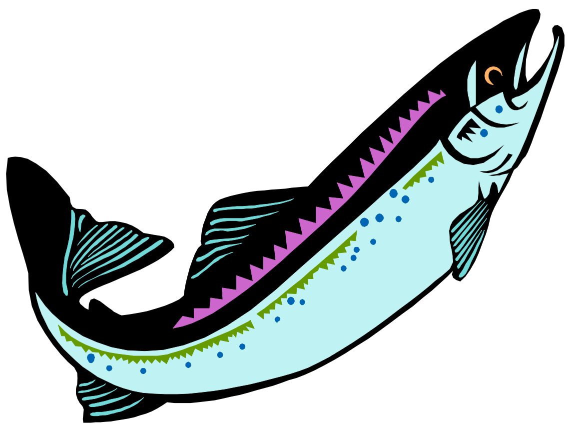
Monitoring the Effectiveness of Instream Substrate Restoration

Final Report



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ACKNOWLEDGMENTS

The methods in this report were developed on the basis of literature review and consultation with scientists specializing in the assessment of substrate suitability for anadromous salmonids. It received peer review from Koll Buer and Tom Lisle. Field data collection was accomplished with the help of Karen Bromley and Mariya Shilz.

Methods were field tested at several locations with the cooperation and support of landowners, California State Parks and the Department of Fish and Game.

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INTRODUCTION

Many restoration projects are intended to improve the quality or quantity of substrate in anadromous salmonid spawning and rearing habitats. In coastal California, spawning habitat improvements may be done by placing instream structures to capture spawning gravels or by enacting measures to reduce fine sediment deposition in gravel beds. Projects intending to improve substrate quality in rearing habitat generally attempt to reduce or prevent fine sediment deposition in pools. The purpose of this report is to provide guidance on field data collection and data analysis for determining the effectiveness of projects with these substrate improvement goals.

Figure 1. Instream Log Structure.
Structures such as this may capture spawning gravel upstream or sort gravels and produce “pockets” of substrate suitable for spawning

With respect to spawning habitat, the quality and quantity of gravel in some rivers and streams can be a limiting factor in salmonid reproduction because of either natural or anthropogenic influences. For example, in streams that have been dammed, disruption of sediment transport may prevent creation of downstream gravel deposits. In other cases, removal of natural obstructions such as large woody debris may reduce storage of gravel in a stream reach. Where the area of potential spawning habitat is limited, spawning salmonids may be forced to suboptimal locations, or redd superimposition may occur.

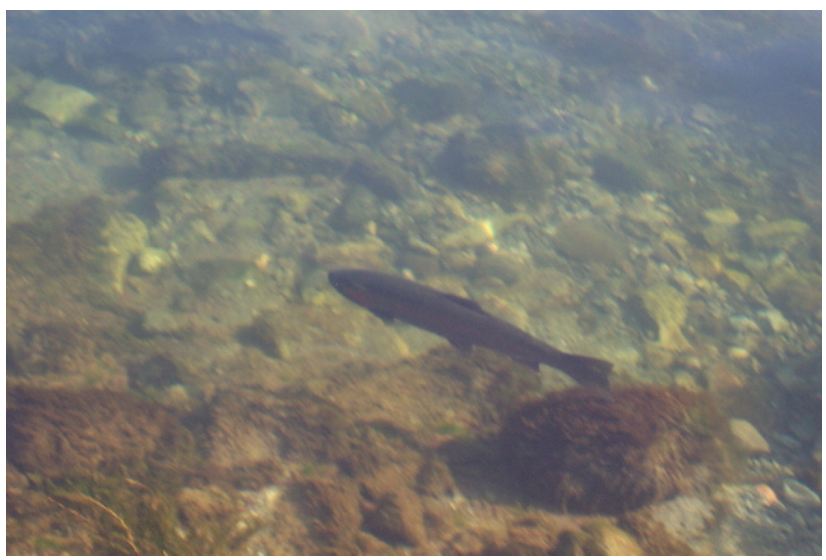


Figure 2. Spawning Habitat Quality.
Suboptimal spawning habitat below Lewiston Dam, Trinity River.

Assuming that gravel beds are present, both surface and subsurface substrate conditions are important. Surface gravel size must be suitable for redd building and egg deposition. Field observations have shown that salmonids can build redds where the average substrate size (D_{50}) is up to 10 percent of average body length (Kondolf 2000). Recommended average sizes for spawning gravels are listed in Table 1.

Table 1. Spawning Gravel Criteria for Salmonids.

Gravel bed criteria	Small bodied salmonids (<35 cm)	Large bodied salmonids (>35 cm)
Dominant substrate particle size	8-64 mm	16-128 mm
Minimum gravel patch size	1.0 m^2	2.0 m^2

The small bodied salmonid on the California coast is cutthroat trout. Large bodied salmonids include coho and Chinook salmon and steelhead trout (after Schuett-Hames and Pleus 1996a).

Surface gravel size distribution can be affected by watershed conditions and processes such as geology, wood inputs, upstream dams, and gravel mining. Streams containing large woody debris often have heterogeneous beds because the debris causes spatially varied flow hydraulics (scour and deposition, see Figure 3) (Bunte and Abt 2001a, House and Boehne 1986). Coarsening (enlargement) of surface gravel sizes is commonly observed below dams because of reduced sediment supply and subsequent armoring. Surface gravels can also be impacted by fine sediment deposition or by scouring during high flows. Scouring of redds by high flow events may cause up to 90 percent mortality in eggs (Schuett-Hames et al. 1996a, Tripp and Poulin 1986, McNeil 1966).

Figure 3. Large Wood Effects on Substrate. Diverse substrate and channel conditions associated with large wood restoration project, Gualala River.

Even if surface substrate is suitable, subsurface conditions may limit egg survival, incubation and emergence. Adequate flow through spawning beds is required to deliver oxygen to maturing egg clusters and remove metabolic wastes (Reiser and Bjornn 1979). Flow can be impaired if there is excessive fine sediment (<one mm) in subsurface strata (Table 2) (Lotspeich and Everest 1981, Platts et al. 1983). After eggs are fully developed, newly hatched fry emerge by swimming

through interstitial spaces. If these spaces are filled by fine sediment (<10 mm), fry may be trapped.

Table 2. Subsurface Fine Sediment Criteria for Successful Emergence.

		Maximum percentage of grains finer than:				
Reference or Statistic	Species	0.83 mm	2.0 mm	3.35 mm	6.35 mm	9.5 mm
Hassle and Coble (1976)	Brook trout		10			
Weaver and White (1985)	Bull trout					16, 40
Bjornn (1969)	Chinook salmon				15, 26	
Tappel and Bjornn (1983)	Chinook salmon				40	
McCuddin (1977)	Chinook salmon				30,35	
Koski (1975, 1981)	Chum salmon			27		
Cederholm and Salo (1979)	Coho salmon	7.5, 17				
Koski (1966)	Coho salmon	21		30		
Phillips et al. (1975)	Coho salmon			36		
Tagart (1984)	Coho salmon	11				
Irving and Bjornn (1984)	Cutthrout trout				20	
Irving and Bjornn (1984)	Kokanee				33	
Irving and Bjornn (1984)	Rainbow trout				30	
NCASI (1984)	Rainbow trout	12			40	
Bjornn (1969)	Stealhead				25	
Tappel and Bjornn (1983)	Stealhead				39	
McCuddin (1977)					27	
Phillips et al. (1975)				25		
Mean		13.7	10.0	29.5	30.3	28.0
SD		4.7	0.0	4.2	7.4	12.0

Based on sources cited in Kondolf (2000). Reported maximum percentages of grains corresponding to 50 percent emergence of salmonids. Anadromous species occurring on California coast include Chinook salmon, coho salmon, cutthroat trout and steelhead.

The percent of fine sediments is higher in watersheds where the geology, soils, precipitation or topography create conditions favorable for erosion (Duncan and Ward 1985). Fine sediments are typically more abundant where activities such as road building or land clearing expose soil to erosion and increased mass wasting (Cederholmn et al. 1981, Swanson et al. 1987, Hicks et al. 1991).

Assessment of spawning habitat and efforts at creating or restoring it therefore requires evaluation of the area of gravel deposits as well as characterization of surface and subsurface substrate conditions (Figure 5). The literature describes several methods for spawning habitat assessment that vary widely in their technical demands (Platts et al. 1983, MacDonald et al. 1991, Bunte and Abt 2001a, Kondolf et al. 2004, others). For major projects on large rivers,

Figure 4. Alevins Emerging From Gravels. *Source:* KRISWEB

rather sophisticated approaches may be warranted (e.g., Merz and Setka 2004). For smaller scale coastal restoration projects, the following evaluation methods are recommended, depending on study objectives:

- Quantifying the area of suitable spawning habitat
- Pebble counts to characterize surface substrate
- Bulk sampling to evaluate fine sediment percentage in subsurface substrate

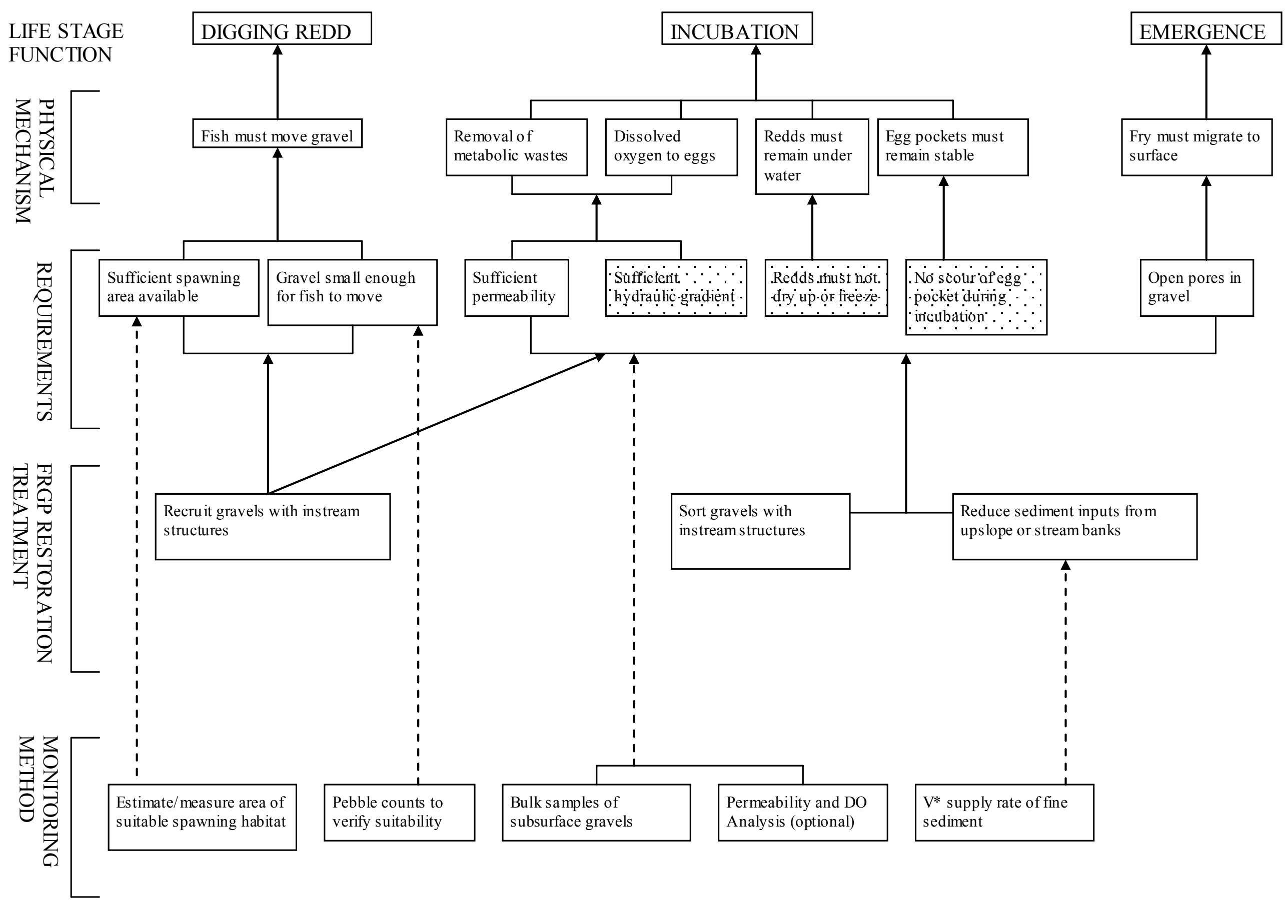


Figure 5. Flow Chart Showing Which Physical Habitat Requirements are Addressed by Fisheries Restoration Grants Program (FRGP) Spawning Habitat Enhancement Projects.
Requirements noted with stippled pattern are rarely targeted for improvement in the FRGP. Flow chart also shows which field methods are appropriate for monitoring the various habitat requirements addressed by restoration projects. V* is a special case because it is intended to determine how well restoration projects reduce fine sediment inputs, rather than evaluate a spawning habitat requirement. Figure was developed from Kondolf (2000) and Lisle (pers. comm. 2004).

Visually estimating the area of potentially suitable spawning habitat before and after treatment at the habitat unit or reach scale is the first step in a quantitative evaluation of spawning habitat. It establishes the locations for sampling substrate composition to validate suitability. Identifying potential spawning habitat is also one of the most difficult things to do consistently. Moreover, spawning gravel is not a static condition but may move due to stream dynamics. The methods presented here are appropriate for detecting relatively large changes in spawning habitat area or quality associated with gravel accretion near instream structure placements. The services of a fisheries biologist familiar with spawning habitat assessment are required.

The pebble count (Wolman 1954, Kondolf 1997) is a relatively easy, well-accepted and inexpensive method for characterizing the grain size distribution of surface gravels and evaluating gravel quality for redd building (Kondolf 2000). In this monitoring approach, pebble counts are conducted in locations initially identified as suitable spawning habitat by an experienced fisheries biologist and/or in areas that may not be currently suitable but are targeted for improvement through restoration treatments. Subsurface sampling in the same locations is conducted to assess conditions for incubation and emergence. Subsurface evaluations are done with bulk sediment sampling equipment.

Permeability and dissolved oxygen content in inter-gravel flow have become increasingly popular as parameters for evaluating substrate conditions for incubation and emergence. Although the physical mechanism is very clear, the amount of literature that correlates permeability to survival through incubation to emergence is small, compared to that which correlates survival to percentage of fine sediment (Tappel and Bjornn 1983). Further research on permeability measurements utilizing variations on the method of Terhune (1958) is needed. For the time being, measurement of permeability and/or dissolved oxygen are not recommended.

Issues regarding bed armoring, development of a static bed pavement, and limited sediment supply, common to conditions below dams or intensive gravel mining, are not addressed here. In special cases where armoring is an issue and it is proposed for treatment, the armored and sub-armored layers may be sub-sampled during bulk sediment sampling (Bunte and Abt 2001a).

In regard to rearing habitat, the focus of this protocol is on evaluating the effectiveness of restoration projects intended to reduce fine sediment deposition in pools by measuring the fraction of residual pool volume filled with fine sediment or "V*" (Figure 5). V* is commonly used for evaluating changes in sediment supply and for interpreting rearing habitat suitability (Lisle and Hilton 1992, Hilton and Lisle 1993 and Lisle and Hilton 1999). If other components of rearing habitat are to be assessed, methods presented in *Monitoring Effectiveness of Instream Habitat Restoration* should be used.

LIMITATIONS

The main focus of the field methods is on the evaluation of the effectiveness of instream structures in creating or improving the quality of spawning and rearing habitat substrate. The methods may also be used to evaluate effectiveness of other restoration activities insofar as they may affect substrate quality, as noted in the next section. Methods that would be necessary for complete evaluations of spawning or rearing habitat quality are not included here. There are many factors unrelated to substrate that may limit spawning. These include water velocity, temperature and depth, location within the channel network, downwelling and upwelling flows, exposure to scouring flows, cover, etc. (Schuett-Hames and Pleus 1996a). Rearing habitat quality is likewise affected by other factors such as shelter, riparian vegetation, streamflow, etc.

Coastal restoration practices rarely involve direct placement or mechanical treatment, e.g., ripping or raking, of spawning gravels. Consequently, the full suite of methods that may be necessary for monitoring such projects is not presented here. The reader should consult the literature for descriptions of methods appropriate for those projects.

RESTORATION OBJECTIVES

Methods presented here apply to the following restoration project types:

- Installation of Structures: placement of structural elements in a stream for the purpose of slowing sediment transport rates thereby recruiting or storing spawning gravel.
- Bank Stabilization: armoring or other treatment of erodible banks to reduce fine sediment delivery and deposition in spawning or rearing habitat.
- Vegetation Control: removal of vegetation from the channel to reverse sequestration of spawning gravels.
- Upland Erosion Control: projects aimed at reducing fine sediment inputs to streams.

Figure 6. Accumulation of Gravel at Instream Log Structure. Large wood placed in the stream has interrupted sediment transport and created patches of suitable spawning gravel.

The general objectives of these projects include:

- Increasing the quantity and/or quality of spawning habitat for targeted species.
- Reducing fine sediment deposition in spawning and/or rearing habitats.

The ultimate goal is to improve production and survival of juvenile salmonids. This report does not provide methods for biological monitoring. It only addresses changes in substrate conditions.

Figure 7. Riparian Vegetation Encroachment, Trinity River. Riparian vegetation has sequestered spawning gravels below Lewiston Dam on the Trinity River. Restoration efforts include removing the vegetation and grading to reconnect the stream to its floodplain.

EFFECTIVENESS MONITORING QUESTIONS

Methods presented here may be used either to evaluate individual projects, or to provide the data for statistical comparisons of alternative project designs and implementation techniques. In either case, a specific study design will be required.

The following general questions may be addressed:

- Has the project or project type improved spawning gravel suitability within the targeted stream reach(es) or habitat units?
- Has the project or project type improved the quality of rearing habitat within the targeted stream reach(es) or habitat units?
- What is the duration of the beneficial effects on spawning or rearing habitat?

Figure 8. Potentially Suitable Spawning Habitat.
A qualified fisheries biologist should be involved in any assessment of substrate quality due to the professional judgment needed for delineating potentially suitable habitat.

Table 3 lists the parameters, effectiveness criteria and field methods that are recommended to address substrate monitoring questions. Field method numbering corresponds to their description in the Field Methods section. Specific effectiveness criteria, e.g., goals for the amount of increased habitat or substrate size, should be defined in project contracts and/or within study plans for effectiveness monitoring.

Table 3. Questions, Parameters, Effectiveness Criteria and Field Methods

Monitoring Question	Parameters	Effectiveness Criteria	Field Methods
1) Has the project or project type improved spawning gravel suitability within the targeted stream reach(es) or habitat units?			
a) Has the area of potentially suitable spawning habitat increased?	Suitable spawning habitat area	Area of potentially suitable habitat has increased by a specified amount.	Field Method 1: Quantifying Potentially Suitable Spawning Habitat
b) Is the surface substrate of the potential habitat suitable for redd construction?	Average surface particle grain size (D50).	Substrate size is suitable for redd construction by the targeted species	Field Method 2: Pebble Counts
c) Has subsurface gravel quality improved for egg incubation, maturation, and emergence?	Subsurface particle grain size and percent fine sediment	Percentage of fine sediment does not exceed levels required for survival of targeted species.	Field Method 3: Bulk Sampling
2) Has the project or project type improved the quality of rearing habitat within the targeted stream reach(es) or habitat units?			
a) Has the amount of fine sediment in pools been reduced?	V* - change in fine sediment volume in pools.	V* values are below targeted thresholds and pre-treatment levels.	Field Method 4: Fine sediment in pools -V*
3) What is the duration of the beneficial effects on spawning or rearing habitat?			
a) Have conditions in spawning and rearing habitat remained above targeted thresholds over successive years?	All of the above spawning and rearing habitat parameters.	Persistence of beneficial effects meets targets specified in the study design or contract.	All of the above spawning and rearing habitat methods.

STUDY DESIGN

As with other restoration monitoring protocols, the recommended study design for effectiveness monitoring is the before-after-control-impact approach (BACI) (Stewart-Oaten et al. 1986, Sit and Taylor 1998, Crawford and Johnson 2004). Depending on study objectives, controls may either be habitat patches or stream reaches. Control reaches/sites should be located immediately upstream (preferably) of the treated site within a reach that is directly comparable to the treated reach[1]. If suitable controls cannot be located on the same tributary as the treatments, then controls should be established on a nearby tributary that is comparable to the treated area.

Although BACI design studies are preferred in most applications, other study designs may also be used. Before-after monitoring may be more appropriate for studies of specific projects (single project monitoring) and controls may or may not be used (Merz and Setka 2004). In other cases, such as studies of the duration of restoration effectiveness, retrospective studies may be used (Roni and Quinn 2001, Frissell and Nawa 1992, Smith 1998). Retrospective studies can provide useful information with only 1-2 years of data collection but they do have statistical limitations (Smith 1998, Hicks et al. 1991).

[1] Pairs of reaches (treatment/control) need to be as similar as possible, including: channel dimensions, watershed area, climate, geology, gradient, land use, etc.

Further information on study design for effectiveness monitoring is provided in *Monitoring the Implementation and Effectiveness of Fisheries Habitat Restoration Projects*.

SAMPLING DESIGN

For evaluation of spawning habitat restoration, the approach outlined here involves an initial stratification of "potentially suitable spawning habitat" and/or habitat units prescribed for treatment followed by quantitative sampling to validate the area and substrate characteristics of the habitat. This is a variant of the "spatially segregrated sampling" method described in Bunte and Abt (2001a). Generally, riffle crests and pool tail outs will be identified as potentially suitable spawning habitat (see Field Method 1) (Briggs 1953, Shapovalov and Taft 1954). Riffles will also tend to exhibit changes in size distributions attributable to changes in coarse sediment supply (Buffington and Montgomery 1999b).

For evaluation of changes in rearing habitats due to changes in fine sediment supply, sampling will be conducted in pools. They are the primary rearing habitats used by juvenile salmonids. They also are the most vulnerable locations for fine sediment deposition.

Monitoring may focus on specific riffles or pools targeted for improvement or may be done at the stream reach scale, in which case riffles or pools may be sampled in a statistical design. For example, a study evaluating the recruitment of gravel in association with instream structures could be done at the structure/habitat unit scale or at the stream reach scale in cases where multiple structures are installed. Sampling surface or subsurface sediment in riffles or pools alone will not provide a reach-averaged particle-size distribution. Reach-averaged evaluations would require a sampling scheme that includes all geomorphic units of the reach (Kauffman et al. 1999, Bunte and Abt 2001a). When the focus is on the quality of either spawning or rearing habitat specifically, reach-averaged substrate conditions are not relevant.

Figure 9. Instream Structure and Associated Scour Pool. Studies of restoration effects on fine sediment deposition in pools could be performed in either or both created and natural pools.

In a comprehensive study of the effects of restoration on both spawning and rearing habitat, field methods for spawning and rearing habitat evaluation may both be used. For example, a study of stream reaches where instream structures are intended to benefit both types of habitat may evaluate effects on spawning habitat area and suitability as well as effects on fine sediment deposition in pools.

TIMING AND FREQUENCY

The timing of restoration monitoring should be tied to project objectives, feasibility, and the ecological sensitivity of the site. This requires that study objectives include site specific guidelines so that monitoring efforts do not interfere with cycles of redd building, incubation, or emergence for the targeted species. For many studies, feasibility is also an important issue. Performing pebble counts, bulk sampling, and measuring residual pool volume is generally impractical in deeper flowing water.

It is not advisable (or legal) to make measurements within redds during incubation. For this reason bulk sampling should be performed in areas adjacent to active redds that appear similar in other respects or within redds after emergence has occurred. Sampling redds after emergence gives an indication of conditions that existed within the redd during incubation, which will be different than unspawned areas due to flushing of fine sediments during redd building and subsequent fine sediment infiltration during incubation. For potential spawning gravels where actual spawning has not yet occurred samples may be collected during the low flow season. Kondolf (2000) suggests adjusting the amount of fine sediment measured in unspawned gravels down to account for probable cleaning effect due to redd building.

For studies with the specific objective of quantifying infiltration of fines into redds during the incubation period suitable methods are described in Lisle and Eads (1991). This type of study would be appropriate where a limiting factors analysis has indicated that capping of redds by fine sediment or infiltration of fine sediment into redds after spawning is limiting incubation or emergence and a restoration project has been designed to address these factors.

DATA QUALITY

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

FIELD METHODS

Field Method 1: Estimating the Area of Potentially Suitable Spawning Habitat

The first step in an evaluation of spawning substrate restoration effectiveness is to identify potentially suitable spawning habitat within a project area. This is done before and after treatment in restored and control sites or reaches. The estimate of spawning habitat area and quality is then validated through quantitative sampling. Because this initial step is so important, it should be done by a qualified fisheries biologist in conjunction with habitat typing.

The definition of “suitable spawning habitat” should be tailored to target species and local conditions if those criteria are available. An example of criteria tailored to a single species can be found in the *Recovery Strategy for California Coho Salmon* (DFG 2004). If specific local criteria are not available, the general definition developed by Schuett-Hames and Pleus (1996a) may be used (Table 4). Since there is no strictly objective method that measures all aspects of spawning habitat suitability directly and simultaneously, an estimate based on the professional judgment of an experienced fisheries biologist is the preferred method for initial identification (Kondolf et al. 2004).

Table 4. Spawning Habitat Suitability Criteria.
The small bodied salmonid on the California coast is cutthroat trout. Large bodied salmonids include coho and Chinook salmon and steelhead trout. (after Schuett-Hames and Pleus 1996a).

Habitat Parameter	Small bodied salmonids (<35cm)	Large bodied salmonids (>35cm)
Dominant substrate particle size	8-64 mm (0.32-5.6”)	16-128 mm (0.64-5.12”)
Water depth	10 cm (4”)	15 cm (6”)
Velocity	moving	moving
Minimum gravel patch size	1.0 m^2	2.0 m^2

Visual estimates of spawning habitat area are imprecise and there may be significant differences between preliminary estimates and quantified areas. Consequently, this procedure is valid if the expected change of spawning habitat area is > 50 percent. This level of precision is commensurate with the observer error and flow dependency inherent to the habitat typing methodology (Azuma and Fuller 1995, Roper and Scarnecchia 1995, Kaufmann et al. 1999) and natural variability in stream morphological features (Archer et al. 2004). More sophisticated methods would be required for monitoring small, incremental changes in habitat area (e.g., Merz and Setka 2004).

Site Selection
Visual estimates of spawning habitat area can be applied to 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. In the context of a BACI design, 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. For example, some structures may store gravel upstream of the structure while others may sort gravels downstream of the structure or both (Figure 10). Complication can arise in places with a high density of structures due to interactions between them. In those instances, evaluation at the reach scale is more appropriate.

Samples of substrate composition will be collected in areas defined as suitable spawning habitat (see Field Methods 2 and 3). The most common locations of suitable spawning habitat are the upstream end of riffles (heads), downstream end of pools (tail-outs) and isolated pocket gravels located in various habitat types (Kondolf 2000). Stratification by habitat unit and by suitable spawning areas within habitat unit reduces the variance for sampling substrate composition.

Figure 10. Substrate Sorting Caused by Scour Structure. While the amount of fine sediment appears to be reduced on the right side of the photograph, cobble size may be too large to move by small bodied fish, and suitability would be determined by target species. The two distinct size classes would be sampled individually for substrate analyses, e.g. pebble counts or bulk samples.

Determination of Sample Size

Habitat typing and visual estimation of suitable spawning area are survey procedures. 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 effectiveness 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 all effectiveness monitoring, 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. 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 50 percent increase in suitable spawning area 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. Projects implemented in different years can be included in the same analysis to achieve the desired sample size. Further information on study design and sample size can be found in *Monitoring the Implementation and Effectiveness of Fisheries Habitat Restoration Projects* and Archer et al. (2004).

Timing of Surveys

Surveys of potentially suitable spawning habitat should be conducted during flows that are similar to when spawning occurs. Spawning surveys are typically conducted in late fall, however target species and local conditions may alter this timing. Surveys should be conducted on the receding limb of the hydrograph when turbidity levels are likely to be low enough to see the substrate. Although it is preferable to estimate suitable spawning habitat during spawning season, it may not be possible to conduct quantitative sampling of substrate at that time. For this reason it may be necessary to re-visit the site during low flows and use measurements of habitat unit boundaries (length and width) obtained during spawning flows to visualize the wetted width and locations of suitable spawning habitat patches during low flows when it is possible to sample the substrate (Figure 11).

Field Sampling Methods
The proportion of each habitat unit that is suitable for spawning (based on criteria in Table 4 and observations by a qualified fisheries biologist) is recorded as a percentage of the surface area of the entire habitat unit. Using habitat unit measurements, this percentage can be applied to obtain the preliminary estimate of spawning habitat area. It is anticipated that this estimate will have a relatively low level of precision due to inter-observer and inter-flow variability, which can be minimized by re-visiting sites at similar flows and using the same personnel if possible. The locations of suitable spawning habitat patches within each habitat unit are noted on a sketch map. Figure 12 shows a photograph with delineated areas. Figure 13 is an example of a sketch map. If there is a need to map out locations of specific habitat patches in more detail, in order to track movement of boundaries or detect small changes in area, a suitable method can be found in Schuett-Hames et al. (1999).

Figure 11. Habitat Changes at Different Flows. Area within the dashed lines is downstream of a scour log and was a pool tail out suitable for spawning at higher flows. Photograph was taken at low flows when most substrate analyses are performed. Although the target area does not meet depth criteria at low flow, it did at spawning flows and should still be a sample site for substrate analyses.

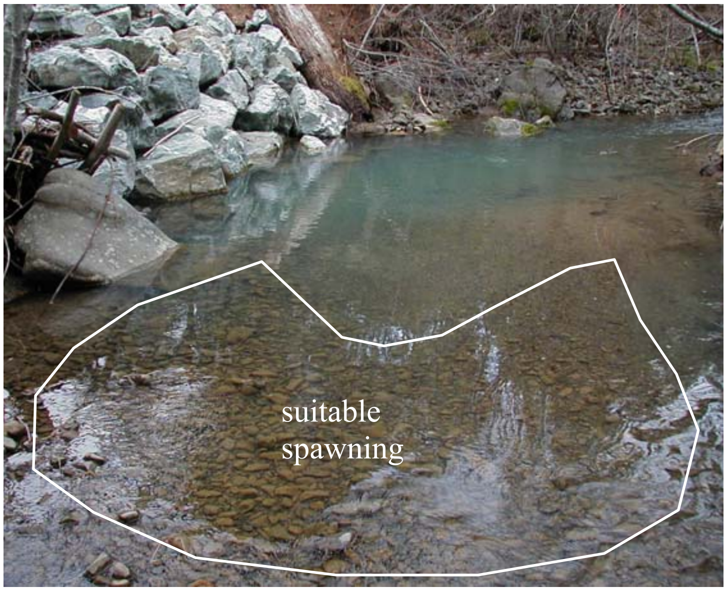
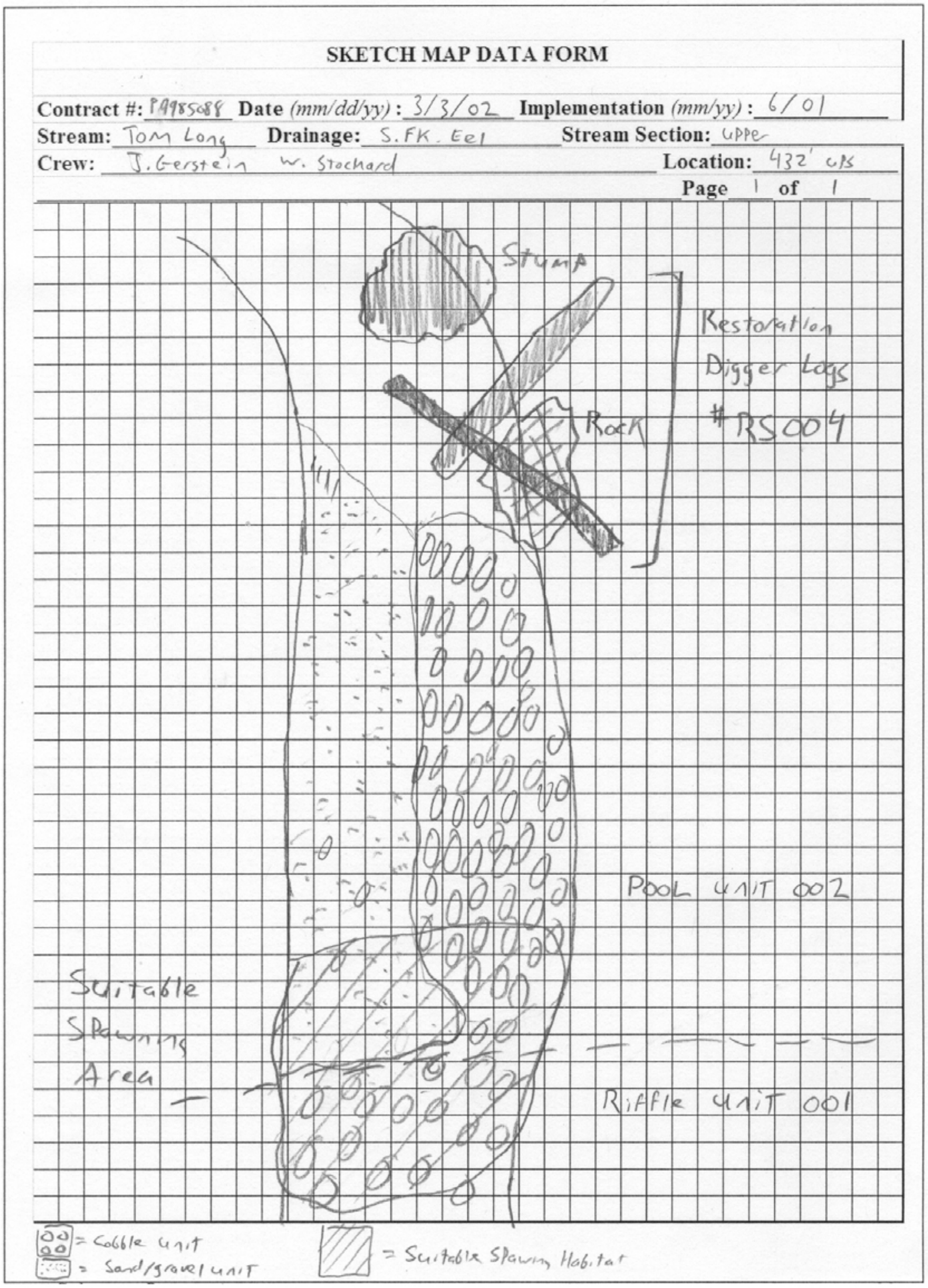


Figure 12. Delineation of Suitable Spawning Habitat.
Suitable habitat occurs in the pool tail out which occupies approximately 20 percent of the habitat unit. Rock armor was not designed to improve spawning habitat and data from pre-treatment time period would be required to determine if suitable spawning area or substrate composition had changed after the bank stabilization project was installed.


SKETCH MAP DATA FORM

Contract #: PA985088 **Date** *(mm/dd/yy)* **:** 3/3/02 **Implementation** *(mm/yy)* **:** 6/01

Stream: Tom Long **Drainage:** S. Fk. Eel **Stream Section:** Upper

Crew: J. Gerstein W. Stockard **Location:** 432' u/s

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Figure 13. Sketch map of Delineated Spawning Habitat.

Delineating habitat types and estimating suitable spawning habitat involves walking up the channel and classifying each habitat unit as it is encountered (Flosi et al. 1998). A reconnaissance survey of the entire reach to be surveyed first is advisable (Bunte and Abt 2001a). Using the fewest number of habitat classes possible increases accuracy and repeatability between observers (Azuma and Fuller 1995, Roper and Scarnecchia 1995, Ramos 1996). Level

III habitat typing is recommended. 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 unit and existing or proposed structure 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 will be calculated after data entry by subtracting 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: For reach-scale studies, the 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 (see *Documenting Salmonid Habitat Restoration Project Locations*). 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.

For site-scale studies, habitat units in the vicinity of proposed or existing structures should be surveyed. The extent of the survey should be based on the expected area of influence of the treatment. In most cases, this will be one habitat unit upstream or downstream.

Field procedures are as follows:

- 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. No further data are recorded on the side channel unless it received restoration treatments or was created through channel modification. If side channels received treatment or were created, they should be surveyed in the same manner as the main 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. The width of stream channels may have to be measured using a range finder if wading across the channel is not possible.

Average depth of water is recorded for suitable spawning habitat areas and recorded within the habitat unit where it occurs. This measure is intended to help determine if the areas meet the depth criteria listed in Table 4. Depth should be estimated in suitable spawning areas, not the entire habitat unit.

Percent suitable spawning habitat is an estimate of the portion of each habitat unit that is suitable for spawning using criteria from Table 4. All criteria should be used for this estimate. That is, if an area meets some but not all criteria, it is not included. This estimate should be made by a professional fisheries biologist during spawning season.

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.

Data Analysis

The purpose of Field Method 1 is to provide the stratification necessary for quantitative sampling of spawning area and substrate. It will provide an estimate of the total suitable spawning habitat as percent of total habitat and as an area in square feet. Area may be calculated by first calculating the area of each habitat unit based on the length and average width measurements. Then the suitable spawning habitat area is calculated by multiplying the percentage of suitable habitat assigned to each habitat unit by the calculated area of each habitat unit. Suitable spawning habitat area is then summed for each study area.

The sketch map produced from this method provides a means for navigating to sample sites during subsequent substrate sampling. It is not used for quantitative analysis.

Instructions for Spawning Habitat 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) **Average Depth of Water—**Enter the average depth of water within the suitable spawning habitat for each habitat unit in feet. Average depth is calculated by taking random sample of depths in each spawning area and computing the average.
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) **% Suitable Spawning Habitat—**Estimate the percentage of each habitat unit that contains suitable spawning habitat based on criteria in Table 1 (or local criteria) and best professional judgment of a fisheries biologist.

Restoration Structure Data

16) **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.

17) **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.

18) **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.

19) **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.

20) **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.

21) **% Suitable Spawning Habitat created by structure—**Enter the percent of the total area of suitable spawning habitat within the habitat unit that the restoration structure is causing.

22) **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.

SPAWNING HABITAT FORM

Page ___ of ___

Contract #:___________________________ Contract name:____________________________

Stream:__________________________ Date: ______________ Evaluation crew:___________

Drainage:____

All Habitat units	**Habitat Unit Number**										
	Habitat Unit Type										
	Main or **S**ide channel										
	End Distance										
	Average Depth of Water w/in Spawning Habitat										
	Width @ 1/3										
	Width @ 2/3										
	% Spawning Habitat										
Restoration Structure Data	**Habitat Unit Number**										
	Structure Number										
	Structure Type										
	Structure Condition										
	Structure Problem										
	Upstream End Distance										
Comments											

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

Instructions for Sketch Map Data Form

1) **Contract #-** Enter in the contract number assigned to this project by the Department of Fish and Game.
2) **Date-** Enter the date: *mm/dd/yy*
3) **Implementation-** Enter the month and year that implementation of the project feature being evaluated is scheduled for or was completed*: mm/yy*.
4) **Stream -** Enter in the name of the stream. If unnamed, use named stream to which it is tributary.
5) **Stream Section -** Enter the habitat unit number from Field Method 1.
6) **Location –** Enter location upstream and downstream structures/implementations or additional measurements of distance from known benchmarks or survey start points.
7) **Crew-** Enter the names of the survey crew in the following format: *last name, first initial*.
8) **Site sketch –** Illustrate and label the channel features such as:
   Left edge of water (LEW)
   Right edge of water (REW)
   Direction of flow (indicate and label with arrow)
   Sediment Patches and ocular estimate of average grain size.
   Pebble count locations (PC #1, PC #2, etc)
   Key of symbols, if necessary.

SKETCH MAP DATA FORM

Contract #:_________ **Date** *(mm/dd/yy)* **:**___________ **Implementation** *(mm/yy)* **:**_____________

Stream:______________ **Drainage:**___________________**Stream Section:**___________________

Crew: ____ **Location:**_____________

____**Page**____ **of** ______

Field Method 2: Quantifying Spawning Habitat Area and Surface Texture

Field Method 1 provides an ocular delineation of potentially suitable spawning habitat. In Field Method 2, the area of habitat and its surface texture are quantified. Area is quantified while conducting pebble counts that are used to determine if surface gravel size is suitable for redd building. Depending on the results obtained from Field Method 1, surface substrate may be quantified for all spawning habitat combined or for separate patches within a reach. The pebble count method presented below is adapted from Wolman (1957).

Figure 14. Sampling Surface Substrate Size Using the Pebble Count Method. Pebbles are selected for measurement at systematically determined intervals.

Site Selection

Sampling areas are defined as the potentially suitable spawning habitat delineated and mapped in Field Method 1. Site selection depends on the scale of the effect to be monitored. For projects that attempt to affect an entire reach, pebble counts should be done throughout the reach in the defined suitable spawning areas, which will often be riffle crests (Schuett-Hames et al. 1999). Locations that may be impacted by landslides or other localized effects such as bank sloughing should be avoided in reach scale studies.

For site scale effects, sampling should be done in areas immediately adjacent to restoration structures intended to recruit or improve gravel. For instream restoration project sites where spawning habitat may not exist prior to implementation, pebble counts should be conducted in areas where gravels are expected to accumulate after construction.

Information Needed Before Sampling: Locations and descriptions of all installed or proposed structures should be presented to the monitoring team prior to the initial sampling (pre-treatment). The 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. Subsequent monitoring should also include distance measurements to restoration structures.

Determination of Sample Size
For each pebble count, a sample size of 100 particles is generally sufficient to consistently measure the median grain size (D_{50}) of a specific gravel patch or graph the cumulative frequency distribution. In reach-scale studies, pebble counts may be conducted on separate patches of potentially suitable habitat and summed to create a cumulative frequency distribution. If the study design requires reproducibly measuring the lower five and upper 95 percentiles of the distribution (D_5 or D_{95}), samples of 200 to 400 particles per patch are recommended (Fripp and Diplas 1993).

Equipment List. The equipment needed for conducting pebble counts includes:
- Sketch map (Field Method 1)
- Gravel template
- Pebble count data sheets, sketch map data sheet, pencils, and a clipboard
- Hand held counter
- Waders or stream wading shoes
- 2 or 3 – 100 foot tapes
- Flagging and permanent marking pens

Field Sampling Method
Pebbles should be selected at regular intervals along a transect or multiple transects in each sampling area, i.e., using a tape measure to determine where to pick up pebbles. This reduces errors caused by observer bias in selecting each particle based on paces or steps (Bunte and Abt 2001a). Particle size should be measured using a template with square openings representing phi and half phi sieve sizes (Figure 15 and Table 5).

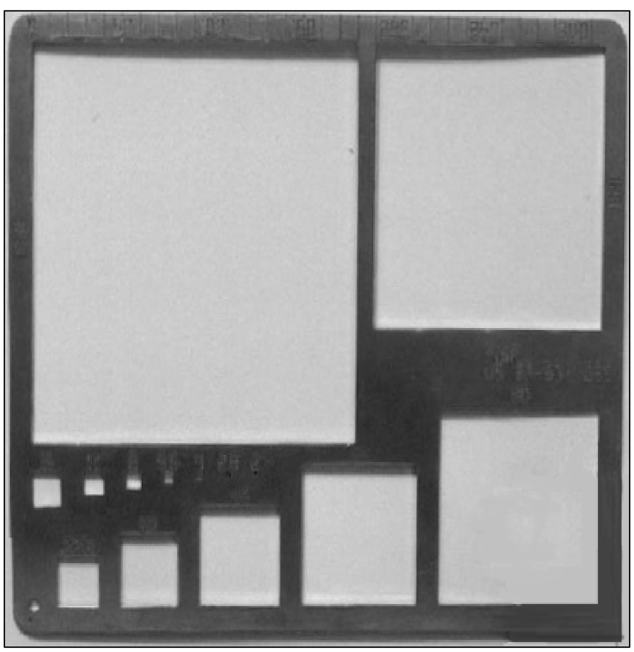

Figure 15. Gravelometer Used for Pebble Counts. Each frame constitutes a specific gravel size. *Source:* Bunte and Abt (2001b)

Table 5. Sediment Size Scales.
Size gradation for sediment in the range of sand to boulders showing the four common scales (from left to right): Wentworth (text), phi ($-\log_2$), millimeters (mm) and psi ($\log_2$). Source: (Bunte and Abt 2001a).

Description of particle size			$\phi = -\log_2$	mm	$\psi = \log_2$
			- 12.0	4096	12.0
	very large		- 11.5	2896	11.5
			- 11.0	2048	11.0
	large		- 10.5	1448	10.5
Boulder			- 10.0	1024	10.0
	Medium		- 9.5	724	9.5
			- 9.0	512	9.0
	small		- 8.5	362	8.5
			- 8.0	**256**	**8.0**
	large		- 7.5	181	7.5
Cobble			- 7.0	128	7.0
	Small		- 6.5	90.5	6.5
			- 6.0	**64**	**6.0**
	very coarse		- 5.5	45.3	5.5
			- 5.0	32	5.0
	coarse		- 4.5	22.6	4.5
		Pebble	- 4.0	16	4.0
Gravel	medium		- 3.5	11.3	3.5
			- 3.0	8	3.0
	fine		- 2.5	5.66	2.5
			- 2.0	4	2.0
	very fine	**Granule**	- 1.5	2.83	1.5
			- 1.0	**2**	**1.0**
	very coarse		- 0.5	1.41	0.5
			0	1	0
	coarse		+ 0.5	0.707	- 0.5
			+ 1.0	0.500	- 1.0
Sand	medium		+ 1.5	0.354	- 1.5
			+ 2.0	0.250	- 2.0
	fine		+ 2.5	0.177	- 1.5
			+ 3.0	0.125	- 3.0
	very fine		+ 3.5	0.088	- 3.5
			+ 4.0	**0.063**	- 4.0
Silt					
			+ 8.0	**0.0039**	**- 8.0**
Clay					
			+ 12.0	**0.00024**	**- 12.0**

The following steps should be followed:

- Identify each patch of potentially suitable spawning habitat that will be sampled according to the study design. In extensive studies, the population of suitable spawning patches may be sub-sampled.
- Measure the length and width, and calculate the area of each sampling site. This may be done when laying out tapes to define the sampling grid, see below.
- Lay the surveyors tape longitudinally along the sediment patch, and divide the length into evenly spaced transects to create a sampling grid that evenly covers the entire patch. The easiest grid to layout is a 10 X 10 grid, which yields 100 particles. The longitudinal length is divided into 10 evenly spaced locations where the lateral tape will be placed. Each lateral tape length is then divided into 10 points to pick up a pebble. The sampling grid must always be at least two times the largest representative particle. To determine the minimum sampling spacing or grid, measure the length (i.e., b-axis) of largest representative particle D_{max} and multiply this value by two. The largest representative particle is the largest particle likely to be moved by yearly average flows, such as a large cobble. A boulder is not likely to be moved by yearly average flows.
- Select particles from under the surveyors tape based on the grid spacing. Do not double count any single particle. Counting large particles more than once introduces serial correlation into the sample, overemphasizes the presence of large particles in small samples, and breaks the correlation between sample size and error (Bunte and Abt 2001a, 2001b)
- Measure selected particles using the gravel template. Pass the particle through the smallest square that can accommodate it, and record particle size as being in between the size of the hole through which it passed and the next smallest size. For example, a particle that fits through the 64 mm hole but not the 45.3 mm hole should be recorded next to the 45.3 to 64 mm category in the "Count" column in the data sheet.
- Continue sampling at each tape intercept until a sample size of at least 100 particles is reached.

Data Analysis
Two pieces of information are obtained from this field method. The estimated area of potential spawning habitat, obtained from Field Method 1, is validated. Data collected before and after treatments or in control reaches may show increases or decreases in area or number or sizes of habitat patches relative to the initial estimates. Pebble count data may confirm or refute initial estimates of substrate suitability. This information will not only be valuable for assessing restoration effectiveness, it will provide a means to improve Field Method 1.

Evaluating the substrate particle size distribution involves tabulating the grain sizes and creating a cumulative frequency distribution. This can be easily computed and graphed by using a published spreadsheet program such as "Size-ClassPebbleCountAnalyzer2001.xls" (Potyondy and Bunte 2002). An example is shown in Figure 16. There are also copyrighted and some freely distributed spreadsheet templates on the internet:

- Size-Class Pebble Count Analyzer V1 2001.xls
  By John Potyondy and Kristin Bunte
  http://www.stream.fs.fed.us/publications/PDFs/Size-ClassPebbleCountAnalyzer2001.xls

- PebbleSort, Particle Size (Ptxsize):
  By Andre K. Lehre (1993)
  http://www.humboldt.edu/~geodept/geology531/531_macros_templates_index.html
- The reference reach spreadsheet Version 2.2 L
  By Dan Mecklenburg:
  http://www.dnr.state.oh.us/soilandwater/streammorphology.htm

PEBBLE COUNT DATA PROCESSING FORM

Contract #:__________ **Date** *(mm/dd/yy)* **:**__________ **Implementation** *(mm/yy)* **:**____
Stream:________________ **Drainage:**_______________**Stream Section:**__________
Crew: _____________________ **Transect #:**________ **Transect length:**__________
Page_____ of ______

Class Name	Particle Size Class (mm)	Reference Total	Study Total	Reference Cumulative %	Study Cumulative %
Sand	<2				
VF Gravel	2 - 2.8				
	2.8 - 4				
Fine Gravel	4 - 5.6				
	5.6 - 8				
Med. Gravel	8 - 11.3				
	11.3 - 16				
Coarse Gravel	16 - 22.6				
	22.6 - 32				
VC Gravel	32 - 45.3				
	45.3 - 64				
Sm. Cobble	64 - 90.5				
	90.5 - 128				
Lg. Cobble	128 - 181				
	181 - 256				
Sm. Boulder	256 - 362				
	362 - 512				
Med. Boulder	512 - 1024				
Lg. Boulder	1024 - 2048				
VL Boulder	2048 - 4096				
Bedrock	>4096				
	Totals				

Figure 16. Pebble Count Data Processing Form.
Source: Potyondy and Bunte (2002).

To compute the cumulative frequency grain size distribution:

- Count the number of particles for each size class, and enter that number in either the “Reference Total” or “Study Total” column. The reference site may be the upstream, untreated site. The study site is the treated or restored site.

- The sum of the number of particles collected should be entered in the Totals column at the bottom.
- Cumulative percent is calculated as a running sum of particles up to each size class divided by the total number of particles in the sample. For example, for the reference site totals less than 32 mm, the cumulative percent = 100 * (9+5+1)/98 = 15.3 percent. That is, 15.3 percent of the sample is smaller than 32 mm.
- The data should be graphed as a cumulative distribution curve, with the *X*-axis displaying the range of particle sizes in logarithmic scale, from zero to the largest size class counted in the study, and the *Y*-axis displaying the percent frequency. Lines on the graph should indicate the common descriptors for the sample such as the median (D_{50}), and the upper and lower standard deviations (D_{84}, D_{16}) or a specified statistic used for evaluating habitat quality.

To compare numerous sites and successive years of data, graph the summaries in box and whisker plots. Examples of cumulative frequency distribution curves and box and whisker plots may be reviewed in Kondolf (2000).

Instructions for Pebble Count Data Collection 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.
8) **Habitat Unit # -** Enter the number of the habitat unit where the pebble count is conducted, refer to "Spawning Habitat Form" for assigned habitat unit numbers.
9) **Patch # -** If multiple patches of substrate (i.e. facies) were delineated for this spawning habitat area; enter which patch this pebble count corresponds to. If only one patch was delineated, enter '1'.
10) **Length of Sediment Patch –** Enter the length of patch, record which measurement units were used
11) **Width(s) of Sediment Patch –** Enter the width of the sediment patch, if multiple widths were measured during establishment of grid record each width separated by a comma. Record measurement units.
12) **Ave. Width –** Calculate the average of the width values recorded above, enter this value.
13) **Area of Sediment Patch –** Multiply the length of the sediment patch by the average width to determine the area of the sediment patch, enter that value.

14) **Particle Size Information – Section 2**
15) **Count –** Tally the number of particles within each size class during the count.
16) **Total –** After completing the pebble count, sum the tally of particles for each size class and enter the value.
17) **Comments –** Enter any important remarks or notes.

PEBBLE COUNT FORM **Page ___ of ___**

Contract #: **Contract name:**

Stream/Road: **Date:** **Evaluation Crew:**

Drainage:____

Habitat Unit #________________ **Patch #**______________________

Length of Sediment Patch:_________________________

Width(s) of Sediment Patch:______________________________________ **Ave. Width**_________

Area of Sediment Patch:__________________________________

Description	Size Class (mm)	Count	Total
Sand & Silt	<1		
Coarse Sand	1-2		
VF gravel	2 - 2.8		
	2.8 - 4		
Fine gravel	4 - 5.6		
	5.6 - 8		
Medium gravel	8 - 11.3		
	11.3 - 16		
Coarse gravel	16 - 22.6		
	22.6 - 32		
Very coarse gravel	32 - 45.3		
	45.3 - 64		
Small cobbles	64 - 90.5		
	90.5 - 128		
Large cobbles	128 - 181		
	181 - 256		
Small boulders	256 - 362		
	362 - 512		
Med boulders	512 - 1024		
Large boulders	1024 - 2048		
Very large boulders	2048 - 4096		
Bedrock	>4096		
TOTAL			

Commments:

Field Method 3: Bulk Sampling to Confirm Spawning Habitat Suitability

Spawning salmon usually deposit their eggs 10 to 30 cm below the surface of a gravel patch. Since substrate composition may change with depth (Everest et al. 1982), pebble counts, observation, and other surface based sampling methods are inadequate and potentially misleading indicators of spawning gravel quality for incubation and emergence. Bulk sediment sampling is used when it is necessary to quantify important factors that relate to incubation and emergence such as the percentage of fine substrate.

Potentially suitable spawning habitat identified with Field Method 1 constitutes the location(s) for bulk sampling. Bulk samples, in conjunction with pebble counts (Field Method 2) are used to confirm suitability for spawning. Results from quantitative sampling may indicate that the areas are: 1) suitable for all phases of reproduction; 2) suitable for redd building but not incubation and emergence; or 3) unsuitable for redd building but suitable for incubation and emergence.

In general, the approach developed by Schuett-Hames et al. (1999) provides excellent guidance for bulk sampling and sample processing. It includes both detailed and basic information on site selection, sampling method options, sample processing options, crew training, timing, and quality assurance reviews. Sampling and processing options may be determined by the study objective, remoteness of the site, and available resources. Schuett-Hames et al. (1999) is available on the references disk provided with this report.

Certain variations from Schuett-Hames et al. (1999) were recommended by scientists consulted during the preparation of this report (T. Lisle, personal communication, K. Buer, personal communication):

- Use a larger bore sampler, such as the “Cookie Cutter” (Klingeman and Emmett 1982) or CSU barrel sampler (Figure 17) rather than a McNeil Sampler to enable collection of larger sample sizes and to allow for a sample that is two times the D_{max} particle size.
- Use the gravimetric (drying weighing method) rather than the volumetric method. When using this method, the portion of the sample ≥ 16 mm can be wet sieved and weighed in the field.
- The remaining portion of the sample (including the suspended sediment) is dried and processed in the lab. To reduce the volume of the remaining sample, the sample portion ≤ 4 mm may be split by a sample splitter to the weight required for the particle size.

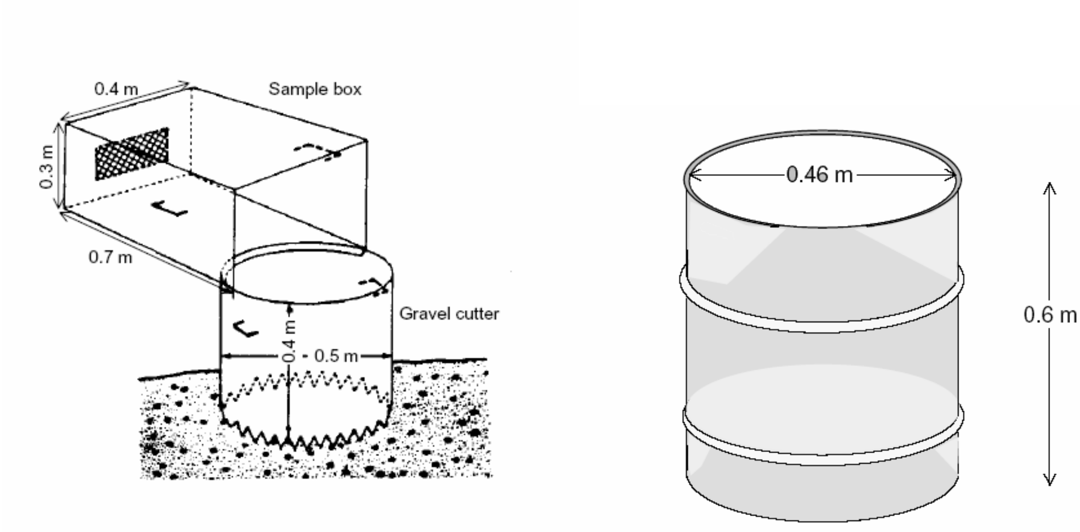

Figure 17. Cookie Cutter (Klingeman and Emmett 1982) and CSU Barrel Samplers.

Site Selection
Sampling sites should be selected according to the monitoring study plan and the results of Field Method 1. Sampling may focus only on specific sites such as the habitat units targeted for restoration (e.g., gravel deposits upstream from instream structures) or on entire stream reaches. For reach-scale studies, all or a sample of potentially suitable spawning sites may be sampled. Sampling at each location should be done by sample weight according to maximum mobile sediment size, as described below.

Determination of Sample Size
The recommended method for deriving the sample size for bulk samples is by weight of the sample. The weight of the entire sample is determined by the representative largest particle (D_{max}) (Figure 18). D_{max} need not be the largest particle at the site or in the reach. It can be the largest particle size that gets moved during a commonly recurring flood (Bunte and Abt 2001a). In cases where the particle size indicates an excessively heavy sample, Kondolf et al. (2004) provide “practical sample sizes” for different grain sizes as follows: 64-128 mm: 32 Kg; 32-64 mm: 16 Kg; 16-32 mm: 8 Kg; and 8-16 mm: 4 Kg.

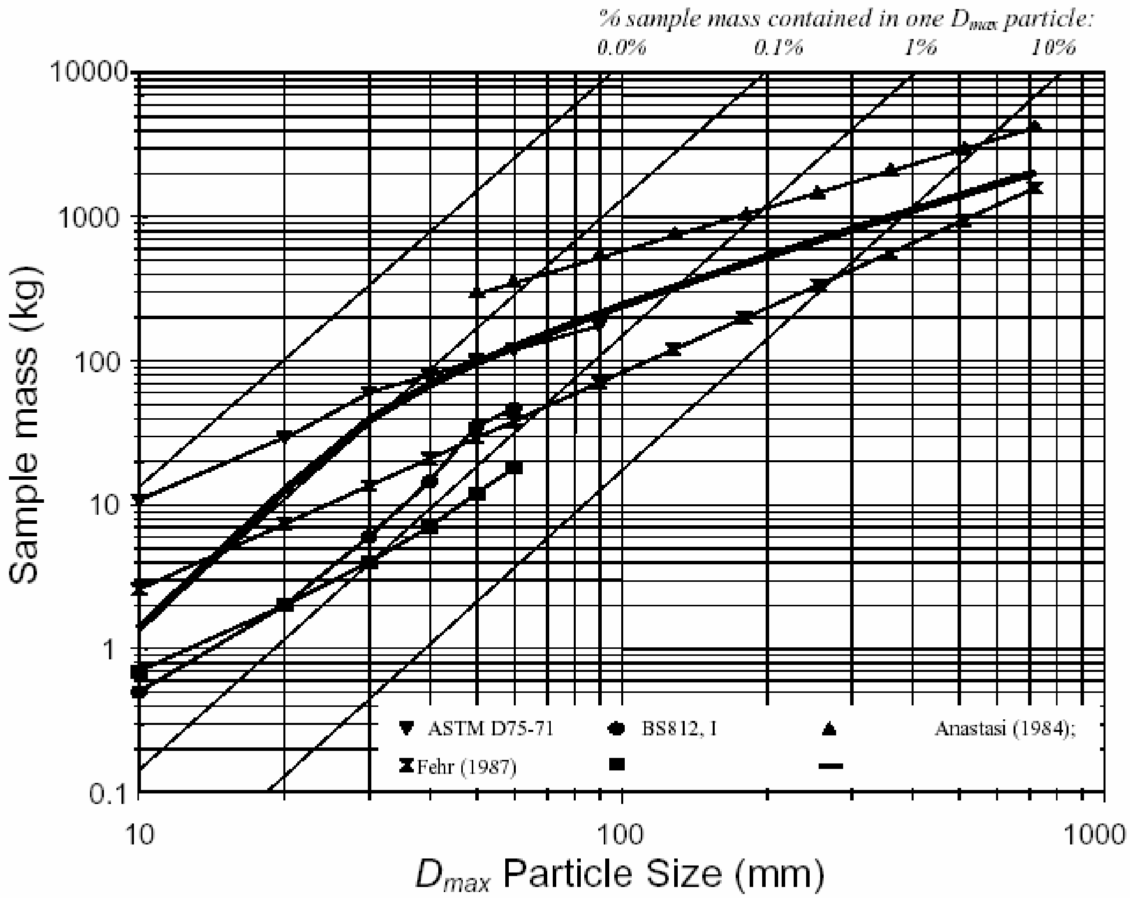

Figure 18. Bulk Sample Weight Determined By D_{max} Particle Size.
Recommended bulk sample weights based on the size of the largest mobile particle (D_{max}) observed on the surface of the deposit. Sample weights should be based on values derived from the dark curved line (adjusted), rather than the (original) stair stepped line. The dashed, diagonal lines refer to the percent sample mass contained in the mass of the D_{max} particle. Source: Bunte and Abt (2001)

Equipment List. The field equipment requirements for bulk sampling are fairly extensive. Because of the equipment needs, access to sampling sites is an important consideration. The following list is derived from Schuett-Hames et al. (1999):

- Previously collected project data (Field Methods 1 and 2)
- Bulk sampling data sheets and pencils
- Barrel or cookie cutter sampler
- Can with screened bottom
- Three five gallon buckets
- Scale (digital scale or hanging Pesola scale with adjustable tare weight and S-hooks)
- Two or three drying tarps or black filter fabric.
- Gravel template
- Sieving apparatus (rocker and Wentworth scale mesh sieves such as Gilson Co.)
- Heavy duty sediment sampling bags (for removing finer sample portions for lab processing)
- Plastic sediment sample collection bottle.
- Plastic squeeze bottle.

Field Sampling Method

The gravimetric method involves drying and then measuring the weight of each size class (Schuett-Hames et al. 1999). The recommended approach is to process the larger sized material (>16 mm) in the field, and then process the rest of the sample that contains the fine material in the lab.

Figure 19. Bulk Sampling With Barrel Sampler.

Field procedures are as follows:

- Locate the field sampling site(s).
- Lay the drying tarps or filter fabric on a moderately inclined section of the stream bank near the sampling location.
- Insert the sampler using downward pressure and a twisting or rotational motion. Do not use side to side motion as it will cause particles to be lost from the sample. The sampling depth should be 30 cm, or the average egg pocket depth for the targeted species.
- From the surface, select the largest particle. This will be the particle that determines the sample size. Measure the b-axis of that particle (mm) and determine the sample size from Figure 18 (Church et al. 1987). If conducting a surface to subsurface comparison, the depth of that particle will also be the depth of the surface sample.
- With a large, screen bottomed can (or by hand for large particles) remove particles and place them in a sub sample bucket. Make sure not to lose any fines.
- Measure particles that are larger than the largest screen size with a gravel template, and weigh each size class.
- Use the rocker sieve apparatus to pass process all but the finer (<16 mm) portion of each sub sample. Weigh and record each size class of each sub sample.

- Set the fine portion of the sample out to dry or place it in the sediment sampling bags to be removed for processing in the lab. Label each bag for project, location, date and time. In a separate bucket, rinse, set aside any remaining liquid in the sub sample bucket, and leave it to settle. Later, pour off the clear water and collect the remaining fine sediment for lab processing.
- Repeat the process until the desired sample weight is achieved.
- For suspended sediment, use a sampling bottle to remove a sample of agitated water from within the sampling barrel. Label each bottle with project and location information

Figure 20. Field Processing of Bulk Samples.

Data Analysis
The response variable measured through bulk sampling is the percent of fine particles within the subsurface particle matrix. McHenry et al. (1994) found that when fine sediments (<0.85mm) exceeded 13 percent (dry weight), salmonid survival dropped drastically. Bjornn and Reiser (1991) found that salmonid embryo survival dropped considerably when the percentage of substrate particles smaller than 6.35 mm exceeded 30 percent. Kondolf (2000) provides additional detail on the effects of subsurface substrate on incubation and emergence. Monitoring that shows lower percentages of sediments in these sizes in the potentially suitable spawning habitat would confirm its suitability for incubation and emergence.

The percent of fine sediment is part of the substrate particle size distribution that is tabulated to yield a cumulative frequency distribution as in Field Method 2, above. A sample data worksheet for gravimetric particle size analysis is provided in Figure 21.

x-axis: Size of sieve		y₁-axis: Weight retained on sieve		y₂-axis: Cumulative weight	Percentiles			
(mm)	(ϕ)	(kg)	(%)	(cum. % finer)	(ϕ_p)	(ϕ)	(D_p)	(mm)
<2	<-1	6.7	6.5	-				
					ϕ_5	-0.89	D_5	1.8
2	-1.0	2.3	2.3	6.5				
2.8	-1.5	2.5	2.4	8.8				
4	-2	2.6	2.5	11.2				
5.6	-2.5	3.7	3.6	13.7				
					ϕ_{16}	-2.82	D_{16}	7.1
8	-3.0	5.3	5.1	17.3				
11.3	-3.5	7.8	7.6	22.4				
					ϕ_{25}	-3.67	D_{25}	12.7
16	-4.0	9.6	9.4	30.0				
22.6	-4.5	10.9	10.6	39.4				
32	-5.0	9.3	9.1	50.0	ϕ_{50}	-5.00	D_{50}	32.0
45	-5.5	11.4	11.1	59.1				
64	-6.0	12.2	10.9	70.1				
					ϕ_{75}	-6.22	D_{75}	74.7
90.5	-6.5	7.4	7.2	81.1				
					ϕ_{84}	-6.70	D_{84}	104.3
128	-7.0	5.4	5.3	88.2				
181	-7.5	6.6	6.5	93.5				
					ϕ_{95}	-7.61	D_{95}	195.8
256	-8.0	0.0	0.0	100.0				
total:		102.7	100.0					

Figure 21. Sample Data Worksheet for Gravimetric Particle Size Analysis.
(Modified from Bunte and Abt (2001a).

Data processing and analysis can be performed using common spreadsheet software as noted above for Field Method 2. Weight of each size class is used instead of the particle count.

Field Method 3 – Bulk Samples

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.
8) **Habitat Unit # -** Enter the number of the habitat unit where the bulk sample is collected, refer to "Spawning Habitat Form" for assigned habitat unit numbers.
9) **Patch # -** If multiple patches of substrate (i.e. facies) were delineated for this spawning habitat area; enter which patch this bulk sample was collected in. If only one patch was delineated, enter '1'.
10) **Length of Sediment Patch –** Enter the length of patch, record which measurement units were used
11) **Width(s) of Sediment Patch –** Enter the width of the sediment patch, if multiple widths were measured during establishment of grid record each width separated by a comma. Record measurement units.
12) **Ave. Width –** Calculate the average of the width values recorded above, enter this value.
13) **Area of Sediment Patch –** Multiply the length of the sediment patch by the average width to determine the area of the sediment patch, enter that value.

Particle Size Information – Section 2

14) **Count –** enter the weights of each size class, if sample is divided up to facilitate processing multiple weights may be entered in this column.
15) **Units of Measure –** Enter the units used to weigh each sample.
16) **Total –** After weighing all parts of each size class, sum the sub-total weights for each size class and enter the value.
17) **Comments –** Enter any important remarks or notes.

BULK SAMPLE FORM

Page ___ of ___

Contract #: **Contract name:**

Stream: **Date:** **Evaluation Crew:**

Drainage:

Habitat Unit #________________ Patch #________________________

Length of Sediment Patch:_________________________

Width(s) of Sediment Patch:_______________________________________ Ave. Width_________

Area of Sediment Patch:_________________________________

Description	Size Class (mm)	Weight Units of Measure: ___________	Total
Sand & Silt	<1		
Coarse Sand	1-2		
VF gravel	2 - 2.8		
	2.8 - 4		
Fine gravel	4 - 5.6		
	5.6 - 8		
Medium gravel	8 - 11.3		
	11.3 - 16		
Coarse gravel	16 - 22.6		
	22.6 - 32		
Very coarse gravel	32 - 45.3		
	45.3 - 64		
Small cobbles	64 - 90.5		
	90.5 - 128		
Large cobbles	128 - 181		
	181 - 256		
Small boulders	256 - 362		
	362 - 512		
Med boulders	512 - 1024		
Large boulders	1024 - 2048		
Very large boulders	2048 - 4096		
Bedrock	>4096		
TOTAL			

Commments:

Field Method 4: Fine Sediment in Pools (V*)

A common objective amongst restoration projects is the reduction of sediment delivery to the stream channel. Decreasing sediment supply may improve one or all of the following limiting factors: water quality, spawning habitat quality or rearing habitat quality. A sensitive indicator of sediment supply to the stream channel is the quantity of fine sediment found in pools. The fraction of residual pool volume filled with fine sediment, known as V*, may be used as an index of mobile sediment supply (Lisle and Hilton 1992; Lisle and Hilton 1999). It may also be interpreted as an indicator of rearing habitat quality. Decreases in fine sediment supply may be reflected in lower V* numbers and higher residual pool volumes hence, improved rearing habitat quality. Bjornn et al. (1977) found that introducing fine sand into a natural third order stream pool reduced its volume by half (V*=0.5) and caused fish numbers to decline by two thirds. Other studies have also linked pool size to habitat suitability and fish size (Heiffetz et al. 1986).

Fine sediment in pools tends to be deposited and scoured many times during a single year (range 5-30 times per year), so responses to changes in fine sediment availability may be observed on a sub-annual basis (Lisle and Hilton 1999). This characteristic of V* makes it especially useful for monitoring responses to restoration because lag times are short between implementation and response in the channel, and results may be observed in studies lasting less than five years.

V* is best suited to track changes in fine sediment supply over time within the same stream, rather than comparing values among streams (Hilton and Lisle 1993). Different streams tend to have different responses based on parent material and channel characteristics. Therefore BACI type study designs are well suited to V*, as opposed to a retrospective approach comparing V* values of streams with differing amounts of restoration activity.

V* is not suitable for all channels. A key requirement is that channels have easily recognizable sediment deposits in pools. This occurs in channels with well sorted substrate, leading to fine sediment deposits of a significantly different size class than the substrate making up the armor layer at the bottom of the pool. A rule of thumb is that the particles in the armor layer should be greater than 45 millimeters in diameter (S.Hilton personal communication). One example where V* was not suitable due to the inability to differentiate fine sediment from bed material was on lower Redwood Creek (Orick, CA) where the average size of surface bed material was 15 mm. Other characteristics of channels where V* may be used include: stable banks, single thread and gradients less than five percent (Hilton and Lisle 1993). The suitability of the V* metric for a particular channel should be established by reconnaissance of the study sites by a qualified professional (T.Lisle, personal communication).

Knopp (1993) successfully used V* on 60 streams within the Franciscan geologic formation on the north coast exhibiting slopes of 1-4 percent with channel substrates of coarse gravel to small cobbles. Lisle and Hilton (1999) used V* in a variety of lithologies but found it was sensitive to sediment supply only in those that produced a high fraction of sand and fine gravel during erosion. These lithologies included poorly indurated sandstones (common in the Franciscan Formation) and coarse-crystalline rocks such as granite and schist. Since the lithology of most basins is varied, a reconnaissance visit is necessary to confirm that V* is a feasible metric in any proposed study (T. Lisle personal communication).

V* was used to document reductions in sediment supply due to road upgrade practices in French Creek on the Klamath National Forest. According to Lisle and Hilton (1999), “Large chronic inputs were reduced by an erosion control program from 1991 to 1994, which mainly targeted roads (Power 1995). During this period, fine sediment volume decreased by more than half as scoured-pool volume remained essentially unchanged. Values of V* decreased to approximately one-third the initial value. However, a large rain-generated flood in January 1997 (recurrence interval = 14.5 years in trunk stem) caused fine sediment volume and V* to nearly double."

Determination of Sample Size
Studies may be done at the scale of individual pools in the vicinity of restoration structures or at the reach level. In reach-scale studies, V* values for multiple pools are combined into a weighted average value for the reach, (V^*_w). Therefore the sample units are stream reaches, not individual pools. The number of pools required to yield an accurate estimate of V^*_w will depend on the variability between pools and desired accuracy of the estimate of V^*_w (Hilton and Lisle 1993). If variability between pools is low, 10 to 15 pools per reach will usually be adequate. If the pools in the reach are structurally stable, measurement of 4 to 5 pools may be adequate.

As with any other sample size calculation, an estimate of variance of the parameter of interest (V^*_w) from the reaches where the study will be conducted is necessary to calculate the appropriate number of treated sites and controls to sample. 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 decrease in the V^*_w values relative to pre-treatment and control data sets is the treatment objective, then this value is the threshold for testing.

Field Sampling Method
The originators of V* wrote an excellent description of how to use the method and analyze the data (Hilton and Lisle 1993). A basic summary of methods from this document is presented below. For additional guidance, consult Hilton and Lisle (1993).

The equipment needed for conducting V* sampling includes two surveyor's tapes, chaining pins and a graduated rod long enough to measure water and sediment depth in the deepest part of the pool without bending.

- First, determine the boundaries of the scoured residual pool to be measured.
- Draw a map of the pool showing the locations of major features including the edges, riffle crest, logs and boulders, and location of cross sections.
- Then, measure the riffle crest depth by taking between 5 and 20 depth measurements along the shallowest continuous line of water close to where the water surface becomes continuously riffled.
- Stretch a tape along the longest dimension of the pool and measure the pool length. If the pool is irregular in shape, measure the length of subsections of the pool so that each section uses a straight line tape.
- Establish between 4 and 10 cross sections across the length of the pool perpendicular to the tape. These should be regularly spaced if doing systematic sampling. Establish the location of the first cross section using random methods such as a random number generator or a random number table.
- On each cross section, establish between 7 and 16 depth measurement points. Locate these at regular spacing if doing systematic sampling. Locate the first measurement point on each cross section using random methods such as a random number generator or a random number table.

- At each measurement point, measure the depth of the pool and the thickness of the sediment accumulated on the bottom using the graduated rod. Determine the depth of the sediment by probing into the sediment deposit with the rod until greater resistance (from the pool bottom) is felt.
- Repeat procedure at next pool.

Non-systematic sampling may be used to improve data accuracy when sediment deposits cover less than a third of the pool bottom. Modifications include reducing the distance between cross sections and/or measurement points in the location of sediment deposits, or measuring areas of sediment deposit separately.

Measurements should be taken at moderately low flows in order to reduce the variability of the estimates and eliminate potential bias. V* is independent of discharge so re-measurements and measurements at control reaches can be conducted anytime when flows are low enough to work in the channel and sediment transport is not occurring.

Data Analysis
The response variable affected by restoration is the fraction of pool volume filled with fine sediment (V*) and/or the weighted average for V* along the reach (V*w). Effective restoration efforts that reduce fine sediment inputs should show a reduction in the measured value of V* or V*w. To calculate V*w and V*, the volume of pool water and the volume of pool sediment must first be calculated. To make the values independent of flow, the data collected must be transformed to yield “residual” depths, or the depths of pools with negligible surface flow. This is done by subtracting the data values from the depth of water at the pool’s downstream end, or riffle crest.

$$d_r = d - drc$$

Residual depth (d_r) equals the water depth (d) minus the riffle crest depth (d_{rc}). (Figure 22). If the water depth in the pool (d) is always greater than the depth at the riffle crest, then the fine sediment thickness (y_f) does not need to be transformed and is equal to the residual fines depth (y_{rf}).

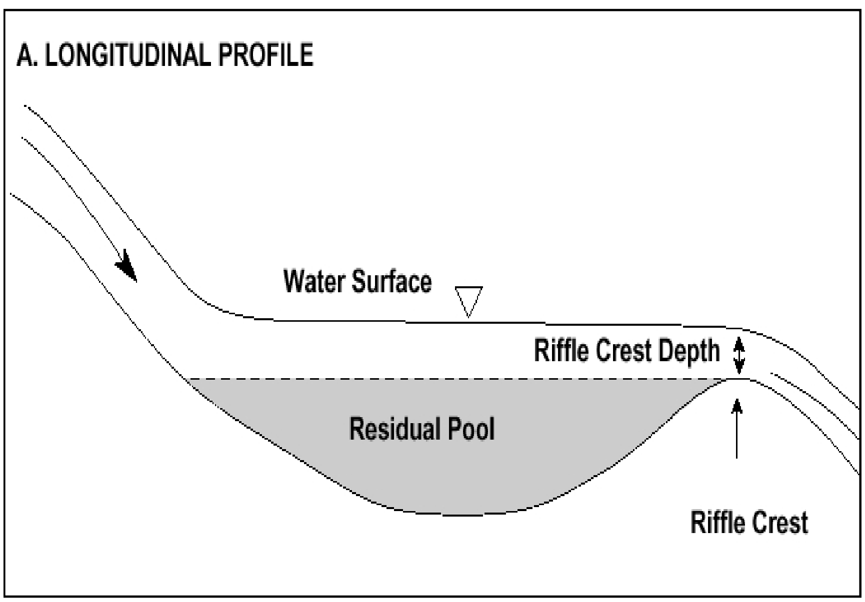

Figure 22. Measuring Residual Pool Depth. *Source:* Hilton and Lisle 1993.

In the next step, the average width (w_i), residual depth (d_r), and residual fines depth (y_{rf}) are calculated for each "cell" of the pool formed around each individual depth measurement. These are used to calculate the cross sectional area of water and fine sediment in each cell. The volume of each cell is then calculated by multiplying the area times the length of that cell. The volumes of each cell are summed to yield the total volumes of water and sediment for the pool.
V* is then calculated by dividing the total residual fines volume by the total scoured residual pool volume as shown below:

V = residual fines volume/[scoured residual pool volume = (residual fines volume + residual water volume)]*

V*w is the average of all the V* values for every pool in a reach, weighted by its volume.

*V*w = Σ (residual fines volume)/ Σ (scoured residual pool volume).*

For more detail on these calculations see Hilton and Lisle (1993). The data forms and instructions are also available online at http://www.fs.fed.us/psw/programs/cumulative_effects/

Instructions for Completing the V* Data Collection Form

General Information—Section 1

18) **Page ___ of ____—**Number the page. For example, if this is page 2 out of 3 total pages, enter: Page 2 of 3.
19) **Contract #—**Enter in the contract number assigned to this project by the Department of Fish and Game.
20) **Contract Name –** Enter the name of the contract.
21) **Stream Name—**Enter in the name of the stream. If unnamed, use named stream to which it is tributary.
22) **Date—**Enter the date: *mm/dd/yy*
23) **Evaluation Crew—**Enter the names of the survey crew in the following format: *last name, first initial*.
24) **Drainage Name—**Enter the name of the main drainage basin that the stream is a tributary to.
25) **Habitat Unit # -** Enter the number of the habitat unit where the V* sample is collected, refer to "Spawning Habitat Form" or 'Habitat Monitoring Form' for assigned habitat unit numbers.

Pool Information- section 2

13) **Riffle crest depth –** Enter the value of each riffle crest depth measurement taken, up to 20 measurements. Circle the median value on the data sheet.
14) **Pool length –** Enter the length of the entire pool if this is able to be measured in a straight line. OR
15) **Section length –** Enter the length of each section of pool measured on a straight line, up to seven sections.

Cross Section Information- section 3

16) **Cross Section # -** Enter the number of the cross section for which data is being collected.
17) **X-sect dist from edge or last x-section –** Enter the distance of this cross section from the edge of the pool along the length tape, if this is the first x-section established. Enter the distance of this cross section from the previous cross section otherwise.
18) **Dist between systematic depth measurements –** Enter the distance between measurement points when these are distributed evenly on the cross section. If measurement points are not evenly distributed, leave this section blank.
19) **Point # -** Enter the number of the measurement point on this cross section.
20) **Dist from edge/last –** Enter the distance between this measurement point and the last measurement point or the edge of the pool if this is the first measurement point. If this is not the first measurement point, and points are evenly distributed on the cross section, leave this blank.

Depth Information – section 4

21) **Water depth –** Enter the depth of the water from the surface of the pool bottom or sediment layer, if any, to the top of the water surface.
22) **Sediment depth –** Enter the depth of the sediment from the pool bottom to the top of sediment layer.

V* DATA COLLECTION FORM

Contract #:__________ Date *(mm/dd/yy)* **:_________ Implementation** *(mm/yy)* **:_________ Stream:_____________________________**

Drainage:______________________________Crew: ________________________________ Reach #:______Reach length:_________

Start Point:_____________________________________ Direction: (Upstream or Downstream) Pool #: ______ Page___ of ____

(circle median)

Riffle crest depth										

Pool length		OR	Section Length							

X-Section #		X-sect dist from edge or last X-sect		Dist between systematic depth measurements	

Point #										
Dist from edge/last										
Water depth										
Sediment depth										

Point #										
Dist from edge/last										
Water depth										
Sediment depth										

X-Section #		X-sect dist from edge or last X-sect		Dist between systematic depth measurements	

Point #										
Dist from edge/last										
Water depth										
Sediment depth										

Point #										
Dist from edge/last										
Water depth										
Sediment depth										

Sketch map: Draw a sketch map of the pool on the reverse side of this form.
Include locations of the edges of the pool, areas of fine sediment deposition and major features such as rocks and logs

Instructions for Sketch Map Data Form V*

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.
8) **Habitat Unit # -** Enter the number of the habitat unit(s) covered by the site sketch, refer to "Spawning Habitat Form" or "Habitat Monitoring Form" for assigned habitat unit numbers.
9) **Site sketch –** Illustrate and label the channel features such as:
   - Left edge of water (LEW)
   - Right edge of water (REW)
   - Direction of flow (indicate and label with arrow)
   - Habitat unit boundaries
   - Restoration structure locations and ID numbers
   - Areas of fine sediment deposition
   - Other major features such as rocks and logs
   - Key to symbols, if necessary.

SKETCH MAP FORM

Page ___ of ___

Contract #: **Contract name:**

Stream: **Date:** **Evaluation Crew:**

Drainage:

Habitat Unit #________________

HISTORY OF METHODS DEVELOPMENT AND REVISION

These methods were initially developed in 2003 based on a literature review and consultation with scientists experienced with substrate sampling. Field testing occurred during the spring and summer of 2004. A draft report was released in June 2004 and subjected to peer review. The final report reflects changes made in response to peer reviewers.

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GLOSSARY

B axis	The intermediate or middle axis, the a-axis being the longest, and the c-axis being the shortest. The b-axis is that which determines which size sieve a particle can pass through.
D_{max}	The largest particle size of the sample population that is moved by flows. Boulders unearthed from glacial deposits, or supplied from rock fall, should not be considered D_{max} for bulk samples.
D_{50}	The 50th percentile or mean particle size in a cumulative frequency distribution.
Interstices	The pore spaces in between framework gravel particles.
Gravelometer	A template used to measure substrate particles.