State of California
North Coast Regional Water Quality Control Board

SALMONID FRESHWATER HABITAT TARGETS FOR SEDIMENT-RELATED PARAMETERS

November 2004

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1. INTRODUCTION

In many streams and rivers throughout coastal Northern California, excessive amounts of human caused sediment have reduced water quality and detrimentally impacted the beneficial uses of those waters. As of the time of this writing, water bodies that drain approximately fifty-nine percent of the area of the North Coast Region are listed as impaired due to sediment under Section 303(d) of the Clean Water Act.

The North Coast Regional Water Quality Control Board (Regional Water Board) is charged with protecting and enhancing the water quality and the beneficial uses of water throughout coastal Northern California. As the Regional Water Board and other agencies, organizations, and individuals strive to reduce sediment waste discharges to North Coast water bodies, it is necessary to monitor the conditions of those streams and rivers.

Some of the most sensitive beneficial uses are impacted by sediment. Those uses are associated with the migration, spawning, reproduction, and early development of cold water fish such as coho salmon (***Oncorhynchus kisutch***), chinook salmon (***O. tshawytscha***), and steelhead trout (***O. mykiss***). If water quality conditions support the most sensitive beneficial uses associated with the salmonid fishery (which are often expressed through salmonid freshwater habitat conditions), then it can often be assumed that water quality supports all the less demanding designated beneficial uses, including municipal drinking water use, agricultural water use, and recreation.

The purpose of this document is to describe the salmonid freshwater habitat conditions that, when considered together, are expected to result in water quality that is free of sediment impairment and supports the beneficial uses associated with the cold water fishery. These conditions are expressed as target values for benthic macroinvertebrate assemblage, embeddedness, large wood debris frequency and volume, pool distribution, substrate composition, thalweg profile variation, and V* percentage. Each parameter is alphabetically summarized in Figures 1 through 3 and described in detail in Chapters 2 though 13.

USE OF THIS DOCUMENT

The following target values are intended to be used by the Regional Water Board and other agencies, organizations, or individuals that are interested in assessing sediment impacts to water quality, particularly salmonid freshwater habitat, and the monitoring of those impacts. Stakeholders, landowners, land managers, and other resource agencies are encouraged to monitor existing instream conditions and compare their data to these targets and future conditions.

The target values are most appropriate for comparison with compliance and trend monitoring data, which is repeatable and conducted over a long period of time. In regards to instream effectiveness monitoring, the following salmonid freshwater habitat parameters are useful and applicable tools, but the target values may not be applicable. Please see Chapter 14 for a discussion on compliance, trend, effectiveness, and other types of monitoring.

It is important to note that no single parameter adequately describes water quality related to sediment in all reaches and gradients of all water bodies. Because of the inherent variability associated with stream channel conditions, and because no single target applies in all situations, attainment of the targets should be evaluated using a weight-of-evidence approach. Additionally, in order to address the variability in climatic conditions and storm-flow characteristics, monitoring data for the following parameters should be compared to reference conditions during the same time period, when possible. When considered together, the following suite of parameters should provide a valuable assessment of instream sediment conditions on water quality.

It is also important to note that detecting statistically significant changes in the following parameters in response to changes in upslope practices and sediment discharges may take a considerable amount of time, perhaps years to decades. However, valuable feedback on water quality trends is likely to occur within shorter periods, perhaps five to ten years.

RELATION OF THE TARGETS TO SEDIMENT-RELATED WATER QUALITY OBJECTIVES

The ***Water Quality Control Plan for the North Coast Region*** (the Basin Plan) contains narrative water quality objectives for sediment, suspended material, and settleable material which periphrastically state that waters shall not contain sediment, suspended material, and settleable material in concentrations that cause nuisance or adversely affect beneficial uses. Additionally, the turbidity water quality objective states, in part, that turbidity shall not be increased more than twenty percent above naturally occurring background levels. The targets contained in this document may be used as numeric surrogates for these mostly narrative water quality objectives when the beneficial uses of concern are those uses associated with the cold water salmonid fishery. However, the targets in no way replace or revise the existing sediment-related water quality objectives or standards.

RELATION OF THE TARGETS TO OTHER NATURAL RESOURCE DOCUMENTS

This document would not be possible without the research, time, and effort of others. I wish to thank the staff of the California Department of Fish and Game for their ***California Salmonid Stream Habitat Restoration Manual***, which was relied upon for the justification of several of the targets, and all the other authors whose work is cited below. Where more information is desired on cited publications, the reader is encouraged to refer to that publication, many of which are available online. Additionally, copies of all cited publications are on file at the offices of the Regional Water Board and are available upon request.

FUTURE UPDATES

It is likely that monitoring of the targets, watershed conditions, and beneficial uses in the North Coast Region and throughout Northern California and the Pacific Northwest will result in the future refinement of these targets. Regional Water Board staff intends to update this document in the future as new research, data, and technology become available.

Figure 1
Salmonid Freshwater Habitat Targets for Sediment-Related Parameters

Parameter	Target	Applicability	Monitoring/Sampling Notes
Benthic Macroinvertebrate Assemblage	≥ 18 Index Score per the Russian River Index of Biological Integrity (IBI). See Figure 2 for the Russian River IBI.	All wadeable streams and rivers.	Monitoring and calculation should occur in the spring according to the protocols found in the ***California Stream Bioassessment Procedure*** by the CA Department of Fish and Game (2003).
Embeddedness	Increasing trend in the number of locations where gravels and cobbles are ≤ 25% embedded.	All wadeable streams and rivers.	Monitoring should occur according to the protocols found in the ***California Salmonid Stream Habitat Restoration Manual, Third Edition*** by Flosi et al. (2004).
Large Woody Debris (LWD)	See Figure 3 for the target values.	Streams and rivers with a bankfull channel width from 1 m to 100m that drain watersheds predominately composed of redwood and/or Douglas fir forests.	Monitoring should occur according to the protocols found in the ***California Salmonid Stream Restoration Manual, Third Edition*** by Flosi et al. (2004), or in the Washington State ***Method Manual for the Large Woody Debris Survey*** by Shuett-Hames et al. (1999b).
	Increasing trend in the volume and frequency of LWD and key pieces of LWD.	Streams and rivers that drain watersheds not predominately composed of redwood and/or Douglas fir forests and all streams and rivers with bankfull channel widths < 1m.	Monitoring should occur according to the protocols found in the ***California Salmonid Stream Restoration Manual, Third Edition*** by Flosi et al. (2004), or in the Washington State ***Method Manual for the Large Woody Debris Survey*** by Shuett-Hames et al. (1999b).
Pools – Backwater Pool Distribution	Increasing trend in the number of backwater pools.	Wadeable streams and rivers with channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this target.	Monitoring should occur periodically during the low-flow period and after a heavy winter storm according to the protocols found in the ***California Salmonid Stream Restoration Manual, Third Edition*** by Flosi et al. (2004).
Pools – Lateral Scour Pool Distribution	Increasing trend in the number of lateral scour pools.	Wadeable streams and rivers with channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this target.	Monitoring should occur during the low-flow period, after a heavy winter storm, once every five to ten years according to the protocols found in the ***California Salmonid Stream Restoration Manual, Third Edition*** by Flosi et al. (2004).
Pools – Primary Pool Distribution	Increasing trend in the number of reaches where the length of the reach is composed of ≥ 40% primary pools.	All wadeable streams and rivers.	Monitoring should occur once every five to ten years during the low-flow period and after a heavy winter storm according to the protocols found in the ***California Salmonid Stream Restoration Manual, Third Edition*** by Flosi et al. (2004). Reported data should include length and depth of pools, and the number of primary pools.

Parameter	Target	Applicability	Monitoring/Sampling Notes
Substrate Composition – % fines	≤ 14% fines < 0.85 mm in diameter. ≤ 30% fines < 6.40 mm in diameter.	Wadeable streams and rivers with a gradient < 3%.	Monitoring should use a McNeil sediment core sampler similar to the specifications found in ***Success of Pink Salmon Spawning Relative to Size of Spawning Bed Materials*** by McNeil and Ahnell (1964), except the diameter of the sampler's core should be at least 2-3 times larger than the largest substrate particle usually encountered. Monitoring should occur according the protocols found in ***Stream Substrate Quality for Salmonids: Guidelines for Sampling, Processing, and Analysis*** by Valentine (1995), and use the methodology for the redd or pool/riffle break sampling universe. A 0.85 mm a 6.40 mm sieve should be used during sample processing. The wet volumetric method is recommended with the use of the wet volumetric method and the dry gravimetric method on 10% of the samples.
Thalweg Profile	Increasing variation in the thalweg elevation around the mean thalweg profile slope.	Streams and rivers with slopes ≤ 2%.	Monitoring should occur during the low-flow period, after a heavy winter storm, once every five to ten years. The monitored stream segments should be at least 20, but usually 30 to 40, times as long as the average bankfull channel width. Points that should be surveyed include the thalweg, all breaks-in-slope, riffle crests, maximum pool depths, tails of pools, and surface water elevation. Acceptable monitoring protocols include the Channel Geometry Survey of ***Water in Environmental Planning*** by Dunne and Leopold (1978).
V*	≤ 0.21 (21%)	3rd order streams with slopes between 1% and 4% that drain watersheds geologically composed of the Franciscan Formation.	Monitoring should occur according to the protocols found in ***Testing Indices of Cold Water Fish Habitat*** by Knopp (1993), or in ***Measuring the Fraction of Pool Volume Filled with Fine Sediment*** by Hilton & Lisle (1993).

Figure 2
Russian River Index of Biological Integrity

<table>
<tr><th rowspan="2">Biological Metric</th><th colspan="3">Score</th><th rowspan="2">How to use the
Russian River Index of Biological Integrity</th></tr>
<tr><th>5</th><th>3</th><th>1</th></tr>
<tr><td>Taxa Richness</td><td>> 35</td><td>35-26</td><td>< 26</td><td rowspan="6">Obtain a sample of benthic macroinvertebrates following the state standard procedures in California Stream Bioassessment Procedure. Protocol Brief for Biological and Physical/Habitat Assessment in Wadeable Streams by CA Dept. of Fish and Game dated 2003. There must be at least three replicate samples collected at each monitoring location. The samples should be processed by a professional bioassessment laboratory using the Level 3 Taxonomic Effort. Determine the mean values for the six listed biological metrics, compare them to the values in the columns, and add the scores listed in the column headings. The total score will be between a low of 6 and a high of 30. Determine biotic condition of the monitoring location from the following categories:
Excellent 30-24   Good 23-18   Fair 17-12   Poor 11-6</td></tr>
<tr><td>% Dominant Taxa</td><td>< 15</td><td>15-39</td><td>> 39</td></tr>
<tr><td>EPT Taxa</td><td>> 18</td><td>18-12</td><td>< 12</td></tr>
<tr><td>Modified EPT Index</td><td>> 53</td><td>53-17</td><td>< 17</td></tr>
<tr><td>Shannon Diversity</td><td>> 2.9</td><td>2.9-2.3</td><td>< 2.3</td></tr>
<tr><td>Tolerance Value</td><td>< 3.1</td><td>3.1-4.6</td><td>> 4.6</td></tr>
</table>

* from ***Measuring the Health of California Streams and River. A Methods Manual for: Water Resource Professionals, Citizen Monitors, and Natural Resources Students*** by Harrington & Born (1999).

Figure 3
Large Woody Debris Targets

<table>
<tr><th></th><th>Bankfull Channel Width (m)</th><th>Target (per 100 m of channel length)</th></tr>
<tr><td rowspan="3">LWD Frequency</td><td>1 to 6</td><td>> 38 pieces</td></tr>
<tr><td>> 6 to 30</td><td>> 63 pieces</td></tr>
<tr><td>>30 to 100</td><td>> 209 pieces</td></tr>
<tr><td rowspan="2">LWD Volume</td><td>1 to 30</td><td>> 72 m^3</td></tr>
<tr><td>> 30 to 100</td><td>> 317 m^3</td></tr>
<tr><td rowspan="2">Key Piece Frequency</td><td>1 to 10</td><td>> 11 pieces</td></tr>
<tr><td>> 10 to 100</td><td>> 4 pieces</td></tr>
</table>

2. BENTHIC MACROINVERTEBRATE ASSEMBLAGE

Freshwater benthic macroinvertebrates are aquatic invertebrates that are at least 0.5 mm in length and live primarily on the bottom substrate of streams and rivers. Benthic macroinvertebrates include worms, snails, clams, crustaceans, aquatic beetles, the nymph forms of mayflies, stoneflies, dragonflies, and damselflies, and larval forms of caddisflies and true flies. They are most easily categorized into feeding guilds (species that obtain a common food source in a similar manner) such as shredders, filter-collectors, collect-gatherers, scrapers-grazers, and predators. The complex of benthic macroinvertebrates is influenced by its location in a watershed. In first to second order streams, the predominant feeding guilds are shredders and collectors. There are very few scrapers and predators are found in low numbers. In third, fourth, and fifth order streams, the predominant feeding guilds are scrapers/collectors, and there are low numbers of shredders and predators. In sixth order and higher streams, the predominant feeding guild are collectors. Shredders and scrapers are absent and predators are found in low, but somewhat higher numbers than smaller order streams.

Benthic macroinvertebrate populations are "continuous monitors of the water they inhabit, enabling long-term analysis of both regular and intermittent discharges, single or multiple pollutants, and even synergistic or antagonistic effects" (Harrington & Born 1999, p. 7-7). In other words, benthic macroinvertebrates are significantly influenced by water quality and are often adversely affected by excess fine sediment. "Furthermore, when integrated with physical and chemical assessments, biological assessments . . . provide a more appropriate means for evaluating discharges of non-chemical substances (e.g., sedimentation and habitat destruction)" (Harrington & Born 1999, p. 5-10).

Additionally, benthic macroinvertebrates are important for their role as a food source for salmonids. Increases of fine sediment in a stream channel can result in changes in the types and assemblages of benthic macroinvertebrates present. For example, Suttle et al. (2004) experimentally manipulated fine bed sediment in the South Fork Eel River and found that "With increasing fine sediment, invertebrate assemblages shifted from available prey organisms (i.e., epibenthic grazers and predators) to unavailable burrowing taxa . . . , so that steelhead confined to channels with higher levels of sedimentation experienced lower food availability than those with less embedded channels" (p. 971).

An Index of Biological Integrity (IBI) has been developed by the California Department of Fish and Game's Water Pollution Control Laboratory. This IBI is specific to first, second, and third order streams in the Russian River Watershed. The IBI analyzes six matrices (Taxa or Species Richness, Percent Dominant Taxa, EPT Taxa, Modified EPT Taxa, Shannon Diversity, and Tolerance Value) and integrates them into a single score for biotic condition. See Figure 4 for the Russian River IBI.

According to Harrington & Born (1999), the six metrics ". . .were integrated into a single scoring criteria by producing a histograms [sic] of the values for each of the biological metrics and visually determining breaks in their distribution. The approach of determining scoring criteria was more intuitive and probably most appropriate given the data came from streams that could have been moderately impaired and not actually representative of pristine reference conditions."

Figure 4
Russian River Index of Biological Integrity
(taken from Harrington & Born 1999)

Biological Metric	Score			How to use the Russian River Index of Biological Integrity
	5	3	1	
Taxa Richness	> 35	35-26	< 26.0	Obtain a sample of benthic macroinvertebrates following the state standard procedures (CDFG 2003). There must be at least three replicate samples collected at each monitoring location. The samples should be processed by a professional bioassessment laboratory using the Level 3 Taxonomic Effort. Determine the mean values for the six listed biological metrics, compare them to the values in the columns, and add the scores listed in the column headings. The total score will be between a low of 6 and a high of 30. Determine biotic condition of the monitoring location from the following categories: Excellent 30-24; Good 23-18; Fair 17-12; Poor 11-6
% Dominant Taxa	< 15	15-39	> 39.0	
EPT Taxa	> 18	18-12	< 12.0	
Modified EPT Index	> 53	53-17	< 17.0	
Shannon Diversity	> 2.9	2.9-2.3	< 2.3	
Tolerance Value	< 3.1	3.1-4.6	> 4.6	

EPT Index: The percent composition of Ephemeroptera, Plecoptera, and Trichoptera, more commonly known as mayflies, stoneflies, and caddisflies. These organisms require higher levels of water quality and respond rapidly to improving or degrading water quality conditions. The EPT Index is calculated by adding the number of organisms in the EPT orders and dividing it by the total number of organisms. Multiply by 100.

EPT Taxa: The number of families in the Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) insect orders. This metric will decrease in response to disturbance.

Percent Dominant Taxa: The percent composition of the single most abundant taxon. Collections dominated by one taxon generally represent a disturbed ecosystem.

Shannon Diversity: An index used to characterize species diversity in a community. The calculation of the Shannon Diversity requires a Level 3 Taxonomic Effort.

Species Richness Index: Also known as the Taxa Richness Index, the Species Richness Index is the total number of taxa represented in the sample. Higher diversity can indicate better water quality.

Taxa Richness: The total number of individual taxa. This metric will decrease in response to disturbance.

Tolerance Value: Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) and intolerant (lower values). This metric will increase in response to disturbance.

According to Harrington (personal communication 2003), the Russian River IBI has been found to be an effective and applicable measure of benthic macroinvertebrate health outside of the Russian River Watershed. The California Department of Fish and Game is currently developing a North Coast IBI that is specific to three different eco-regions within the North Coast Region. Regional Water Board staff propose to use the North Coast IBI upon its completion, which is currently scheduled for the end of 2004.

Benthic Macroinvertebrate Assemblage Target Value

The salmonid freshwater habitat target for benthic macroinvertebrate assemblage is a $\geq$ 18 Index Score per the Russian River IBI, which corresponds to a biological integrity rating of good to excellent. Regional Water Board staff strongly suggest that, upon completion, the North Coast IBI replace the Russian River IBI in all areas but the Russian River Watershed.

Benthic macroinvertebrates allow for the use of biological information to determine whether a body of water has been affected by a disturbance. It is the only target which directly focuses on a biological parameter. This target applies to wadeable streams and rivers. A wadeable stream or river is one which an average human can safely cross on foot during the summer, low flow season while wearing chest waders. Monitoring and calculation of the above indices should occur in the spring and follow the ***California Stream Bioassessment Procedure*** by the CA Department of Fish and Game revised December 2003, which is a regional adaptation of the national Rapid Bioassessment Protocols.

3. EMBEDDEDNESS

Embeddedness is the degree to which larger particles such as gravels and cobbles are surrounded or covered by fine sediment (e.g., silt and/or sand), which effectively covers or cements them into the channel bottom. A spawning salmonid slaps its tail against the channel bottom when constructing the redd, which lifts out un-embedded gravels and cobbles and removes some of the fine sediment. This process results in a pile of cleaner and more permeable gravel or cobble that is better suited to the nurturing of eggs. Embedded gravels can be cemented, generally do not lift out easily, and can prevent spawning salmonids from building their redds to lay eggs. Most importantly, embedded gravels contain high levels of fine material, reducing permeability in the egg pocket which can slow growth and cause mortality.

Embeddedness Literature Review

The ***California Salmonid Stream Habitat Restoration Manual*** (Flosi et al. 2004) indicates that embeddedness of 25% or less is considered to indicate good spawning substrate for salmon and steelhead. Unfortunately, very few inventoried Northern California streams contain substrates that are less than 25% embedded (Flosi, personal communication 2003).

The ***Gualala River Watershed Assessment Report*** (Klamt et al. 2003, p. 3-27) habitat inventory surveys conducted by the Department of Fish and Game used an embeddedness target of "50 percent or greater of the pool tails samples are 50 percent or less embedded." In other words, the criteria for suitable habitat is ≤ 50% embeddedness in at least half the sampled pool tail-outs.

The National Marine Fisheries Service developed a ***Matrix of Pathways and Indicators*** that was designed to summarize important salmonid habitat parameters and corresponding levels of condition. This matrix is found in the ***Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast*** (NMFS 1996). According to the matrix, the properly functioning condition for embeddedness in coastal streams is < 20%. This value was derived from data from Washington streams.

Embeddedness Target Value

The salmonid freshwater habitat target for embeddedness is an increasing trend in the number of locations where gravels and cobbles are ≤ 25% embedded. Although this target is an increasing trend, Regional Water Board staff do not expect nor intend every reach of every water body to meet this condition. However, it is not possible at this time to identify the specific number of locations with embeddedness values of ≤ 25% that are necessary for salmonid success due to lack of sufficient research, and an the above target is established until more information is available.

This target is based on information by Flosi et al. (2004) and the National Marine Fisheries Service (1996). The 25% value is more representative of properly functioning conditions than the 50% value contained in Klamt et al. (2003) and provides balance between the three literature values in a manner conservative toward the protection of the cold water salmonid fishery.

The embeddedness target is only applicable to wadeable streams and rivers. A wadeable stream or river is one which an average human can safely cross on foot during the summer, low flow season while wearing chest waders.

Embeddedness Monitoring Recommendations

Embeddedness should be monitored according to the protocol found in the ***California Salmonid Stream Habitat Restoration Manual, Third Edition*** (Flosi et al. 2004) at locations in the stream where salmonids are likely to build a redd, such as pool tail-outs and riffle heads. Please note that an apparent change between two successive embeddedness results may be due to natural variability and fluctuations in streamflow. Embeddedness should, therefore, be monitoring over a more extensive period of time.

4. LARGE WOODY DEBRIS

Large Woody Debris (LWD) is defined in the ***California Salmonid Stream Habitat Restoration Manual*** (Flosi et al. 2004) as wood with a minimum diameter of one foot and a minimum length of six feet. Root wads with a minimum diameter of one foot at the base of the trunk are also considered LWD. Root wads do not have a minimum length criteria.

LWD plays an important role in channel morphology by forming habitat such as pools, by storing sediment and organic matter, by providing cover to salmonids and other species from predators, by increasing hydraulic complexity, and by contributing to the production of benthic macroinvertebrates (Bisson et al. 1987; O'Connor & Harr 1994; Peterson et al. 1992). LWD plays different roles in different sized streams. For example, in steep headwater streams where logs span the channel, LWD creates a stepped longitudinal profile that governs the storage and release of sediment (Bisson et al. 1987). When the stream channel becomes too wide to be spanned by logs, LWD is found along the channel margins and often forms the most productive fish habitat in the mainstem. In addition, LWD is an important component of the floodplain, where it can meter sediment, provide refuge in floods, and stabilize stream banks.

Beechie and Sibley (1997) studied twenty-eight sites in four Washington watersheds and found LWD to be a dominant pool forming mechanism. They also found a direct cause and effect relationship between LWD abundance and pool abundance. Bisson et al. (1987) found a strong correlation between the volume of LWD and the size of the associated pool, especially in streams wider than 10 meters (33 feet). In their survey of Prairie Creek and Little Lost Man Creek, two reference streams in Humboldt County, Keller and Tally (1979) inventoried all large organic debris in the stream channel larger than 10 cm (4 in.) in diameter. They found that in Prairie Creek, at least 50% of the pools in the low gradient study reaches were controlled or influenced by LWD. In the steeper reaches of Little Lost Man Creek, more than 90% of the pools were controlled by LWD.

LWD Key Pieces

The Washington Forest Practices Board's ***Manual for Conducting Watershed Analysis*** (WFPB 1997) states that it is necessary for a stream channel to contain a few larger pieces of wood that provide stability and function in unison with the smaller pieces. These larger pieces of LWD are called "key pieces." A key piece of LWD is defined as a log or root wad that (1) is independently stable in the stream bankfull width and not functionally held by another factor (e.g., not pinned by another log, buried, or trapped against a rock, etc.) and (2) is retaining, or has the potential to retain, other pieces of organic debris that are likely to become mobilized in a high flow without the key piece (WFPB 1997, p. F-26).

Although the above definition is performance based, two sources give guidance on how to choose a piece of wood that might perform as intended by the definition. One source is the ***Method Manual for the Large Woody Debris Survey*** which is included in the Timber, Fish, and Wildlife Monitoring Program of the Northwest Indian Fisheries Commission in Washington State (Schuett-Hames et al. 1999b). They give a volume based criteria for LWD key piece selection for streams with a bankfull width of 20 m (65.6 ft.) and smaller. Volume criteria for streams with a bankfull width of 20 m to 100 m (65.6 ft. to 328 ft.) are taken from research by Fox (2001). These criteria are combined in Figure 5 .

Figure 5
LWD Key Piece Volume Criteria
(taken from Schuett-Hames et al. 1999b; modified with results from Fox 2001)

Min. Diameter in meters	Minimum Length of LWD in meters			
	BFW > 0 to < 5	BFW 5 to < 10	BFW 10 to < 15	BFW 15 to < 20
0.20	32			
0.25	21			
0.30	15	36		
0.35	11	26		
0.40	8	20		
0.45	7	16	38	
0.50	6	13	31	
0.55	5	11	26	
0.60	4	9	22	32
0.65	3	8	19	28
0.70	3	7	19	24
0.75	3	6	14	21
0.80	2	5	12	18
0.85	2	5	11	16
0.90	2	4	10	15
0.95	2	4	9	13
1.00	2	4	8	12
1.05	2	3	7	11
1.10	2	3	7	10
1.15	1	3	6	9
1.20		3	6	8
1.25		3	5	8
1.30		2	5	7
1.40		2	4	6
1.55		2	4	5
1.60		2	3	5
1.70		2	3	4
1.80		1	3	4
2.00			2	3
2.40			2	2
2.80			1	2
3.40				1

Meter/Feet conversion: meters x 3.281 = feet

Minimum LWD Volume to Qualify as a Key Piece

BFW (m)	Volume (m^3)
0 to < 5	1
5 to < 10	2.5
10 to < 15	6
15 to < 20	9
20 to < 30	9.75
30 to < 50	10.5*
50 to 100	10.75*

* Wood piece must have an attached root wad.

Procedure:
1. Select segment bankfull width (BFW) category.
2. Measure diameter of candidate pieces and round to nearest 0.05 m (5 cm)
3. Follow matrix across to find the minimum length requirement.

Key Log Example:
1. Segment has an average BFW of 12 m (use BFW column of 10 to < 15 m).
2. Candidate log diameter is measured/ estimated to be 0.53 m (round to 0.55 m).
3. Log must be a minimum of 26 m long (measure/estimate log length to assess if it is a key piece).

Key Rootwad Example:
1. Segment has an average BFW of 4 m (use BFW column of 0 to < 5 m).
2. A rootwad Key Piece must have a minimum diameter of 1.15 m and length of 1 m.

The ***Salmonid Stream Habitat Restoration Manual*** (Flosi et al. 2004) is a second source of guidance on how to choose a piece of wood that might perform as intended by the LWD key piece definition. Specifically, the following minimum size requirements for LWD in unanchored applications are given: logs with a minimum diameter of twelve inches and minimum length 1.5 times the mean bankfull width of the stream channel type reach and the deployment site. Root wads must have a minimum root bole diameter of five feet and minimum length of 15 feet and minimum width at least half the channel type bankfull width.

In part to test the minimum size requirements for unanchored wood pieces found in Flosi et al. (2004), Collins (1999) conducted a study of LWD purposely placed in Parlin Creek, a tributary to the South Fork Noyo River in Jackson Demonstration State Forest. The bankfull width of Parlin Creek in 1997 was 21 feet, which results in a minimum key piece length of 31.5 feet according to unanchored LWD requirements. The study began in 1996. During the 1997 survey, 147 of the 162 pieces of wood tagged in 1996 were located (91%). Their average length was 39 feet with an average diameter of 25 inches. The wood not found in 1997 had a significantly smaller average length of 22 feet, although their average diameter of 28 inches was not significantly different. The average length of wood displaced downstream was 31 feet, while the average length of wood found in their original positions was 40 feet. However, it is possible that some of the missing 1996 project wood may have either lost their tags or rolled on top of them obscuring the tags from view, and not all of these pieces were necessarily lost from the project area. Collins (1999) determined that these surveys appear to support the unanchored LWD length criteria found in Flosi et al. (2004).

LWD Literature Review

Bilby and Ward (1989) surveyed 22 streams located in undisturbed old-growth Douglas fir forests in southwestern Washington. They found that the mean diameter and length of LWD increased and the LWD frequency decreased as channel width increased. In other words, as channels became wider, LWD pieces were larger but found in fewer numbers due to the increasing capacity of the channel to transport LWD. Bilby and Ward also found that the frequency of LWD ranged from between 0.8 pieces per meter of stream in the smallest channels to 0.1 pieces per meter in the largest stream systems. In the ***Assessment of Cumulative Effects on Salmonid Habitat: Some Suggested Parameters and Target Conditions***, Peterson et al. (1992) used Bilby and Ward's regression analysis to develop targets for LWD frequency. These target conditions are based on channel width and are listed in Figure 6. It is interesting to note that these values exceed Washington State's LWD frequency target for good streams of two or more pieces per channel width.

Figure 6
LWD Frequency Thresholds
per Peterson et al. 1992

Channel Width (m)	# of Pieces per Channel Width	# of Pieces per 100 m
4	2.44	61.05
5	2.38	47.56
6	2.33	38.77
7	2.28	32.62
8	2.25	28.09
9	2.22	24.62
10	2.19	21.88
11	2.16	19.66
12	2.14	17.84
13	2.12	16.31
14	2.10	15.01
15	2.08	13.89
16	2.07	12.92
17	2.05	12.08
18	2.04	11.34
19	2.03	10.66

Fox (2001) surveyed 150 stream segments draining unmanaged basins (without logging, roads, dams, or other human-induced conditions that may influence natural wood loading and retention rates) in order to enhance the LWD target in Washington State and review the properly function condition value proposed by the National Marine Fisheries Service (NMFS 1996). For the purposes of this study, Fox used the definitions of a LWD piece and a key piece found in the Washington manuals (WFPB 1997; Shuett-

Hames et al. 1999b). Fox found that the most consistent predictor of wood volumes and quantities is bankfull width and eco-region. He also found that the WFPB (1997) LWD frequency target was not appropriate for all stream channels less than 20 m (65.6 ft.) in bankfull width: that it is too high for channels less than 3 m (10 ft.) in bankfull width and too low for channels wider than 12 m (39.4 ft.) in bankfull width. Fox concluded that the LWD properly functioning condition proposed by NMFS (1996) does not differentiate between bankfull width classes and is inappropriate for small streams in western Washington. In place of the WFPB and NMFS targets, Fox proposes ranges for instream LWD in “good” streams, as shown in Figure 7. Fox’s LWD target values are taken from streams in Western Washington, which drain basins of Stika Spruce, Western Hemlock, Silver-fir, Douglas fir, and Western Red Cedar, the most applicable of the Washington eco-regions to Northern California.

The quantities of key pieces found in Washington should be similar to those found in Northern California watersheds composed of redwood and/or Douglas fir (Fox, personal communication 2003). Other tree species found in such forests include Stika spruce, western hemlock, big leaf maple, and red alder. Although redwoods and other trees of Northern California may have some differences in density, buoyancy, and subsequent entrainment, it is not likely significant enough to warrant a change in the target values[1], and the targets are valid for Northern California. In addition, redwood remains in streams as LWD longer than any other tree species: usually to approximately half the age of the tree. Furthermore, the targets are scaled by stream size and bankfull width, and thus fluvial processes, rather than eco-region.

Keller et al. (1995) focused on the relationship between in-channel woody debris (logs, stems, limbs, and rootwads > 10 cm (4 in.) in diameter), channel morphology, sediment storage, and anadromous fish habitat in the Redwood Creek Watershed of Northern California. Several of the streams studied by Keller et al. are considered reference streams. Little Lost Man Creek has not had previous management and Prairie Creek has not be managed since before 1953. Keller et al. included pieces of wood smaller than the minimum size requirements for LWD per Flosi et al. (2004). Consequently, Keller et al. likely overestimated the volume of LWD. Data on woody debris volume from four unmanaged stream segments are listed in Figure 8. The data presented in Figure 8 are converted from the original units of m^3 of debris loading per m^2 of active channel expressed in Keller et al (1995). Data on reach lengths, which were used for the conversions, were taken from Keller and Tally (1979), who studied the same reaches.

Figure 7
LWD Target Values per Fox 2001

	Bankfull Channel Width (m)	**Target (per 100 m of channel length)**
LWD Frequency	0 to 6	> 38 pieces
	> 6 to 30	> 63 pieces
	>30 to 100	> 209 pieces
LWD Volume	0 to 30	> 99 m^3
	> 30 to 100	> 317 m^3
Key Piece Frequency	0 to 10	> 11 pieces
	> 10 to 100	> 4 pieces

[1] The wood density of trees found in Northern California and the trees found in Washington are relatively similar. Keller and Tally (1979) assumed an average wood density of 500 kg/m^3 for woody debris in Prairie Creek and Little Lost Man Creek (tributaries to Redwood Creek). Fox (2001) relied on an average wood density of 415 kg/m^3 for trees in Washington.

Figure 8 Summary of Literature Values for LWD				
Reference	**Study Location**	**Bankfull Channel Width**	**LWD Volume (per 100 m of channel length)**	**LWD Frequency**
Fox 2001	western Washington	See Figure __		
Keller et al. 1995	Little Lost Man Ck - Upper	6.4 m*	181 m^3	N/A
	Little Lost Man Ck – Lower	9.6 m*	94 m^3	N/A
	Prairie Creek – Brown Ck	11.0 m*	187 m^3	N/A
	Prairie Creek – Campground	18.5 m*	72 m^3	N/A
Knopp 1993	North Coast Region	See Figure ___		
Kramer & Klein 2000	Prairie Creek – Upper	7 – 20 m	114 m^3	N/A
NMFS 1996	properly functioning condition	N/A	N/A	> 5 pieces per 100 m of channel length
WFPB 1997	good streams	< 10 m	N/A	> 2 pieces per channel width
		10 – 20 m	N/A	> 0.5 pieces per channel width

* This is the average bankfull channel width of the surveyed stream reach. Keller et al. (1995) also calls this the "characteristic width."

Figure 9 LWD Volume in Northern California Reference Watersheds per Knopp 1993			
Stream	**Tributary To**	**Stream Condition**	**Wood Volume m^3/1000m reach**
Balm of Gilead Creek	Middle Fork Eel River	Unmanaged	13
Canoe Creek	South Fork Eel River	Virtually Undisturbed	241
Cedar Creek	Smith River	Unmanaged	266
Clark Creek	Smith River	Unmanaged	777
Elder Creek	South Fork Eel River	Virtually Undisturbed	45
Graham Gulch	Freshwater Creek	Managed Before 1953[1]	305
Honeydew Creek	Mattole River	Unmanaged	32
Little Lost Man Creek	Redwood Creek	Unmanaged	175
Little River	Pacific Ocean	Managed Before 1953[1]	46
Middle Fork Eel	Eel River	Virtually Undisturbed	10
Morrison	Middle Fork Eel River	Unmanaged	238
North Fork Caspar Creek	Caspar Creek	Managed Before 1900 & from 1985 to 1991	250
North Fork Freshwater	Freshwater Creek	Managed Before 1953[1]	736
Pilot Creek	Mad River	Unmanaged	216
Priarie Creek	Redwood Creek	Managed Before 1953[1]	290
Russian Gulch	Pacific Ocean	Managed Before 1953[1]	410
Squaw Creek	South Fork Eel River	Unmanaged	250
Yew Creek	Mattole River	Managed Before 1953[1]	83
		mean	243.5

1. Streams categorized by Knopp (1993) as having reaches with historic management activity more than 40 years ago.

Knopp (1993) studied 60 streams within the North Coast Region. These streams were composed of small cobble substrates with slopes between 1% and 4% (Rosgen B-3 and C-3 channels). In addition, the sixty streams drained watersheds composed of the Franciscan Formation geology. Twelve of the streams were categorized as "Index No" streams with no human disturbance history and considered to have good quality habitat best able to maintain viable populations of salmonids relative to the geologic formation and channel type. Six other streams were categorized as "Index Yes" streams with reaches of historic management over 40 years old (i.e., the most recent management activity occurred prior to 1953) and had no evidence of residual erosion or instability due to past human activity. As part of this study, Knopp measured the volume of wood within the active channel, which is the area of annually scoured gravels. Each survey was conducted on a 1,000 m reach of stream. The study does not report that a particular size range of wood was surveyed, nor does it include the bankfull channel width. Figure 9 shows the results of the study. The mean wood volume for unmanaged streams and streams managed before 1953 was 243.5 m^3 per 1000 m reach (32 yd^3 per 109 yd.). Knopp also found that in several reaches which had not had channel clearing work, the values for wood volume ranged from 800 to 1,200 m^3 per 1000m reach (105 to 157 yd^3/109yd).

Kramer and Klein (2000) inventoried woody debris in approximately 7 km (4.3 miles) of Upper Prairie Creek in 1997 and 1999. They inventoried all woody debris pieces larger than 10 cm (4 in.) in diameter and 2 m (6.6 ft.) in length (this does not meet the minimum diameter size requirement of LWD per Flosi et al. (2004)). In both years, the total volume of woody debris in the entire reach surveyed approached 8,000 m^3. This equates to an average of 114.3 m^3 of wood per 100 m of stream (an 8 to 21 km^2 drainage area equates to an average bankfull channel width of approximately 7 to 20 m according to the regional curve for Prairie Creek found in Keller et al. (1995)).

The National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, developed a ***Matrix of Pathways and Indicators*** that was designed to summarize important parameters and corresponding levels of condition. This matrix is found in the ***Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast*** (NMFS 1996). According to the matrix, the properly functioning condition for LWD in coastal streams is > 80 pieces per mile (five pieces per 100 m of stream length). LWD is defined as a piece of wood larger than two feet in diameter and larger than 50 feet in length.

Washington State developed ***Indices of Resource Conditions for Interpretation of Field Survey Results and Habitat Analysis***, which contains target values for LWD in poor, fair, and good streams. These indices can be found in the ***Washington Forest Practices Board Manual: Standard Methodology for Conducting Watershed Analysis*** (WFPB 1997). The manual defines LWD as a piece of wood at least 10 cm (4 in.) in diameter and at least 2 m (6.6 ft.) in length. The definition of a key piece of LWD is duplicative of the definition described above from the Washington State LWD Method Manual (Shuett-Hames et al. 1999b). For "good" streams, the indices list a LWD frequency target value of > 2 pieces per channel width and a key piece frequency target value of > 0.30 pieces per channel width (when the bankfull channel width < 10 m) to > 0.50 pieces per channel width (when the bankfull channel width is 10 – 20 m).

LWD Target Value

The salmonid freshwater habitat target for large woody debris (LWD) in water bodies that drain watersheds predominately composed of redwood and/or Douglas fir forests is specified in Figure 10 below. The salmonid freshwater habitat target for LWD in all other water bodies in the North Coast Region is an increasing trend in the volume and frequency and LWD and key pieces of LWD.

Figure 10
LWD Target

	Bankfull Channel Width (m)	**Target (per 100 m of channel length)**
LWD Frequency	1 to 6	> 38 pieces
	> 6 to 30	> 63 pieces
	>30 to 100	> 209 pieces
LWD Volume	1 to 30	> 72 m^3
	> 30 to 100	> 317 m^3
Key Piece Frequency	1 to 10	> 11 pieces
	> 10 to 100	> 4 pieces

The LWD target for water bodies that drain watersheds predominately composed of redwood and/or Douglas fir forests is a modified version of the target proposed by Fox (2001). This target incorporates the vital correlation between bankfull channel width and LWD occurrence, which is lacking in the analysis conducted by Knopp (1993). Fox's work has been modified in several ways. First, water bodies narrow than 1 m in bankfull channel width are excluded from this numeric target, although the narrative target of an increasing trend does apply to such water bodies. This modification ensures that small streams are not subject to a target which might be infeasible to attain. For example, a shallow and narrow stream with a width of less than a meter might be essentially buried in 72 m^3 of LWD. Second, the target for LWD volume in water bodies ranging from 1 m to 30 m in bankfull channel width is set at > 72 m^3 per 100 m of channel length. Fox's target for such water bodies is > 99 m^3 per 100 m of channel length. This modification reflects the minimum volume of LWD found in reference streams in Northern California per Keller et al. (1995), and ensures that the LWD targets correspond to local reference conditions. As more data and information becomes available, the LWD volume target may be revised to an value that is based on the average volume of reference water bodies.

Although the LWD target for water bodies that do not drain watersheds predominately composed of redwood and/or Douglas fir forests is an increasing trend, Regional Water Board staff do not intend nor expect the amount of LWD to increase beyond the capacity of water bodies to form this habitat feature or continue throughout time. Complexity within the stream channel is necessary. However, it is not possible at this time to identify specific volumes or frequencies of LWD that are necessary for salmonid success for such water bodies due to the lack of sufficient research. Therefore, an increasing trend target is established until more information is available.

LWD Monitoring Recommendations

LWD should be monitored according to the protocols found in the ***California Salmonid Stream Restoration Manual*** (Flosi et al. 2004) or in the Washington State ***Method Manual for the Large Woody Debris Survey*** (Shuett-Hames et al. 1999b).

5. POOLS – BACKWATER POOL DISTRIBUTION

Backwater pools are defined in Flosi et al. (2004) as pools found along channel margins within the bankfull channel width that are caused by eddies around an obstruction, such as boulders, root wads, or large woody debris. These pools are usually shallow and are dominated by fine-grained substrate. Current velocities are quite low in backwater pools. Backwater pools are used by salmonids as over-wintering habitat and provide shelter from high storm flows. Backwater pools are especially important habitat for coho salmon. Boulders, root wads, or logs which generally form backwater pools can be removed or buried by excess sediment, thereby reducing the diversity of instream habitat. The loss of habitat, in turn, results in a deleterious impact on the cold water fishery and associated beneficial uses.

Backwater Pool Distribution Target Value

The salmonid freshwater habitat target for backwater pool distribution is an increasing trend in the number of backwater pools. Although this target is an increased trend, Regional Water Board staff do not intend nor expect the number of backwater pools to increase beyond the capacity of water bodies to form this habitat feature or continue throughout time. Complexity within a stream channel is necessary. However, it is not possible at this time to identify a specific number of backwater pools that are necessary for salmonid success due to the lack of sufficient research, and an increasing trend target is established until more information is available.

The backwater pool distribution target is only applicable to wadeable streams and rivers with a channel morphology that supports the development of backwater pools. Steep, v-shaped valleys with little floodplain connection generally do not exhibit this type of habitat and are exempt from this target. At a minimum, this target should be measured periodically during the low-flow periods after a heavy winter storm. This target should be monitored according to the methodology found in the ***California Salmonid Stream Restoration Manual*** (Flosi et al. 2004).

6. POOLS - LATERAL SCOUR POOL DISTRIBUTION

Lateral scour pools are defined in Flosi et al. (2004) as pools formed by flow impinging against a partial channel obstruction consisting of a log, root wad, boulder, or bedrock stream bank. This is also known as channel constriction. The associated scour is generally confined to less than sixty percent of the wetted channel width. Lateral scour pools are widely used habitat for salmonids, including coho salmon.

Lateral Scour Pool Distribution Literature Review

According to a survey by Georgia-Pacific of anadromous fish bearing streams throughout the Ten Mile River Watershed in 1994 and 1995, the percent of scour pools appears to be a critical habitat parameter for coho presence (NCRWQCB 2001a). The survey indicates that scour pools which comprise at least 17% of a stream's length, and at least 23% of a stream's area, will contain coho salmon. Applying the above values for the percent of habitat in scour pools correctly predicts coho presence 80% of the time and coho absence 100% of the time. Although this criteria assists in identifying where coho salmon are likely to be present in the Ten Mile River Watershed, it does not adequately determine which streams historically supported, or have the future potential to support, coho populations.

Lateral Scour Pool Distribution Target Value

The salmonid freshwater habitat target for lateral scour pool distribution is an increasing trend in the number of lateral scour pools. Although this target is an increasing trend, Regional Water Board staff do not intend nor expect the number of lateral scour pools to increase beyond the capacity of water bodies to form this habitat feature or continue throughout time. Complexity within the stream channel is necessary. However, it is not possible at this time to identify a specific number of lateral scour pools that are necessary for salmonid success due to the lack of sufficient research, and an increasing trend target is established until more information is available.

The lateral scour pool distribution target is only applicable to wadeable streams and rivers with a channel morphology that supports the development of lateral scour pools. Steep, v-shaped valleys with little floodplain connection do not usually support such habitat and are exempt from this target. At a minimum, this target should be measured periodically during the low-flow periods after a heavy winter storm. This target should be monitored according to the methodology found in the ***California Salmonid Stream Restoration Manual*** (Flosi et al. 2004).

7. POOLS – PRIMARY POOL DISTRIBUTION

Pools are a very important component of instream salmonid habitat. Pools provide shelter from predators and high flows, cooler water temperatures, and quite habitat. In order for a stream to fully support a sustainable population of salmonids, there must be enough pools, and those pools must be of an adequate depth. Pool frequency and depth is partly a function of geology, topography, watershed size, flow, stream disturbance, and pool-forming elements such as boulders and large woody debris.

According to the ***California Salmonid Stream Habitat Restoration Manual*** (Flosi et al. 2004), primary pools are defined as follows: For 1st and 2nd order streams, primary pools are defined as having a maximum residual depth of at least two feet, occupy at least half the width of the low flow channel, and be as long as the low flow channel width. For 3rd and 4th order streams, a primary pool must have a maximum residual depth of at least three feet, occupy at least half the width of the low flow channel, and be as long as the low flow channel. The stream order designations given above refer to the relative position of stream segments in a drainage basin network. The smallest, un-branched, perennial tributaries, terminating at an outer point, are designated as order 1. The junction of two 1st order streams produces a stream segment of order 2. The junction of two 2nd order streams produces a stream segment of order 3, and so on. Residual pool depth is defined as the maximum depth of a pool minus the maximum depth of its downstream riffle crest (i.e., the depth of the pool at the point of zero flow).

Primary Pool Distribution Literature Review

Flosi et al. (2004) concluded from the Department of Fish and Game's habitat typing data that better California coastal coho streams may have as much as 40% of the length of the total stream habitat in primary pools. The manual also states that pool enhancement projects are considered when primary pools comprise less than 40% of the length of the total stream habitat. The Department of Fish and Game has also stated in their ***Watershed Assessment Field Reference*** (CDFG 1999) that good coho streams have more than 50% of their total available fish habitat in adequately deep and complex pools.

Knopp (1993) studied sixty streams within the North Coast Region, of Franciscan Formation geology, with small cobble substrates, and with slopes between 1% and 4% (Rosgen B-3 and C-3 channels). Twelve of the streams, were categorized as "Index No" streams, meaning the watersheds lacked a history of human disturbance and the stream's habitat was considered of good quality and able to maintain viable populations of salmonids relative to the geologic formation and channel type. Six other streams were categorized as "Index Yes" streams, meaning the watersheds had a history of management over forty years ago (i.e., the most recent management activity occurred prior to 1953) and had no evidence of residual erosion or instability due to past human activity. As part of this study, Knopp measured the number and length of pools within each 1000 m stream reach. All pools that occupied fifty percent or more of the active channel and whose surface did not show turbulence were included. No criteria were included for pool depth, which means that Knopp did not exclusively measure primary pools. However, as the primary pool criteria was partially met, the data is still applicable and useful. Figure 11 shows the results of Knopp's study.

Figure 11 Pool Frequency in Northern California Reference Watersheds per Knopp 1993			
Stream	**Tributary To**	**Stream Condition**	**Pool Frequency per 1000 m reach**
Balm of Gilead Creek	Middle Fork Eel River	Unmanaged	33.9%
Canoe Creek	South Fork Eel River	Virtually Undisturbed	24.5%
Cedar Creek	Smith River	Unmanaged	50.5%
Clark Creek	Smith River	Unmanaged	52.0%
Graham Gulch	Freshwater Creek	Managed Before 1953[1]	40.1%
Honeydew Creek	Mattole River	Unmanaged	16.7%
Little River	Pacific Ocean	Managed Before 1953[1]	53.1%
Middle Fork Eel River	Eel River	Virtually Undisturbed	46.2%
Morrison Creek	Middle Fork Eel River	Unmanaged	35.8%
North Fork Caspar Creek	Caspar Creek	Managed Before 1900 & from 1985 to 1991	45.6%
North Fork Freshwater Creek	Freshwater Creek	Managed Before 1953[1]	46.8%
Pilot Creek	Mad River	Unmanaged	31.5%
Priarie Creek	Redwood Creek	Managed Before 1953[1]	55.8%
Russian Gulch	Pacific Ocean	Managed Before 1953[1]	49.0%
Squaw Creek	South Fork Eel River	Unmanaged	32.2%
Yew Creek	Mattole River	Managed Before 1953[1]	50.1%
		mean	41.5%

1. Streams categorized by Knopp (1993) as having reaches with historic management activity more than 40 years ago (from 1993).

The National Marine Fisheries Service developed a ***Matrix of Pathways and Indicators*** that was designed to summarize important parameters. This matrix is found in the ***Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast*** (NMFS 1996). According to the matrix, the properly functioning condition for pool frequency meets the values listed in Figure 12 and meets the LWD recruitment properly functioning condition target (as described in Chapter 4 above).

Figure 12 Pool Frequency Properly Functioning Conditions per NMFS 1996	
Channel Width (ft)	**# of Pools per Mile**
5	184
10	96
15	70
20	56
25	47
50	26
75	23
100	18

The ***Assessment of Cumulative Effects on Salmonid Habitat: Some Suggested Parameters and Target Conditions*** by Peterson et al. (1992) recommended a target condition of 50% pools. They found 50% pools to be generally indicative of pool habitat in streams with gradients less than three percent in unmanaged forests. Peterson et al. (1992) used the pool classification system of Bisson et al. (1982, as cited in Peterson et al. 1992) and Sullivan (1986, as cited in Peterson et al. 1992). This classification system differs from the use of primary pools.

Primary Pool Distribution Target Value

The salmonid freshwater habitat target for primary pool distribution is an increasing trend in the number of stream reaches where the length of the reach contains ≥ 40% primary pools. The long term goal is for all wadeable streams and river to consist of ≥ 40% primary pools. A wadeable stream or river is one which an average human can safely cross on foot during the summer, low flow season while wearing chest waders.

The target is primarily based on Flosi et al. (2004) and the findings of Knopp (1993). Regional Water Board staff concur with the findings of CDFG in that a water quality objective for pool frequency of $\geq$ 50% would be fully protective of the salmonid population (CDFG 1999). However, streams that are typically considered pristine or near pristine water bodies within the North Coast Region were shown by Knopp (1993) to have a mean pool frequency of 41.5%. In addition, Flosi et al. (2004) recommends pool enhancement projects when primary pools comprise less than 40% of the length of the total stream habitat. Regional Water Board staff are not establishing a target based on the matrix developed by NMFS (1996) because data specific to Northern California are not currently available for verification with local conditions.

Primary Pool Distribution Monitoring Recommendations

At a minimum, this target should be measured during the low-flow period after a heavy winter storm season once every five to ten years. Reported data should include length and depth of pools, and the number of primary pools. If possible, include the type of primary pool (e.g., lateral scour pool, step pool, corner pool, channel confluence pool, plunge pool, or dammed pool). This target should be monitored according to the protocol by Flosi et al. (2004). Furthermore, additional information can be gathered during this process, such as general habitat type and thalweg profile.

8. SUBSTRATE COMPOSITION - % FINES < 0.85mm

The composition of the substrate of a watercourse is a common measure of salmonid spawning habitat. Fine sediment particles, known as fines, in the substrate of a water body have the potential to fill the interstitial spaces of gravels used by salmonids to hold and incubate eggs (a redd). Once salmonid eggs are laid and fertilized, the spawning fish cover the redds with substrate material from just upstream of the redd. Interstitial spaces between substrate particles allow for water to flow into the interior cavity of the redd where dissolved oxygen, a necessity to growing embryos, is replenished. Similarly, the interstitial spaces allow water to flow out of the interior cavity carrying away metabolic wastes. Fine sediment particles can intrude into these interstitial spaces, reducing gravel permeability, which results in reduced rates of oxygen delivery and removal of metabolic wastes (McBain & Trush 1999). Ultimately, reduced permeability results in reduced embryo survival and deleterious effects on the cold water fishery beneficial uses.

Fine sediment that impacts embryo development has been defined as particles that pass through a 0.85 mm sieve. The 0.85 mm diameter cut off is an arbitrarily established value based on the available sieve sizes at the time of the initial studies. As the percentage of fine sediment increases as a proportion of the total bulk core sample, the survival to emergence decreases.

% Fines < 0.85 mm Literature Review

Extensive research has occurred trying to relate a certain amount of salmonid survival or emergence to the size of the substrate. The results of several studies are summarized in Figure 13 below.

Burns (1970) conducted three years of study in Northern California streams, including three streams he classified as unmanaged: Godwood Creek and South Fork Yager Creek in Humboldt County, and North Fork Caspar Creek in Mendocino County. Burns conducted his field work during the summer low flow season. He found a range of values for fines < 0.8 mm in each of these streams: 17.3-17.8% in Godwood Creek, 16.4-22.1% in South Fork Yager Creek, and 17.5-23.2% in Caspar Creek. Data collection for this study began a few years following big storms in 1964, which caused extensive hillside erosion and instream aggradation, the results of which we still observe today.

Cederholm et al. (1980) studied several Washington streams through a combination of both field and laboratory work. Samples were analyzed using a wet-sieve method and were collected during the winter spawning period. Cederholm et al. found that in streams with less than 20% fines < 0.85 mm in diameter, the mean coho salmon survival rate was 31.9%. However, when streams had more than 20% fines < 0.85 mm, the mean coho salmon survival rate was 17.7%. Cederholm et al. also found that streams in road impacted watersheds have fines ranging from 15-20% fines < 0.85 mm, and natural streams have only 10% fines < 0.85 mm in diameter.

Magee et al. (1996) studied the distribution and habitat characteristics of spawning sites of cutthroat trout in Montana. As part of their research, Magee et al. sampled the substrate of 21 redds in Cache Creek (history of livestock and timber management) and 15 redds in upper Wapiti Creek (no known history of logging, grazing, or road building) using a McNeil sampler. Samples were collected in July and August following the first sighting of emergent fry. Magee et al. (1996) found that the percentage of substrate smaller than 0.85 mm was significantly higher in Cache Creek, the managed stream, then in Wapiti Creek, the unmanaged stream; with 21.6% and 17.1% respectively.

McNeil and Ahnell (1964), in their early work in Alaska, found a range of 8.6-12.3% fines < 0.833 mm in diameter in moderately to highly productive pink salmon streams. McNeil and Ahnell sampled during periods of low discharge. Data from Tagart (1976, as cited in Chapman 1988) showed a 32% survival to emergence rate in salmonid redds where sediment was less than 20% fines < 0.85mm.

The National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, developed a ***Matrix of Pathways and Indicators*** that was designed to summarize important parameters and corresponding levels of condition. This matrix is found in the ***Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast*** (NMFS 1996). According to the matrix, the properly functioning condition for sediment in coastal streams is < 12% fines < 0.85 mm.

In a broad survey of literature reporting percent fines in streams without a history of land management activities, Peterson et al. (1992) found fines <0.85 mm in diameter ranging from 6.37% in the Olympic National Forest to 28% on the Oregon Coast. Peterson et al. recommended the use of 11% fines < 0.85 mm in diameter as a target for Washington streams because the study sites in unmanaged streams in Washington congregated around that figure. The 11% target condition should be applied to low and moderate gradient streams (<3% slope) up to 30 m in channel width. Substrate should be sampled in potential spawning reaches prior to spawning. None of the data summarized by Peterson et al. were from California.

Figure 13
Summary of Literature Values for Percent Fines < 0.85 mm

Reference	Study Location	Season Sampled	Analysis Method	Species	Results	
Burns 1970	Godwood Ck – field	low flow	wet volumetric	Coho	natural stream	17.3-17.8% fines < 0.80 mm
	S. Fk. Yager Ck – field	low flow	wet volumetric	N/A	natural stream	16.4-22.1% fines < 0.80 mm
	Caspar Ck - field	low flow	wet volumetric	Coho	managed before 1900	17.5-23.2% fines < 0.80 mm
Cederholm et al. 1980	Washington – field & lab	spawning season	wet volumetric	Coho	31.9% survival	< 20% fines < 0.85 mm
					17.7% survival	> 20% fines < 0.85 mm
					roads/sediment impacted	15-20% fines < 0.85 mm
					natural streams	10% fines < 0.85 mm
Magee et al. 1996	Montana – field	low flow	dry weight	Cutthroat Trout	unmanaged stream	17.1% fines < 0.85 mm
					managed stream	21.6% fines < 0.85 mm
McNeil & Ahnell 1964	Alaska - field	low flow	wet volumetric	Pink	mod to highly productive	8.6-12.3% fines < 0.833 mm
NMFS, 1996	Washington	N/A	N/A	all salmonids	properly functioning condition	< 12% fines < 0.85 mm
Peterson et al. 1992	Washington	pre-spawning season	both methods	N/A	recommended target	11% fines < 0.85 mm[1]
Platts et al. 1979	Idaho - field	unknown	both methods	Chinook	most important spawning streams in Idaho	8% fines < 0.83 mm
Tagart 1976[2]	Washington – field	unknown	unknown	unknown	32% survival	< 20% fines < 0.85 mm
Tappel & Bjornn 1983	Idaho & WA - lab	N/A	N/A	Steelhead	70% survival	≤ 11% fines < 0.85 mm[3]
					50% survival	≤ 14% fines < 0.85 mm[4]
				Chinook	70% survival	≤ 14% fines < 0.85 mm[5]
					50% survival	≤ 19% fines < 0.85 mm[5]

1. The 11% target condition should be applied to low and moderate gradient stream (<3% slope) up to 30m in channel width in WA.
2. as cited in Chapman, 1988
3. when < 23% fines < 9.50 mm in diameter
4. when < 30% fines < 9.50 mm in diameter
5. when < 32% fines < 9.50 mm in diameter
6. when < 36% fines < 9.50 mm in diameter

Platts et al. (1979) studied the effects on fine sediment on chinook salmon in the Salmon River Watershed of Idaho. Samples from 1966 to 1974 were analyzed using the dry weight method and samples taken during 1975 to 1977 were analyzed using the wet volumetric method. Platts et al. found that based on 815 samples taken from the 12 most important chinook salmon spawning areas in Idaho, channels used for spawning averaged 8% fines < 0.83 mm and 30% fines < 4.7 mm.

Tappel and Bjornn (1983) conducted laboratory work on Idaho and Washington sediments. They found that approximately 11% fines < 0.85 mm and 23% fines < 9.50 mm resulted in a 70% steelhead embryo survival rate. A 50% survival rate of steelhead required approximately 14% fines < 0.85 mm and 30% fines < 9.50 mm in diameter. For chinook salmon, a 70% survival rate required less than approximately 14% fines < 0.85 mm and 32% fines < 9.50 mm. A 50% survival rate corresponded to less than approximately 19% fines < 0.85 mm and 36% fines < 9.50 mm in diameter.

% Fines < 0.85 mm Target Value

The salmonid freshwater habitat target for percent fines less than 0.85 mm is a substrate composition where the percent of fine sediment less than 0.85 mm in diameter is less then or equal to 14% of the total bulk core sample (i.e., ≤ 14% fines < 0.85 mm). This water quality target is applicable to wadeable streams and rivers with a gradient of less than 3%. A wadeable stream or river is one which an average human can safely cross on foot during the summer, low flow season while wearing chest waders.

The target was chosen as it is roughly the midpoint between the 8% of Platts et al. (1979), the 9.6% to 12.3% of McNeil and Ahnell (1964), the 11% recommended target of Peterson et al. (1992), the < 12% properly functioning condition target of NMFS (1996), the < 14% of Tappel and Bjornn (1983), the 17.1% of Magee et al. (1996), and the 17.3 to 23.2% range of Burns (1970). The established salmonid freshwater habitat targets takes into account that the recommended value of 11% fines < 0.85 mm from Washington (Peterson et al. 1992; NMFS 1996) is lower than would be expected in California. The same justification applies to the < 12% fines < 0.85 mm properly functioning condition of NMFS (1996), which was based on studies from Washington State. On the other hand, the roughly 17% fines < 0.85 mm seen in unmanaged Godwood Creek of Northern California beginning in 1967 (Burns 1970) is probably too high given the tremendous sediment loads discharged to streams as a result of the 1964 storms. In addition, Tappel and Bjorn (1983) predicted that 15% fines < 0.85 mm, in combination with about 27% fines < 9.5 mm, would provide an average of 50% survival to emergence for steelhead and an average of 80% survival to emergence for chinook salmon. The choice of 50% emergence is arbitrary, but can be justified because redds with at least 50% emergence success would probably be considered productive by most biologists (Kondolf 2000).

The work by Cederholm et al. (1980) was not used in choosing the target because the samples were taken during the spawning season when stream flows were high. High stream flows, and correspondingly high velocities, result in a higher amount of fine sediment suspended in the water column. Regional Water Board staff expect that this condition results in a smaller amount of very fine sediment particles present in the substrate during high flows then would otherwise be present during low flow conditions.

% Fines < 0.85 mm Monitoring Recommendations

Monitoring for substrate composition should use a McNeil sediment core sampler similar to the specifications found in McNeil and Ahnell (1964), with the exception that the diameter of the sampler's core should be two to three times larger than the largest substrate particle usually encountered (Shirazi et al. 1979). Common sampler sizes are 6" and 12" in diameter. A McNeil sampler is recommended over the use of a shovel for several reasons. First, the McNeil sampler results in a more accurate and representative core of the substrate. Second, shovels types vary (e.g., round vs. square) and a specific type/brand has not be consistently used. This results in lower repeatability. Third, history data has been collected using a McNeil sampler. Continued use of a McNeil sampler allows for comparison of future monitoring data to historic data.

Sampling of substrate composition should be performed according to the protocol found in ***Stream Substrate Quality for Salmonids: Guidelines for Sampling, Processing, and Analysis*** (Valentine 1995), and should follow the methodology for either the "redd sampling universe" or the "pool/riffle break sampling universe." According to Valentine's methodology, sampling should occur soon after fry have emerged from the substrate (if following the redd sampling universe method) or during the summer low flow period (if following the pool/riffle break sampling universe method). Additionally, a 0.85 mm sieve should be used during sample processing in order to compare data to this water quality target.

In regards to sample processing, there are two options available: (1) the field-based, wet volumetric method, and (2) the laboratory-based, dry gravimetric method. Regional Water Board staff recommend the use of the wet volumetric method and encourage the use of both the wet volumetric and the dry gravimetric methods on 10% of the samples for quality control purposes. As described by Schuett-Hames et al. (1999a), the wet volumetric method uses field-based manual shaking and washing technique to sort the sample by particle size class. The volume of sample particles retained in each sieve is measured by using a water displacement technique. This method is quicker, requires less equipment, and is cheaper. However, it does result in a greater potential for inaccurate data. The dry gravimetric method involves the drying of the samples in an oven prior to sieve sorting. Each particle size class is then weighed. This method involves more labor in carrying out samples from the field, more labor in the laboratory, and is more expensive. However, it eliminates many potential sources of inaccuracy.

9. SUBSTRATE COMPOSITION - % FINES < 6.40mm

Substrate composition is a common measure of salmonid spawning habitat. Fine sediment particles, known as fines, in the substrate of a water course have the potential to cover the redd and prevent the emergence of fry (young swimming fish) out of the gravel and into the flowing stream. The size of fine particles likely to fill the interstices of redds sufficient enough to block passage of fry are larger than those fines likely to suffocate embryos. That is, particles ranging from 1.0 mm to 10.0 mm are capable of blocking fry emergence, depending on the sizes and angularity of the framework particles, while still allowing sufficient water flow through the gravels to support embryo development (Kondolf 2000). The percentage of fines is inversely related to the size of emerging fry (Chapman 1988). These factors impact the ultimate survivability of the embryos and fry.

% Fines < 6.40 mm Literature Review

Extensive research has occurred that studies the amount of salmonid survival or emergence to the size of the substrate. The results of several studies are summarized in Figure 14 below.

Kondolf (1988) evaluated data from twenty three studies which focused on gravel quality criteria for a large variety of salmonids including chinook (five studies), coho (five studies), and steelhead (four studies). Kondolf found values for percentage finer than 3.35 mm and 6.35 mm for fifty percent emergence both average about 30%. He goes on to state that the conflict of similar results obtained with different variables probably reflect differences in experimental design, which makes it difficult to specify a single target value. A strict approach to determining the target value would be to simply use a maximum of 30% finer than 6.35 mm as the standard.

Koski (1966) studied the survival of coho salmon from egg deposition to emergence in three coastal stream in Oregon from 1963 to 1964. The three streams drained small, unlogged watersheds. In 1966, two of the watersheds were scheduled to be logged as part of a paired watershed study. Koski found that as the percentage of fine sediment (particles < 3.327 mm in diameter) in the redds increased, the success of coho survival to emergence decreased.

Koski (1981) studies the rates of survival of chum salmon from egg to emerged fry in an experimental stream that was built into the streambed of a tributary to Big Beef Creek in Washington State. The substrate of the experiment stream was manipulated for the purposes of this study. Koski found that a high percentage of sand (particles < 3.327 mm in diameter) in the spawning gravel resulted in earlier emergence, increased pre-maturity, and decreased survival to emergence rates. Each 1% increment in the amount of sand reduced survival to emergence by 1.26%. Although the research by Koski does not specifically focus on fines < 6.40 mm in diameter, it does focus on fine sediment that are capable of blocking fry emergence.

Magee et al. (1996) studied the distribution and habitat characteristics of spawning sites of cutthroat trout in Montana. As part of their research, Magee et al. sampled the substrate of 21 redds in Cache Creek (which has a history of livestock and timber management) and 15 redds in upper Wapiti Creek (which has no known history of logging, grazing, or road building) using a McNeil sampler. Samples were collected in July and August following the first sighting of emergent fry. Magee et al. (1996)

found that both the managed stream, Cache Creek, and the unmanaged stream, Wapiti Creek, had high percentages of fines smaller than 6.35 mm.

McCuddin (1977) found that the ability of chinook salmon and steelhead trout to emerge from the substrate decreased sharply when sediment less than 6.4 mm in diameter comprised more than 20-25% of the substrate. Reported data varied from 27-55% from several other studies concerning fine sediment levels in un-logged Oregon watersheds. McNeil and Ahnell (1964) studied eight streams in Alaska with moderate to high pink salmon production and found the substrate to consist of 12.6-15.7% fines < 6.68 mm in diameter.

Phillips et al. (1975) studied the relationships between the amount of fine sediment and survival of coho and steelhead fry during emergence. In a laboratory setting, sand (1-3 mm in diameter) and gravel (3-32 mm) were mixed to create the substrate. Phillips et al. found an inverse relationship between the concentration of 1-3 mm sand and emergent survival of coho and steelhead fry. Mean survival for coho ranged from 96% in the control groups with no fine sand, to 8% in substrates of 70% sand. Mean survival of steelhead ranged from 99% in the control group to 18% in substrates with 70% sand. Results also show an inverse relationship between days to emergence for coho and the amount of 1-3 mm sand. Although the research by Phillips et al. does not specifically focus on fines < 6.40 mm in diameter, it does focus on fine sediment that are capable of blocking fry emergence.

Platts et al. (1979) studied the effects of fine sediment on chinook salmon in the Salmon River Watershed of Idaho. Samples from 1966 to 1974 were analyzed using the dry weight method, and samples taken during 1975 to 1977 were analyzed using the wet volumetric method. Platts et al. found that, based on 815 samples taken from the 12 most important chinook salmon spawning areas in Idaho, channels used for spawning averaged 8% fines sediment < 0.83 mm and 30% fines < 4.7 mm.

Figure 14
Summary of Literature Values for Percent Fines < 6.40 mm

Reference	Study Location	Season Sampled	Analysis Method	Species	Results	
Kondolf 1988	N/A	N/A	N/A	Chinook, Coho, Steelhead	50% survival	30% fines < 3.35 or 6.35 mm
Koski 1966	Oregon – field	year round	wet volumetric	Coho	50% survival	30% fines < 3.327 mm
Koski 1981	Washington – field	unknown	N/A	Chum	50% survival	27% fines < 3.327 mm
McCuddin 1977	Idaho – lab	N/A	wet volumetric	Chinook Steelhead	decrease in emergence	20-25% fines < 6.40 mm
Magee et al. 1996	Montana – field	low flow	dry weight	Cutthroat Trout	unmanaged stream	42.6% fines < 6.35 mm
					managed stream	44.6% fines < 6.35 mm
McNeil & Ahnell 1964	Alaska – field	low flow	wet volumetric	Pink	mod. to highly productive	12.6-15.7% fines < 6.68 mm
Phillips et al. 1975	Oregon – lab	N/A	N/A	Coho	96% survival	0% fines < 3.00 mm
					50% survival	27% fines < 3.00 mm
					8% survival	70% fines < 3.00 mm
				Steelhead	99% survival	0% fines < 3.00 mm
					50% survival	37% fines < 3.00 mm
					18% survival	70% fines < 3.00 mm
Platts et al. 1979	Idaho – field	unknown	both methods	Chinook	most important spawning streams in Idaho	30% fines < 4.70 mm
Tappel & Bjornn 1983	Idaho & WA - lab	N/A	N/A	Chinook	70% survival	32% fines < 9.50 mm[1]
					50% survival	41% fines < 9.50 mm[1]
				Steelhead	50% survival	30% fines < 9.50 mm[1]

1. when <14% fines < 0.85 mm in diameter

Tappel and Bjornn (1983) have done extensive research on percent fines, in which they focused on the combination of fines smaller than 0.85mm and 9.50mm in diameter. They predicted that 30% fines < 9.50 mm, in combination with 14% fines < 0.85 mm, would provide an average of 50% survival to emergence for steelhead. The same study predicted that 32% fines < 9.50 mm, in combination with 14% fines < 0.85 mm, would provide an average of 70% survival to emergence for chinook salmon. No relationship was reported for coho salmon, but it should be noted that both steelhead and chinook are expected to have greater emergence success than coho salmon when redds are sedimented.

% Fines < 6.40 mm Target Value

The salmonid freshwater habitat target for percent fines less than 6.40 mm is a substrate composition where the percent of fines sediment less than 6.40 mm in diameter is less than or equal to 30% of the total bulk core sample (i.e., ≤ 30% fines < 6.40 mm). This water quality target is applicable to wadeable streams and rivers with a gradient less than 3%. A wadeable stream or river is one which an average human can safely cross on foot during the summer, low flow season while wearing chest waders.

The target was selected due to the findings of Kondolf (1988) and because it is roughly the midpoint of the results from the studies listed in Figure 14 above. Specifically, the percentages of fines corresponding to 50% survival were considered as a target values because redds with at least 50% emergence success would probably be considered productive by most biologists (Kondolf 1988). Studies which focused on coho salmon were also given greater consideration due to the expected lower emergence success rate of coho salmon than either chinook salmon or steelhead trout when redds are sedimented. The Regional Water Board has the responsibility to protect the most sensitive species, which is often coho salmon. As easily seen in Figure 14 above, not every study focused on fine sediment particles < 6.40 mm in diameter. Koski (1966), Magee et al. (1996), and Phillips et al. (1979) studied the effects of fine sediment less than approximately 3.00 mm in diameter. Platts et al (1979) studied fine sediment < 4.70 mm in diameter. Regional Water Board staff expect that the percentages of fine sediment would be higher if the studies took into account all fine sediment particles < 6.40 mm in diameter. Conversely, Tappel and Bjornn (1983) studied the effects of fine sediment < 9.50 mm in diameter and Regional Water Board staff expect that the percentages of fine sediment would be lower if the studies took into account only fine sediment particles < 6.40 mm.

% Fines < 6.40 mm Monitoring Recommendations

Monitoring for substrate composition should use a McNeil sediment core sampler similar to the specifications found in McNeil and Ahnell (1964), with the exception that the diameter of the sampler's core should be two to three times larger than the largest substrate particle usually encountered (Shirazi et al. 1979). A twelve inch diameter sampler is suitable for a broad range of typical substrates. Sampling of substrate composition should be performed according to the protocol found in ***Stream Substrate Quality for Salmonids: Guidelines for Sampling, Processing, and Analysis*** (Valentine 1995), and should follow the methodology for either the "redd sampling universe" or the "pool/riffle break sampling universe." According to Valentine's methodology, sampling should occur soon after fry have emerged from the substrate (if following the redd sampling universe method) or during the summer low flow period (if following the pool/riffle break sampling universe method). Additionally, a 6.40 mm or 6.35 mm sieve should be used during sample processing in order to compare data to this water quality target.

In regards to sample processing, there are two options available: (1) the field-based, wet volumetric method, which is described in Valentine (1995), and (2) the laboratory-based, dry gravimetric method. Regional Water Board staff recommend the use of the wet volumetric method and encourage the use of the dry gravimetric method on 10% of the samples for quality control purposes. As described by Schuett-Hames et al. (1999a), the wet volumetric method uses field-based manual shaking and washing technique to sort the sample by particle size class. The volume of sample particles retained in each sieve is measured by using a water displacement technique. This method is produces quicker results, is less expensive, and requires less equipment. However, it does result in a greater potential for inaccurate data. The dry gravimetric method involves the drying of the samples in an oven prior to sieve sorting. Each particle size class is then weighed. This method involves more labor in carrying out samples from the field, more labor in the laboratory, and is more expensive. However, it eliminates many potential sources of inaccuracy.

10. SUBSTRATE COMPOSITION – D_{50}

D_{50} is the median particle diameter of a sampled population. The sampled population is composed of particles from the surface substrate of a stream or river that is sampled by a pebble count. For example, a D_{50} value of 65 mm means that 50% of the substrate particles were smaller than 65 mm and 50% were larger. D_{50} can be used as a measure of substrate composition and salmonid spawning habitat. Fine sediment particles in a stream's substrate have the potential to clog the interstitial spaces of substrate gravels used by salmonids as a nest, which is known as a redd. Once salmonid eggs are laid and fertilized, the spawning fish cover the redds with substrate material from just upstream of the redd. Interstitial spaces between substrate particles allow for water to flow into the interior cavity of the redd where dissolved oxygen, a necessity to growing embryos, is replenished. Similarly, the interstitial spaces allow water to flow out of the interior cavity carrying away metabolic wastes. Fine sediment particles can intrude into these interstitial spaces, reducing gravel permeability, which results in reduced rates of oxygen delivery and removal of metabolic wastes (McBain & Trush 1999).

D_{50} Literature Review

Knopp (1993) studied sixty streams within the North Coast Region which were of the Franciscan Formation and were composed of small cobble substrates with slopes between one and four percent (Rosgen B-3 and C-3 channels). The data for each stream was derived from three separate riffle reaches using 200-count pebble counts. Twelve of these streams, categorized as "Index No" streams, had no human disturbance history and were considered good quality habitat that is best able to maintain viable populations of salmonids relative to the above specific geologic formation and channel type. Six other streams, categorized as "Index Yes" streams, had reaches with historic management greater than forty

Figure 15
D_{50} Values in Reference Streams
per Knopp 1993

Stream	Tributary To	Stream Condition	D_{50} (mm)
Balm of Gilead Creek	Middle Fork Eel River	Unmanaged	111.4
Canoe Creek	South Fork Eel River	Virtually Undisturbed	63.5
Cedar Creek	Smith River	Unmanaged	45.4
Clark Creek	Smith River	Unmanaged	37.4
Elder Creek	South Fork Eel River	Virtually Undisturbed	183.1
Graham Gulch	Freshwater Creek	Managed Before 1953	38.4
Honeydew Creek	Mattole River	Unmanaged	105.9
Little Lost Man Creek	Redwood Creek	Unmanaged	42.0
Little River	Pacific Ocean	Managed Before 1953	47.6
Middle Fork Eel River	Eel River	Virtually Undisturbed	109.3
Morrison Creek	Middle Fork Eel River	Unmanaged	50.2
North Fork Caspar Creek	Caspar Creek	Managed Before 1900 & from 1985 to 1991	52.1
North Fork Freshwater Creek	Freshwater Creek	Managed Before 1953	50.9
Pilot Creek	Mad River	Unmanaged	83.8
Prairie Creek	Redwood Creek	Managed Before 1953	57.7
Russian Gulch	Pacific Ocean	Managed Before 1953	40.7
Squaw Creek	South Fork Eel River	Unmanaged	83.7
Yew Creek	Mattole River	Managed Before 1953	47.2
			mean 69.5

years old (i.e., the most recent management activity occurred prior to 1953) and had no evidence of residual erosion or instability due to past human activity. The D_{50} values for both categories of stream can be found in Figure 15.

Knopp found a statistically significant difference in average and minimum D_{50} values when comparing references reaches with reaches in moderately and highly disturbed watersheds. Therefore, the D_{50} levels identified in the references streams are good candidates for numeric targets.

D_{50} Target Value

Although sediment supply is an important variable affecting sediment substrate, reach-scale flow perturbations add considerable variability to grain size and transport capacity. Due to this variability, Regional Water Board staff do not propose a target for D_{50} at this point in time.

11. THALWEG PROFILE

The thalweg is the deepest part of the stream channel at a given cross section. The thalweg profile is constructed by surveying the elevation of the channel bed in a downstream direction along the deepest part of the channel. The profile appears as a jagged but descending line which is relatively flat at pool areas and descends sharply at cascades. The thalweg profile can show the number of pools, depths of pools, pool-riffle spacing, and the spatial pattern of pool distribution (Madej 1999). In other words, the thalweg profile is an indicator of instream salmonid habitat complexity. More variability in the thalweg profile indicates more complexity in the habitat. Variety and complexity in habitat are needed to support salmonids at different times in the year during different stages in their life cycles. Both pools and riffles are utilized by salmonids for spawning, incubation of eggs, and emergence of fry. Once fry emerge, they rest in pools and other slower moving water, darting into faster riffle sections to feed where insects are more abundant. Deep pools also provide cover from predators.

Thalweg Profile Literature Review

Successive thalweg profiles can document trends in stream aggradation or degradation (Madej 1999). A channel will rise in elevation, or agrade, if larger amounts of sediment is delivered to a channel than it is able to carry away (which is a function of flow and channel geometry). If the channel is able to carry away more sediment than is being delivered from upstream sources, the channel will degrade, or scour.

Madej (1999) studied trends in the thalweg profiles of several streams in the Redwood Creek Watershed between 1977 and 1997. The analysis of the profiles showed there were statistically significant differences in the distributions of pool residual water depths and in the variation of channel bed elevations impacted by high sediment loads.

Thalweg Profile Target Value

The salmonid freshwater habitat target value for the thalweg profile is an increasing trend in the variation around the mean thalweg profile slope for water bodies with slopes of 2% or less. In other words, the target is an increasing trend towards more variation in the thalweg profile. Additionally, it is expected that overall thalweg profile of aggraded streams will drop in elevation as sediment loads are reduced.

It is not possible at this time to establish a specific numeric target due to relatively slow response times and the lack of sufficient research that compares thalweg profiles from different streams. The thalweg profile target is limited to water bodies with slopes of 2% or less because such water bodies are often simplified due to increased sediment supply and loss of LWD. Changes in the thalweg profile due to changes in the sediment load will be most pronounced in low gradient water bodies.

Thalweg Profile Monitoring Recommendations

The thalweg profile target should be monitored during the low-flow period, after a heavy winter storm season, once every five to ten years. The stream segment must be at least 20, but usually 30 to 40 times, as long as the average bankfull channel width. Points to be surveyed include the thalweg profile, all breaks-in-slope, riffle crests, maximum pool depths, tails of pools, and surface water elevation. It is essential that the spacing of survey shots be close enough to define the channel bed features of interest. Acceptable monitoring methodologies for the thalweg profile include, but are not limited to, the Channel Geometry Survey of ***Water in Environmental Planning*** (Dunne & Leopold 1978, pp. 653-655).

12. TURBIDITY

Turbidity is an optical measure of the amount of suspended particles in the water column, including suspended sediment, algae, organic matter, and pollutants. Turbidity can be measured in Jackson Turbidity Unite (JTUs) or Nephelometric Turbidity Units (NTUs), which are not interchangeable. While JTUs are suitable for evaluating gross changes in turbidity levels, NTUs offer more precise and sensitive measurements. Turbidity is a very important component of the water column and highly turbid waters can have a variety of negative effects on salmonids, including avoidance response, reduced feeding rates, reduced growth rates, damage to fish gills, and fatality. “Turbidity is regarded by many as the single most sensitive measure of the effects of land use on streams. This is due partly to the fact that relatively small amount of sediment can cause a large change in turbidity, and partly to the estimated accuracy of turbidity measurements.” (MacDonald et al. 1991, p. 105).

Suspended sediment is the amount of particles suspended in the water column. It is measured in milligrams of suspended sediment per liter of water (mg/L) or in parts per million (ppm). The relationship between suspended sediment and turbidity is variable. At low concentrations (approximately less than 50 NTUs and mg/L), one NTU is typically equal to one mg/L. At higher concentrations, the relationship must be developed on a site specific basis.

Turbidity Literature Review

Extensive research on turbidity and its effects on salmonids has occurred. The results of several studies are summarized in Figure 18 below.

According to Anderson (1975), turbid water is separated from non-turbid water at a suspended sediment concentration of 27 mg/L. Water with 27 mg/L of suspended sediment has been characterized as “not drinkable,” results in a fifty percent drop in the catch of fish, and results in a less than a ten percent drop in fish production (Anderson 1975). Klein (2001) states that suspended sediment concentrations above 27 mg/L affects the ability of juvenile salmonids to forage for food.

Barrett et al. (1992) studied the effects of turbidity on the reactive distance of rainbow trout over a period of twenty four hours in Georgia. They found that an increase of 10 NTUs of turbidity over the ambient background of 5 NTUs reduced the reactive distance of rainbow trout by approximately twenty percent. Reactive distance is the distance moved by the fish from its holding position to the point where it took its prey.

Bisson and Bilby (1982) conducted several laboratory based avoidance tests on young-of-the-year coho salmon taken from a Washington stream. They found that coho who were acclimated to clear water (less than 0.3 NTUs) avoided water with turbidities of 70 NTUs and greater. Juvenile coho who were acclimated to slightly turbid water (2-15 NTUs) avoided water with turbidities of 100 NTUs and greater. The avoidance reaction to turbid water has been commonly attributed to the sight-feeding requirements of salmonids as overall visibility, flotation, and background contrast are key factors in food selection by juvenile coho.

Literature sources also state that water with low concentrations of turbidity can be beneficial to salmonids as turbidity can provide temporary cover and protection from predators. Gregory and Northcote (1993) investigated the effect of turbidity on the foraging behavior of juvenile chinook salmon taken from the Fraser River in British Colombia. They found that plankton foraging by chinook occurred at high rates at low turbidity, and at much reduced rates at elevated turbidity levels (greater than 150 NTUs). However, this trend was not found in the foraging rates for surface and benthic prey. Instead Gregory and Northcote found that chinook foraging on surface and benthic prey was roughly the greatest between 18 and 150 NTUs. They suggested that turbidity may act as a form of cover, reducing the perception of risk in juvenile chinook. However, at turbidity levels greater than 150 NTUs, visual ability becomes substantially impaired and foraging ability is reduced.

Klein (2001) studied suspended sediment concentrations on one pristine and two near-pristine tributary streams throughout the 1999 water year. Elder Creek is a pristine tributary to the South Fork Eel River. Upper Prairie Creek and Little Lost Man Creek are both near-pristine tributaries to Redwood Creek and have experienced minimal management activity. Klein sampled for suspended sediment at established gaging stations both manually and with an automated pumping sampler controlled by a data logger. A stage-based sampling routine was used to control the pumping sampler that increased sampling frequency with increased stage height above a set threshold. Samples taken manually and with the automated sampler were used to determine suspended sediment flux and to define a rating curve. The rating curves were than used to estimate continuous suspended sediment data from the discharge record. A confidence level was not given. When plotted, these data composed “sedigraphs,” which reflect the variation of suspended sediment concentrations over a period of time. Klein found that Elder Creek had 11 days, Upper Prairie Creek had 25 days, and Little Lost Man Creek had 25 days in which turbidity levels exceeded 27 NTUs. In comparison, Panther Creek and Lacks Creek have been, and continue to be, managed primarily for timber production. Panther Creek had 101 days in which turbidity exceeded 27 NTUs, and Lacks Creek had 135 days in which turbidity exceeded 27 NTUs.

Klein (2003) further assembled and analyzed turbidity data from eight continuous turbidity and stage recording stations located on small streams in the North Coast Region. The study basins were Little Jones Creek, Horse Linto Creek, Upper Prairie Creek, Godwood Creek, Upper Jacoby Creek, Freshwater Creek, and the North and South Forks of Caspar Creek. Data from individual streams spanning three water years (WY 2000-2002) were processed to calculate the lengths of time that turbidity exceeded several thresholds. From suspended sediment data collected in Upper Prairie Creek and Little Lost Man Creek, Klein inferred that intrinsic differences in a watershed’s attributes (e.g., geology, soils, stream and slope gradient) that affect erosion can cause large differences in suspended sediment concentrations during storms at peak stream flows. However, suspended sediment concentrations during small storms and winter baseflows are much less affected by intrinsic differences in different watersheds. Specifically, Klein found that “for most of the winter runoff period, . . . undisturbed watersheds, even those with very different soils, geology, and steepness, tend to have similarly low turbidity and [suspended sediment concentration] durations” (Klein 2003, p. 22).

Newcombe & Jensen (1996) performed a meta-analysis of eighty published and adequately documented reports on fish response to suspended sediment. From these reports, they developed the Severity Index (see Figure 16) which provides a very useful means for ranking and analyzing these effects of suspended sediment on salmonid species.

Regional Water Board staff suggest that a Severity Index Rank of four or greater represents significant harm to salmonids so as to be detrimental to the beneficial uses associated with the cold water fishery. The rationale for this determination is as follows. First, it is obvious that mortality is significantly harmful. Second, based upon work by Trush (2001), long term reductions in the success and feeding rate (corresponds to a Rank of 8) are considered significantly harmful to salmonids. Trush found that the survival of salmonids during the smolt life stage is strongly a function of smolt size. Reductions in growth decrease the chance of smolts to mature and return as spawning adults, which cumulatively jeopardizes population sustainability (Trush 2001). Third, discrete short-term reduction in feeding rates and/or feeding success (corresponds to a Rank of 4) which repeatedly occur can lead to an overall long-term reduction in growth. Again, reductions in juvenile salmonid growth jeopardize population sustainability.

In addition to developing the Severity Index, Newcombe and Jensen (1996) analyzed suspended sediment dose. The suspended sediment dose is the product of the suspended sediment concentration in mg/L and length of exposure in hours. Newcombe and Jensen took the natural log of the dose to give a simple Dose Index. The expression is as follows:

$$\text{Suspended Sediment Dose Index} = \ln(\text{SSC x Hrs Exposed})$$

For example, exposure to only 3.13 mg/L of suspended sediment for 24 hours results in a Dose Index of 4. Similarly, exposure to 75.19 mg/L of suspended sediment for only one hour results in a Dose Index of 4.

Newcombe & Jensen then made a connection between summarized suspended sediment data, their Dose Index, and their Severity Index. Figure 17 plots their findings in the form of Dose Index versus the Severity Index Rank for coho, chinook, and steelhead. Only coho salmon were studied sufficiently to see a strong correlation (R^2=0.8481) between suspended sediment and negative responses. These plots illustrate that as suspended sediment concentrations and exposure increase, the effects on salmonids becomes increasingly deleterious.

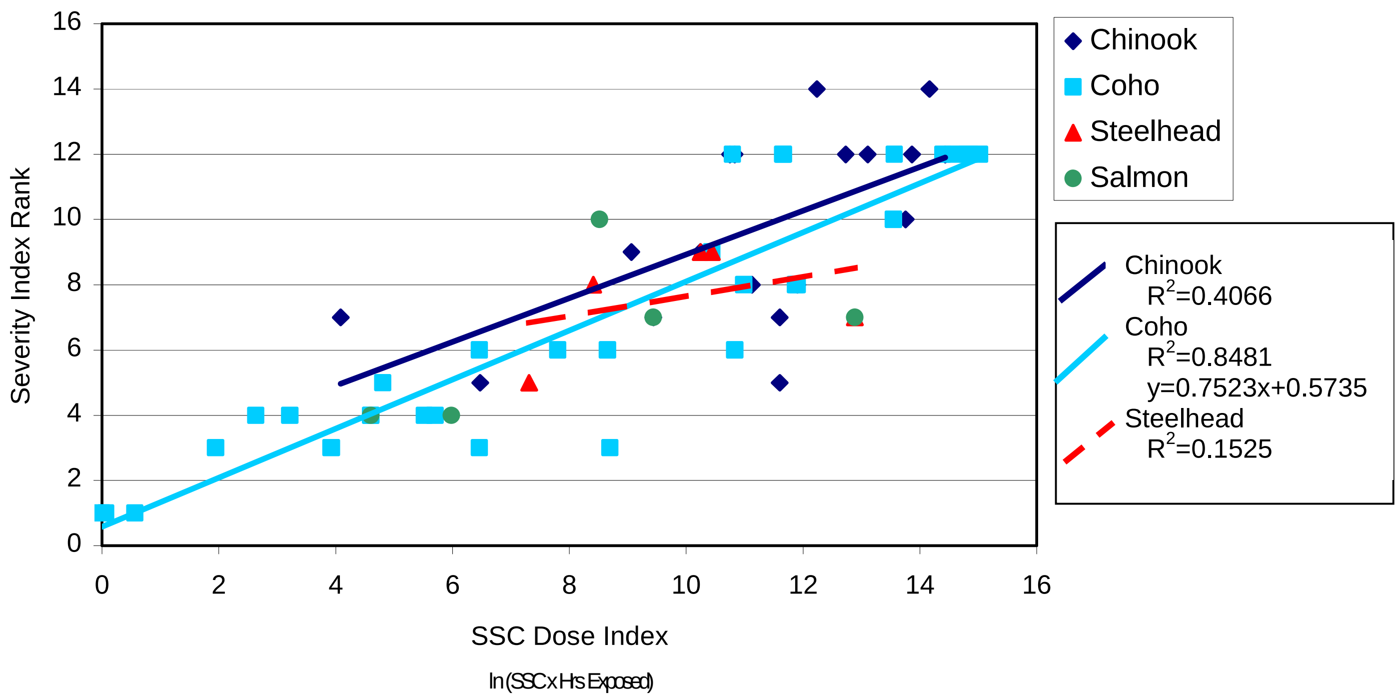
As proposed above, a Severity Index Rank of four (4) or greater is considered to be significantly harmful to salmonids to be detrimental to the beneficial uses associated with the cold water fishery. As determined from the linear regression line for coho salmon on Figure 17, a Severity Index Rank of four (4) equates to a Suspended Sediment Dose Index of 4.55. The data from studies on coho salmon were used due to the data robustness and the high sensitivity of coho to changes in their environment. Thus, a potential target for the protection of salmonids using the Suspended Sediment Dose Index could be a Dose Index of less than or equal to 4.55.

Sigler et al. (1984) studied the effects of chronic turbidity on juvenile coho from Oregon hatcheries and juvenile steelhead from Idaho hatcheries over a twenty one day period. They found that, in general, more salmonids stayed in channels with clear water than turbid water, and the weight and length of salmonids increased faster in clear water. Sigler et al. also found that large numbers of fish avoided highly turbid water, especially over the first two diel cycles of the study. Some of these juveniles still had a portion of their yolk sac, indicating that foraging and feeding were not the principal reasons for the avoidance. Sigler et al. concluded that as little as 25 NTUs over twenty one days caused a reduction in fish growth.

Figure 16
Severity Index
from Newcombe & Jensen 1996

Rank	Description of Effect Associated w/ Excess Turbidity or Suspended Sediment
0	No Effect
1	Alarm Reaction
2	Abandonment of Cover
3	Avoidance Response
4	Short-term Reduction in Feeding Rates and/or Feeding Success
5	Minor Physiological Stress, Increased Coughing Rate, and/or Increased Respiration Rate
6	Moderate Physiological Stress
7	Moderate Habitat Degradation and/or Impaired Homing
8	Major Physiological Stress, Poor Condition, and/or Long-term Reduction in Feeding Rates and/or Feeding Success
9	Reduced Growth Rate, Delayed Hatching, and/or Reduced Fish Density
10	0 to 20% Mortality, Increased Predation, and/or Moderate to Severe Habitat Degradation
11	>20 to 40% Mortality
12	>40 to 60% Mortality
13	>60 to 80% Mortality
14	>80 to 100% Mortality

Figure 17
SSC Dose vs. Severity Index Rank for Chinook, Coho, and Steelhead
(data from Newcombe & Jensen 1996)



According to testimony given by Dr. William Trush (2001), a turbidity exposure threshold for anadromous salmonids that minimally inhibits recovery of salmonid populations is near 27 NTU when the measured flow rate is at ten percent of the daily average flow rate. Trush further clarifies that these criteria should apply to late-winter baseflows when the stream flow is at ten percent of the daily average flow rate. These criteria will allow reliable measurements for the development of baseflow turbidity rating curves. In addition, one winter season of baseflow sampling should be sufficient (though certainly not ideal) for developing a baseflow turbidity rating curve at each monitoring station.

Figure 18
Summary of Literature Values for Turbidity

Reference(s)	**Study Location**	**Species (j) = juvenile**	**Effects**	**Results[1]**
Anderson, 1975	N/A	N/A	Not Drinkable	27 mg/L
Barrett et al., 1992	Georgia	Rainbow Trout	Reduced Reactive Distance	Increase of 10 NTU[2]
Bisson & Bilby, 1982	Washington	Coho (j)	Avoidance	70 NTU
Gregory & Northcote, 1993	British Colombia	Chinook (j)	Reduced Feeding	150 NTU
Klein, 2001	Elder Ck	N/A	Pristine Stream	11 days of > 27 NTU
	Upper Prairie Ck	N/A	Near Pristine Stream	25 days of > 27 NTU
	Little Lost Man Ck	N/A	Near Pristine Stream	25 days of > 27 NTU
Sigler et al., 1984	Oregon & Idaho	Coho (j) & Steelhead (j)	Reduced Growth	25 NTU
Trush, 2001	N/A	Salmonids	Minimally Inhibits Recovery	27 NTU

1. Turbidity expressed in NTU. Suspended Sediment expressed in mg/L.
2. Increase of 10 NTUs over ambient background of 5 NTUs.

Turbidity Target Value

Regional Water Board staff do not propose a salmonid freshwater habitat target for turbidity, but refer to the Water Quality Objective for turbidity that is found in Chapter 3 of the Basin Plan, which is as follows: "Turbidity shall not be increased more than 20 percent above naturally occurring background levels" (NCRWQCB 2001b, p. 3-3.00).

Preliminary findings from Klein's (2001; 2003) work in Upper Prairie Creek and Little Lost Man Creek suggest that turbidity and suspended sediment concentration can be used as a diagnostic tool for quantifying management effects. In addition, Klein (2003) stated that should his hypothesis hold true following more comprehensive studies (more streams, more years of data), then expressions of chronic turbidity - such as the number of days exceeding 27 NTUs or the 10% exceedence NTU - will have good potential for setting robust water quality standards or targets. Until more comprehensive studies take place and additional robust data is available to allow the proposal of a numeric water quality target for turbidity, Regional Water Board staff do not propose a new turbidity target. It may also be possible to suggest a suspended sediment Dose Index-based target according to the findings of Newcombe & Jensen (1996).

13. V*

V* (pronounced v-star) is a unit-less measure of the fraction of a pool's volume that is filled by fine sediment and is representative of the in-channel supply of mobile bedload sediment (Lisle and Hilton 1992). V* gives an indication of the depth of a pool prior to sedimentation. Lisle and Hilton (1999) demonstrated the usefulness of the parameter by comparing annual sediment yields of select streams with their average V* values. The comparison indicated that V* was well correlated to annual sediment yield and that V* values can quickly respond to changes in sediment supply. For example, V* values in French Creek, a tributary to the Scott River, decreased to approximately one-third the initial value soon after an erosion control program focusing on roads was implemented.

V* Literature Review

Knopp (1993) studied sixty streams within the North Coast Region which were of Franciscan Formation geology and were composed of small cobble substrates with slopes between one and four percent (Rosgen B-3 and C-3 channels). V* values identified by Knopp represent the average of six separate pools. Twelve of these streams, categorized as "Index No" streams, had no human disturbance history and were considered good quality habitat that is best able to maintain viable populations of salmonids relative to the above specific geologic formation and channel type. Six other streams, categorized as "Index Yes" streams, had reaches with historic management greater than forty years old (i.e., the most recent management activity occurred prior to 1953), and had no evidence of residual erosion or instability due to past human activity. The V* values for both categories of stream can be found in Figure 19 below.

Knopp (1993) concluded that the median particle size of instream sediment samples was significantly different at the 95% confidence level between the Index reaches and those of Moderate and High disturbance. The region-wide mean V* value for index reaches was 0.21 of the pool volume filled with fine sediment. The mean value for undisturbed reaches was 0.17 of the pool volume filled with fine sediment.

Lisle and Hilton (1999) also reported that V* values for Elder Creek, a stream of 2.2% slope, averaged 0.09. Elder Creek is a pristine tributary to the South Fork Eel River and is composed of Coastal Belt Franciscan Geology (U.S. EPA 1999a). In September 1998, V* values in Elder Creek ranged from 0.01 to 0.02. Other streams in the North Coast Region were studied by Lisle and Hilton (1999). These streams and their corresponding V* values are included in Figure 19 below. All these streams have a slope between 1% and 4%. Of the streams studied, Horse Linto Creek, Little North Fork Salmon River, South Fork Salmon River, Sugar Creek, and Taylor Creek are, according to the general knowledge and best professional judgment of Regional Water Board staff, considered to be relatively undisturbed streams.

Figure 19 Literature Summary of V* Values				
Stream	**Tributary To**	**Stream Condition**	**Reference**	**V***
Balm of Gilead Creek	Middle Fork Eel River	Unmanaged	Knopp, 1993	0.08
Canoe Creek	South Fork Eel River	Virtually Undisturbed	Knopp, 1993	0.24
Cedar Creek	Smith River	Unmanaged	Knopp, 1993	0.13
Clark Creek	Smith River	Unmanaged	Knopp, 1993	0.23
Elder Creek	South Fork Eel River	Virtually Undisturbed	Knopp, 1993 Lisle & Hilton, 1999 U.S. EPA, 1999a	0.07 0.09 0.01
Graham Gulch	Freshwater Creek	Managed Before 1953	Knopp, 1993	0.35
Honeydew Creek	Mattole River	Unmanaged	Knopp, 1993	0.10
Horse Linto Creek	Trinity River	Relatively Undisturbed	Lisle & Hilton, 1999	0.12
Little Lost Man Creek	Redwood Creek	Unmanaged	Knopp, 1993	0.26
Little North Fk Salmon River	Salmon River	Relatively Undisturbed	Lisle & Hilton, 1999	0.046
Little River	Pacific Ocean	Managed Before 1953	Knopp, 1993	0.22
Middle Fork Eel River	Eel River	Virtually Undisturbed	Knopp, 1993	0.13
Morrison Creek	Middle Fork Eel River	Unmanaged	Knopp, 1993	0.21
North Fork Caspar Creek	Caspar Creek	Managed Before 1900 & from 1985 to 1991	Knopp, 1993	0.27
North Fork Freshwater Creek	Freshwater Creek	Managed Before 1953	Knopp, 1993	0.19
Pilot Creek	Mad River	Unmanaged	Knopp, 1993	0.15
Priarie Creek	Redwood Creek	Managed Before 1953	Knopp, 1993	0.14
Russian Gulch	Pacific Ocean	Managed Before 1953	Knopp, 1993	0.33
South Fork Salmon River	Salmon River	Relatively Undisturbed	Lisle & Hilton, 1999	0.22
Squaw Creek	South Fork Eel River	Unmanaged	Knopp, 1993	0.24
Sugar Creek	Scott River	Relatively Undisturbed	Lisle & Hilton, 1999	0.15
Taylor Creek	South Fork Eel River	Relatively Undisturbed	Lisle & Hilton, 1999	0.11
Yew Creek	Mattole River	Managed Before 1953	Knopp, 1993	0.45

V* Target Value

The salmonid freshwater habitat target for V* is less than or equal to 0.21 or 21% (i.e., ≤ 21% of a pool's volume filled with sediment) applicable in 3rd order streams with slopes between 1% and 4%. The V* target is only applicable to streams that drain watersheds geologically composed of the Franciscan Formation. This target is based on the research by Knopp (1993) concerning V* levels in Northern California coastal watersheds which are relatively undisturbed.

V* Monitoring Recommendations

Monitoring should be conducted according to the methodology contained in ***Testing Indices of Cold Water Fish Habitat*** (Knopp 1993) or in ***Measuring the Fraction of Pool Volume Filled with Fine Sediment*** (Hilton & Lisle 1993). A minimum of 6 pools (with an maximum depth ≤ 4 times the riffle crest depth) per 1000 m of stream should be sampled and the mean value for the reach is to be compared to the target. Not all streams will contain a 1000 m reach of stream with at least 6 pools. Where a stream does not meet the minimum pool requirements, the V* target is not applicable.

14. TYPES OF MONITORING

Monitoring can take several different forms, have different objectives, and yet be called, ubiquitously, monitoring. Since the targets contained in this document are intended to be used be all those interested in the monitoring of sediment impacts on salmonid freshwater habitat, consistent nomenclature is necessary for clarity.

Implementation Monitoring

Implementation monitoring assesses whether activities and sediment control practices were carried out as planned. This type of monitoring can be as simple as photographic documentation, provided that the photographs are adequate to represent and substantiate the implementation of sediment control practices. Implementation monitoring is a cost-effective monitoring type because its purpose is to demonstrate that sediment control practices were properly installed and operated. On its own, however, implementation monitoring cannot directly link management activities to water quality, as no water quality measurements are made.

Upslope Effectiveness Monitoring

Upslope effectiveness monitoring is intended to determine, by assessing upslope conditions, if sediment control practices are effective at keeping sediment from being discharged to a water body. In other words, it is ". . .used to evaluate whether the specified activities had the desired effect" (Solomon 1989, as cited in MacDonald 1994, p. 7). This type of monitoring can be as simple as photographic documentation, provided that the photographs are adequate to represent and substantiate that the sediment control practices are effective.

Instream Effectiveness Monitoring

Instream effectiveness monitoring is intended to determine, by assessing instream conditions, if sediment control practices are effective at keeping sediment from being discharged to a water body. This type of monitoring may involve the use of visual observations, limited instream habitat monitoring of the salmonid freshwater habitat parameters described in this document, and/or grab samples for turbidity and suspended sediment in the water column. Instream effectiveness monitoring may be conducted upstream and downstream of the discharge point or before, during, and after the implementation of sediment control practices. Development of an instream effectiveness monitoring program is site-specific and may include, where appropriate, partnerships between landowners and state and federal agencies.

Compliance & Trend Monitoring

Compliance and trend monitoring is intended to determine, on a watershed scale, if salmonid freshwater habitat targets are being met, if sediment-related water quality objectives are being met, if the TMDLs are being met, and if beneficial uses are being protected from the adverse effects of excess sediment.

Different sources refer to this type of monitoring as either compliance monitoring or trend monitoring. For example, MacDonald et al. (1991) states that compliance monitoring is ". . . the monitoring used to determine whether specified water quality criteria are being met" (p. 7). In regards to the sediment impaired water bodies within the North Coast Region, the specified water quality criteria are the water quality objectives for sediment, settleable material, suspended material, and turbidity, as well as the salmonid freshwater habitat parameters contained in this document. The California Department of Forestry (CDF) and the Regional Water Boards across the State have developed general water quality monitoring conditions that use trend monitoring for monitoring "typically applied at a watershed scale, focusing on the combined effects of all watershed management activities for multiple years. Examples of Trend Monitoring objectives include . . . Determin[ing] whether Basin Plan water quality standards are achieved and maintained over time" (Fitzgerald 2004). In reality, monitoring for compliance with salmonid freshwater habitat targets, water quality objectives, and beneficial uses will produce data that is useful for analyzing trends in water quality. Therefore, Regional Water Board staff propose to call this monitoring requirement "Compliance & Trend Monitoring."

Compliance monitoring may involve the use of (1) wet weather turbidity, suspended sediment, and stream flow monitoring using a constant reading turbidimeter (sample taken once every fifteen minutes) and suspended sediment grab samples; and (2) salmonid freshwater habitat monitoring. The extent and degree of compliance monitoring will vary depending on the site, local conditions, land ownership patterns, and the extent of land management activities in an area.

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GLOSSARY

Aggradation	The long term process of sand, silt, gravel, sediment, etc. filling in a stream channel and raising the level or elevation of the stream bed.
Alevin	A young fish; especially a newly hatched salmon when still attached to the yolk sac.
Anadromous Fish	Fish that mature in the ocean but spawn in freshwater. The anadromous salmonids of concern in most of the North Coast Region are chinook salmon, coho salmon, and steelhead trout.
Backwater Pools	Pools found along channel margins and caused by eddies around an obstruction, such as boulders, root wads, or large woody debris. These pools are usually shallow and are dominated by fine-grain substrate. Current velocities are quite low in backwater pools.
Beneficial Use	Uses of waters of the state that may be protected against quality degradation including, but not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and the preservation and enhancement of fish, wildlife and other aquatic resources or preserves.
Benthic Macroinvertebrates	Aquatic invertebrates that are at least 0.5 mm in length and live primarily on the bottom substrate of streams and rivers. Benthic macroinvertebrates include worms, snails, clams, crustaceans, aquatic beetles, the nymph forms of mayflies, stoneflies, dragonflies, and damselflies, and larvel forms of caddisflies and true flies.
Class I Watercourses	According to Section 916.5, 936.5, 956.5 of the Forest Practice Rules, as may be amended from time to time, water class characteristics or key indicator beneficial uses of Class I watercourses include watercourses which contain (1) domestic water supplies, including springs, on site and/or within 100 feet downstream of the operation area; and/or (2) have fish always or seasonally present onsite, including habitat to sustain fish migration and spawning. Class I stream include historically fish-bearing streams.
Class II Watercourses	According to Section 916.5, 936.5, 956.5 of the Forest Practice Rules, as may be amended from time to time, water class characteristics or key indicator beneficial uses of Class I watercourses include watercourses which (1) have fish always or seasonally present offsite within 1000 feet downstream; and/or (2) contain aquatic habitat for non-fish aquatic species. Class II waters do not include Class III waters that are directly tributary to Class I waters.
Class III Watercourses	According to Section 916.5, 936.5, 956.5 of the Forest Practice Rules, as may be amended from time to time, water class characteristics or key indicator

	beneficial uses of Class I watercourses include watercourses which do not have aquatic life present, but show evidence of being capable of sediment transport to Class I and II waters under normal high flow conditions during and after completion of land management activities.
Class IV Watercourses	According to Section 916.5, 936.5, 956.5 of the Forest Practice Rules, as may be amended from time to time, water class characteristics or key indicator beneficial uses of Class I watercourses include man-made watercourses, which usually supply downstream established domestic, agricultural, hydroelectric supply or other beneficial uses.
Compliance & Trend Monitoring	Monitoring that, on a watershed scale, determines if water quality standards are being met.
D_{50}	Median particle diameter of a sampled population. The sampled population is composed of particles from the surface substrate of a stream or river that is sampled by a pebble count. For example, a D_{50} value of 65mm means that 50% of the substrate particles were smaller than 65mm and 50% were larger.
Degradation	The process of a stream bed lowering in elevation.
Embeddedness	The degree that larger particles such as gravels and cobbles are surrounded or covered by fine sediment, which effectively cements them into the channel bottom.
EPT Index	The percent composition of Ephemeroptera, Plecoptera, and Trichoptera, more commonly known as mayflies, stoneflies, and caddisflies. These organisms require higher levels of water quality and respond rapidly to improving or degrading water quality conditions. The EPT Index is calculated by adding the number of organisms in the EPT orders and dividing it by the total number of organisms. Multiply by 100.
EPT Taxa	The number of families in the Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) insect orders. This metric will decrease in response to disturbance.
Fry	A young juvenile salmon after it has absorbed its egg sac and emerged from the redd.
Impaired Waters	Water bodies that are not high quality waters. Impaired water bodies do not meet water quality standards and do not support the beneficial uses of those watersheds. Water bodies that are impaired by sediment may be identified on the List of Impaired Water Bodies for sediment impairment pursuant to Section 303(d) of the federal Clean Water Act.

Implementation Monitoring	Monitoring that assesses whether activities and sediment control practices were carried out as planned.
Instream Effectiveness Monitoring	Monitoring that, by assessing instream conditions, determines if sediment control practices are effective at keeping sediment from being discharged to a water body.
Interstices	The space between particles (e.g. space between sand grains).
Key Piece of LWD	As a narrative, a key piece of LWD is a log or root wad that (1) is independently stable in the stream bankfull width and not functionally held by another factor (e.g., not pinned by another log, buried, or trapped against a rock, etc) and (2) is retaining, or has the potential to retain, other pieces of organic debris that are likely to become mobilized in a high flow without the key piece. Numerically, key pieces are logs with a minimum diameter of twelve inches and minimum length 1.5 times the mean bankfull width of the stream channel type reach and the deployment site. Root wad key pieces have a minimum root bole diameter of five feet and minimum length of fifteen feet and minimum width at least half the channel type bankfull width. Key pieces of LWD are also those pieces that meet the following criteria found in Figure 5.
Percent Dominant Taxa	An index of benthic macroinvertebrate populations. Calculated by dividing the number of organisms in the most abundant taxon by the total n
Large Woody Debris	Wood with a minimum diameter of twelve inches and a minimum length of six feet. Root wads with a minimum diameter of twelve inches at the base of the truck are also considered LWD. Root wads do not have a minimum length criteria.
Lateral Scour Pools	Pools formed by flow impinging against a partial channel obstruction consisting of a log, a root wad, a boulder, or a bedrock stream bank. This is also known as channel constriction. The associated scour is generally confined to less than sixty percent of the wetted channel width.
Natural Sediment Discharge	Sediment waste discharge that cannot be attributed directly to anthropogenic sources or activities.
Percent Dominant Taxa	An index of benthic macroinvertebrate populations. Calculated by dividing the number of organisms in the most abundant taxon by the total number of organisms in the sample. Collections dominated by one taxon generally represent disturbed conditions.
Primary Pools	For 1st and 2nd order streams, primary pools are defined as having a maximum residual depth of at least two feet, occupy at least half the width of the low flow channel, and be as long as the low flow channel width. For 3rd and 4th

	order streams, a primary pool must have a maximum residual depth of at least three feet, occupy at least half the width of the low flow channel, and be as long as the low flow channel.
Recovery	Recovery will be achieved when water quality standards in the Basin Plan are attained and maintained.
Redd	A gravel nest or depression in the stream substrate formed by a female salmonid in which eggs are laid, fertilized and incubated.
Residual Pool Depth	The maximum depth of a pool minus the maximum depth of its downstream riffle crest (i.e., the depth of the pool at the point of zero flow).
Riffle	A shallow extending across a streambed and causing broken water.
Salmonids	Fish species in the family Salmonidae, including salmon, trout, and char.
Sediment	Any inorganic or organic earthen material, including, but not limited to: soil, silt, sand, clay, rock, bark, slash, and sawdust.
Sediment Control Practices	Sediment control practices include, but are not limited to: project design, engineering, and scheduling alternatives that control, prevent, minimize, and/or compensate discharges or threatened discharges of sediment waste.
Sediment-Related Water Objectives	Refers to suspended material, settleable material, sediment, and turbidity water quality objectives as found in Chapter 3 of the Basin Plan, as well as any other state and federal antidegradation policies and any other water quality objective that may be affected by sediment.
Sediment Waste	Sediment waste is defined as sediment that is generated directly or indirectly by anthropogenic activities or projects.
Sediment Waste Discharge Site	An individual, anthropogenic erosion site that is currently discharging or has the potential to discharge sediment waste to a water body.
Shannon Diversity	An index used to characterize species diversity in a community. The calculation of the Shannon Diversity requires a Level 3 Taxonomic Effort.
Smolt	A young salmon at the stage at which it migrates from fresh water to the sea.
Species Richness Index	The total number of taxa represented in the sample. Higher diversity can indicate better water quality. Also known as the Taxa Richness Index.
Stream	See watercourse.

Stream Class	The classification of waters of the state, based on beneficial uses, as required by the Department of Forestry in Timber Harvest Plan development. See definitions for Class I, Class II, Class III, and Class IV for more specific definitions.
Stream Order	The designation (1,2,3, etc.) of the relative position of stream segments in the drainage basin network. For example, a first order stream is the smallest, unbranched, perennial tributary which terminates at the upper point. A second order stream is formed when two first order streams join. Etc.
Taxa Richness	The total number of individual taxa. This metric will decrease in response to disturbance.
Thalweg	The deepest part of the stream channel at a given cross section.
Thalweg profile	The thalweg profile is the plot of the elevation of the thalweg as surveyed along the length of the stream. The profile appears as a jagged but descending line which is relatively flat at pool areas and descends sharply at cascades.
Tolerance Value	Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) and intolerant (lower values). This metric will increase in response to disturbance.
Turbidity	Turbidity is an optical measure of the amount of suspended particles in the water column, including suspended sediment, algae, organic matter, and pollutants. Turbidity can be measured in Jackson Turbidity Unite (JTUs) or Nephelometric Turbidity Units (NTUs), which are not interchangeable. While JTUs are suitable for evaluating gross changes in turbidity levels, NTUs offer more precise and sensitive measurements.
Upslope Effectiveness Monitoring	Monitoring that, but assessing upslope conditions, determines if sediment control practices are effective at keeping sediment from being discharged to a water body.
V*	A unitless measure of the fraction of a pool's volume that is filled by fine sediment and is representative of the in-channel supply of mobile bedload sediment
Wadeable Stream or River	One which an average human can safely cross on foot during the summer, low flow season while wearing chest waders.
Watercourse	Any well-defined channel with a distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel, or soil.

Water Quality Objective	The limit or level of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area.
Water Quality Standard	Consist of (1) designated beneficial uses of water; (2) water quality objectives to protect those designated uses; and (3) the federal and state antidegradation policies.
Waters of the State	Any surface water or groundwater, including saline water, within the boundaries of the state.
Watershed	Total land area draining to any point in a watercourse, as measured on a map, aerial photo or other horizontal plane. Also called a basin, drainage area, or catchment area.