APPENDIX E

to the NCWAP Watershed Assessment Methods Manual

Methods Manual
For
Water Quality Data Gathering and Analysis
for the
North Coast Watershed Assessment Program

by
staff to the

North Coast Regional Water Quality Control Board
5550 Skylane Boulevard, Suite A
Santa Rosa, CA 95403

Robert R. Klamt
Program Manager
707-576-2693

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Objectives and Tasks

The North Coast Watershed Assessment Program (NCWAP) was a multi-agency effort led by the California Resources Agency to provide watershed assessments for north coast streams to aid in watershed management and restoration decisions. The overall goals for the NCWAP are:

1. To develop baseline information about watershed conditions, in order to evaluate effectiveness of various programs over time;
2. To guide watershed restoration programs, e.g. targeting grant dollars to those projects which most efficiently and effectively recover salmonid populations, and assisting local watershed groups, counties, etc. to develop successful projects;
3. To guide cooperative interagency, nonprofit and private sector approaches to "protect the best" through stewardship, easement and other incentive programs;
4. To implement laws which require specific assessments:
   - To implement the Forest Practices Act by providing cumulative effects analyses for Timber Harvest Plans, sensitive watershed rules, Sustained Yield Plans, etc (at planning watershed scale);
   - To implement the Clean Water Act and Porter-Cologne Water Quality Act by providing analyses of the assimilative capacity of the watershed as necessary to meet water quality objectives (hydrologic unit or super planning watershed scale);
   - To implement the Streambed Alteration Act by providing better information about watershed stability and fish habitat (site scale).

Tasks specific to the North Coast Regional Water Quality Control Board were:

1. Data Compilation/analysis: compile, catalogue, and interpret water quality and related data for its relevance for interagency watershed assessment use
2. Review and comment: review team products related to analysis of watershed processes and functions, human influences on instream and watershed environments, and limiting factors for salmonids, and evaluate their relevance for water quality protection and TMDL development
3. Outreach: provide information to watershed stakeholders on nonpoint source, rangeland water quality and TMDL programs, and assist with workshops to facilitate public involvement in the watershed assessment process.

Management Structure and Strategy

The Regional Water Board office is divided into four major program areas: Timber Harvest, Site Cleanup, Watershed Protection, and Watershed Management. The three units in the Watershed Management Division are closely allied with regard to monitoring, watershed assessment, water quality standards, and TMDL development. The NCWAP for the Regional Water Board was administered by the Watershed Assessment and Monitoring Unit (WAMU) within the Division. The TMDL Development Unit and Basin Planning Unit closely coordinated with the WAMU, sharing products and expertise.

The WAMU has experience and knowledge in data analysis, GIS, database, public outreach, monitoring design, water quality sampling, geology, watershed processes, and hydrology.

The TMDL Development Unit develops TMDLs on a schedule set out by a court ordered consent decree for many of the basins targeted by the NCWAP. TMDL development relies heavily on watershed data.

The Basin Planning Unit is responsible for Basin Plan review and updating. Part of the unit is funded through a reimbursable contract with the Sonoma County Water Agency (SCWA) to review Basin Plan standards for compliance with the Endangered Species Act. Assessment of watershed water quality data will include comparison to existing and proposed water quality objectives that come out of that project. Additionally, the SCWA is interested in providing assistance to salmonid recovery planning efforts in a portion of the north coast watersheds area that includes data gathering and analysis. The Klamath Resource Information System (KRIS) is the information and analysis platform for those data and analyses.

Having each of these units under a single division enhances coordination and cross-pollination. Consistency in approaches are assured through frequent strategy sessions and information sharing.

The WAMU coordinates with the Timber Harvest Division regarding timber issues. Considering that all the NCWAP target watersheds are forested, this coordination is essential to proper functioning of the WAMU. Additionally, the Surface Water Ambient Monitoring Program (SWAMP) is overseen by the WAMU and was closely coordinated with the NCWAP.

<u>NCWAP interaction with the TMDL and Surface Water Monitoring programs</u>

NCWAP has a significant interface with the TMDL program as well as the Surface Water Monitoring Program (SWAMP). TMDL development uses watershed information (both historic and recent) for geologic, land use, fisheries, climate, water resources, and water quality factors that may influence the impairment of a beneficial use in a stream.

For instance, a stream listed as impaired for temperature; high water temperatures impair the salmonid fishery beneficial use. NCWAP assessments provide information on water temperatures and stream flows gathered from landowners and agencies doing that type of monitoring. Additional information is made available on the sensitivity of the fish resources to increased temperature, as well as landscape scale information on stream aspect, shading, and climate. The TMDL developer uses those data to model temperature in the watershed and develop scenarios for improving conditions (see Attachment A-3 for a more detailed example).

Another example is a stream listed for sediment-caused fishery and water supply impairments is required to have a TMDL developed that defines sediment sources, estimates delivery rates from the sources, estimates the amount of sediment that can move through the system and still maintain the beneficial uses (the so-called “TMDL” or Total Maximum Daily Load), estimates the reduction in sediment loads from the sources to restore the beneficial uses (i.e., attain the “TMDL”), allocates responsibility for load reductions (likely on a by-source approach instead of specifically naming parties), develops targets by which to gage the success of load reductions, and lays out a monitoring plan to follow implementation of load reductions and the response of the stream and beneficial uses to those reductions (the degree to which targets are attained and are appropriate). The TMDL process is iterative, with TMDLs modified by new information, such as more local data to develop targets. Logically, the NCWAP provided a significant portion of the basic watershed information to support development and implementation of TMDLs (see Attachment A-4 for a discussion of estimating sediment delivery).

The development of targets for a TMDL is based on beneficial use attainment. In essence, water quality objectives (WQOs) set by the Regional Water Board in its *Water Quality Control Plan for the North Coast Region* (Basin Plan) must be attained to support beneficial uses. TMDL targets are not enforceable, rather intended to gage the success of load reductions. The Basin Plan does not contain numeric WQOs for sediment, rather narratives that say no sediment in amounts deleterious is allowed. The job of the

TMDL developer is to interpret those narrative objectives and develop specific measurable TMDL targets consistent with the WQO. Literature searches, existing local information, modeling, and professional judgement are used to develop targets. Those targets are corollary to the reference conditions used in NCWAP for limiting factors analysis and water quality assessment.

Monitoring under the SWAMP benefits both the NCWAP and TMDL programs, in the assessment phase as well as in the follow-up phase. The SWAMP is a two-pronged approach: 1)long-term monitoring sites for trend analysis, and 2)rotating intensive basin surveys. The rotation schedule was closely coordinated with the NCWAP assessment schedule to provide additional and current information on water quality parameters to the NCWAP assessment.

The Basic Approach

The North Coast Regional Water Quality Control Board (NCRWQCB) compiles, analyzes, and presents water quality information from their own files, other agencies, landowners, and watershed groups. Whenever possible, the NCRWQCB collects additional new field data to supplement those existing data and provide current information.

While it is difficult in many situations to identify specific causes of watershed impairment, collection of water quality, biological, and related sediment parameters provides a perspective on watershed health. Assessing water quality and comparing it to baseline conditions is a useful way to gauge success of management practices designed to reduce human impact on the watershed. Likewise, it is useful for pointing out problem areas to address, and properly functioning areas to protect.

Water temperature, dissolved oxygen, turbidity, suspended and bedload sediment, nutrients, and chemical pollutants are important components of water quality that affect fish. Water quality affects all salmonid life stages and influences growth, behavior, and disease resistance.

Water quantity may affect water quality in a variety of ways, including changes in chemistry, water temperature, and sediment transport dynamics. Chemical changes are not expected to be a major factor in most coastal watersheds. However, the amount of water available to the stream affects the water chemistry when land uses produce nutrient and other chemical inputs. Stream flow, in addition to air temperature and solar radiation, may also affect water temperatures. Alterations in the flow regime during winter periods may have a profound effect on sediment transport dynamics as well, since stream flow in large part determines the power applied to the channel.

Water quality data are sparse for most North Coast watersheds. Routine sampling occurred decades ago in some watersheds, but only occasional observations are available for the last 15 years or so. Exceptions apply where local watershed groups or industrial timber companies have conducted sampling. The NCRWQCB collected field data where possible, and relied heavily on landowners and watershed groups for additional information, especially water temperature data.

Questions and Issues

New data will update existing older data, as well as improve our understanding of how well existing water quality meets objectives for the protection of beneficial uses. Current data support the limiting factors analysis, provide some idea of any identified trends, and point out areas for riparian evaluations and rehabilitation.

Currently, assessments of instream sediment conditions are based on aerial photo interpretations of geomorphology and on professional judgment. Collection of up to date information on instream channel characteristics provides a basis on which to make more informed judgments. Water quality data are compared to water quality objectives. Areas with anomalous results are reassessed to determine if unique conditions exist, or if problems are occurring from natural or human influences. New data provide information for comparison to older data, and a baseline from which to measure changes in the future. New field data will assist in addressing water quality assessment questions:

- *Is basic water column chemistry meeting Basin Plan water quality objectives and otherwise supportive of beneficial uses, especially drinking water supplies, cold water fishes, and contact and non-contact recreation?*

- *In a general sense, what are the current water temperature conditions relative to life history requirements of salmonid species?* The detail of answers to this question is variable, depending on the spatial and temporal distribution of temperature sites.

- *Is excessive sediment impairing coldwater fish habitat or otherwise compromising beneficial uses?*

- *Are there specific water quality problems identified by the data?*

- *Are there specific temporal trends in water quality?*

Input from local landowners and watershed groups may modify the above questions, or add to them, allowing the assessment to be tailored to the specific watershed. This sensitivity to local issues and needs allows NCWAP to adapt to local conditions and new information. When local issues are beyond the scope of NCWAP, future studies are recommended.

Data Sources and Gaps

Sources of current water quality data are limited, but include agencies, large industrial timber landowners, and local watershed groups. Gathering these data and evaluating their utility in watershed assessment identifies numerous gaps, both temporally and spatially. New data collection is aimed at filling those gaps. To the degree that programs like SWAMP and local watershed groups continue data collection after a NCWAP assessment, data can be collected into the future, creating fewer temporal and spatial gaps and enhancing future assessments.

Data collected under the SWAMP program provides NCWAP with a more current assessment of conditions. The degree to which SWAMP data is available depends on SWAMP program staffing and laboratory resources. Field sampling is dependent on landowner access to a large degree.

Data Gathering, Collection, and Analysis Protocols

The sections below describe the Regional Water Board’s methods for gathering information from our files, as well as other agencies, landowners, watershed groups, and other interested parties. In addition, the SWAMP is coordinated with the NCWAP and will provide new information to be incorporated into the assessments.

Often our methods are taken directly or are modifications of others’ methods. For that reason, the discussions below are essentially summaries, with attachments referenced for more detail.

Data Gathering
Data gathering is the process of compiling existing data from Regional Water Board files, other agency files, and other sources. The Regional Water Board has several types of water quality information sources within its office, all of which will be evaluated for inclusion into a watershed assessment: Timber Harvest Plan files, water quality monitoring files, grant files, EIRs and other reports. Sources outside the office include data and reports from other agencies (including water rights and diversion information), watershed groups, landowners, and public interest groups.

As data are gathered, the location and general characteristics of the data are catalogued in a computerized database. Catalogued data include non-water quality data related to a watershed assessment that we make available to other agencies. We focussed our energies on the watersheds scheduled for a specific fiscal year. However, as we found data from a particular landowner or agency that overlapped into another NCWAP watershed, we likewise categorized those data to assist in future data gathering efforts.

Data Collection
A basic assumption used in assessment is that watershed conditions are integrated at the stream reach or sub-watershed level. Experience has shown that water quality and biological parameters are often useful in developing a perspective on watershed conditions. It is important to note that water quality and biological parameters include physical as well as chemical characteristics of water column quality, streambed substrate quality, and assemblages of aquatic life.

New water quality data collection for NCWAP occurs primarily through the North Coast Regional Water Quality Control Board's Surface Water Ambient Monitoring Program. The schedule for the Surface Water Ambient Monitoring Program (SWAMP) has been coordinated with NCWAP to provide additional and current information on water quality for watershed assessments. Access to private lands in many cases restricts the extent to which field data are collected.

The SWAMP sampling design is stratified by sub-watershed and tempered by local knowledge and access concerns. Site selection is based on SWAMP needs and goals as well as any special identified NCWAP needs. The goal is to characterize water quality at the sub-watershed level. Generally, data collection stations are at the terminus of a sub-watershed or in conjunction with other NCWAP reach surveys. Station locations are documented for use by all NCWAP personnel and for possible subsequent use by landowners and groups.

SWAMP parameters include: macroinvertebrates, water chemistry and heavy metals (minerals, nutrients, pH, dissolved oxygen, conductance, temperature, metals scan), chlorophyll-a, screening for xenobiotic estrogens, channel geometry, sediment transport, turbidity, bacterial analyses, and MtBE and BTEX analyses in some lakes (obviously not all useful in the NCWAP). SWAMP also includes funding for stream flow gage installation was coordinated with Dept of Water Resources. Data loggers are used at selected sites for "round-the-clock" monitoring of DO, pH, conductance, and temperature.

More detail is provided in Attachment A, *Surface Water Ambient Monitoring Program—Data Collection Protocols*.

Data from other agencies, landowners, and watershed groups are evaluated for their utility to the assessment by employing the concepts presented in the *Data Quality Categories* section. Those data deemed appropriate for use are incorporated into the assessment.

The following methods are employed to collect new field data.

Water Chemistry: Data quality assurance and control techniques common to water quality data collection are employed during collection of new water chemistry data. The SWAMP Quality Assurance Plan details the specific protocols and procedures for water chemistry sampling. It can be downloaded from the State Water Board's website at: http://www.swrcb.ca.gov/swamp /qapp.html.

Grab Sample Collection: Water quality samples are obtained from the centroid of flow, if at all possible, as grab samples following U.S. Geological Survey protocols (USGS 1999). When flows are too high for wading, a thief-type sampler (Kemmerer bottle or equivalent) is suspended into the centroid of flow from bridge crossings or from shore (in well-mixed locations). Grab samples to be analyzed by contract laboratories are collected in appropriate containers prepared by the laboratory. They are labeled, preserved, transported, and analyzed according to SW-846 protocols (USEPA 1998) and USGS (1999). Field parameters (dissolved oxygen, temperature, pH, conductance) are measured on site using portable field meters.

Site conditions, including location, access, special considerations, photos, and sampling point location(s), as well as climatic and hydrologic variables, are documented on waterproof forms. This allows standardization of information, and ensures that all variables are recorded. Flow measurements are obtained when possible and according to the methods described by USGS (1999).

Automated Sample Collection: Data loggers are effective in collecting physico-chemical measurements on short time intervals over many days without constant staff oversight. Data are stored on internal memory chips and downloaded to a computer in the field or office for further data analysis.

Temperature: Temperature loggers manufactured by Onset® Corp., programmed to sample at least every 96 minutes are used. With 8K of internal memory, a full summer of data can be collected. Additionally, the 96-minute sampling interval is the minimum specified in the cooperative effort developed by the Forest Science Project (FSP 1998) to detect daily maxima. A multi-agency temperature monitoring consortium in the Russian River watershed modified the FSP protocol and standardized data downloading from remote loggers (Attachment A-2).

Multi-parameter: The loggers are calibrated and pre-programmed to collect conductance, pH, dissolved oxygen, temperature, depth, and other parameters on a predetermined interval, placed in the water body, and left to record the data on internal memory per protocols detailed in USGS (2000). Once the sampling period is complete, they are returned to the lab for post-calibration checks, and the data downloaded and imported into a spreadsheet for analysis. Typically, the probes need servicing every three or four days, depending on the water body. A four-day deployment can accommodate sampling at 15-minute intervals, providing a dense data set around the clock.

Instream channel characteristics: Stream channel and streambed metrics, such as V*, D50, substrate cores, etc. have utility in describing channel conditions, sediment movement, and recent events, ultimately helping to describe the quality of cold water fish habitat (Attachment A-6). Analysis of those data with other watershed-level data is useful to NCWAP as well as sediment TMDL development efforts.

Percentage of Residual Pool Volume Occupied by Fine Sediment Deposition (V-star or V*): Pool volume has consistently been identified as an important aspect of pool habitat and appears to be vulnerable to increased sediment loads from watershed disturbances. Reductions in pool volumes reduce summer and winter holding capacities for salmonids (Stuehrenberg 1975, Klamt 1976, Bjornn et al. 1977). Bjornn et al. (1977) found that the effect of introducing enough fine sand into a third order stream pool to reduce its volume by half (a V* of 0.5) and to reduce fish numbers by two-thirds. Since pool habitat has often been correlated with the size and volume of pools (Heifetz, et al. 1986 and Lau 1994), it follows that decreasing a pool's volume by introducing excess sediment will simplify pool habitat, also resulting in decreased substrate diversity.

Channel Cross-sections: Channel cross-section measurements provide valuable information on the shape and dimension of a stream channel and its relationship to the flood plain. Coupled with other measurements, cross-sections provide valuable information on transport and storage of sediment in the stream channel. Common parameters include width/depth ratio, gradient (slope), bankfull depth, flood prone area, and sinuosity.

Thalweg profiles: Pools, logs, boulders, riffles, etc. add complexity to the channel that affect sediment transport, channel form, and fish habitat. The variability of the thalweg along a longitudinal axis in the stream is a good measure of complexity of the wetted stream channel. Changes in the thalweg profile reflect overall changes in the channel complexity, which result from channel-forming forces. Reduction of complexity occurs with excessive sediment introduction. Increased complexity indicates a recovery from such a condition. Thalweg profiles provide information on existing conditions, but are also useful in trend analysis over the long term.

Pebble counts: One of the most widely used methods of sampling grain size from a streambed is the pebble count technique (Wolman 1954). It can be used as a simple and rapid stream assessment method to help determine if land use activities or natural land disturbances are introducing fine sediment into streams (Potyondy and Hardy 1994). Pebble counts are routinely used by geomorphologists, hydrologists, and others to characterize the bed material particle size distributions of wadeable, gravel bedded streams. The procedures have been adapted in fisheries studies as a preferred alternative to visually characterizing surface particle sizes commonly used during instream flow studies (Kondolf and Li 1992). The methodology is best applied in gravel and cobble streams with a single channel. It is not applicable to lower gradient, sand-bed dominated channels.

Streambed Cores: The only way to determine the composition of the streambed below the surface is to remove a core and analyze it for particle size distribution. Methods of core sampling include McNeil style core samplers, freeze-core samplers, and shovels. Basically, a sample is removed from the streambed and run through sieves to determine the amount of material within particle size categories.

Biological sampling: Macroinvertebrate samples are obtained using "D" nets per the California Stream Bioassessment Procedure (CDFG 1999). Sampling sites are selected per the guidance provided in those protocols as well as knowledge of the watershed and land uses upstream of the site (Attachment A-1).

Qualitative observations of algal growths are supplemented by grab samples. Identification of algal assemblages is performed at the Regional Water Board laboratory, and relative abundance is delineated.

Other interesting, descriptive, or unusual biota are noted at the time of sampling to provide additional qualitative information on the relative health of the water body.

Data Analysis

Data obtained from other sources most often are provided in summary format. For instance, water temperatures are commonly collected from temperature loggers as described above. Data loggers take temperature readings many times during a day (often exceeding 24 times per day). However, the component data (hourly readings) usually are not made available. Instead, we most often are provided with summary statistics, such as maximum, mean, minimum, and maximum weekly average temperature for the data collection period. In these cases, we are unable to evaluate the data as described below. Instead data quality is evaluate and summary statistics are used. Figure 1 is an example of a summary plot for water temperatures in the North Fork Gualala River.

Data that are collected by the NCRWQCB or for which we are provided the component information are treated as follows:

> Data are entered into a database and converted to formats appropriate for analysis of the information, e.g., spreadsheets for dissolved oxygen, flow, and temperature. Data analysis is tailored to data type and quality. For example, water temperature data from continuous data loggers is evaluated using raw data plots over time and cumulative distribution plots against water quality criteria, TMDL targets, or water quality objectives (WQOs) (Table 1.) This allows determination of the frequency of exceedances (percent of observations and number of days), duration of exceedances (how many hours was a particular standard exceeded in a day), and maximum daily excursions. For example, Figure 2 is a raw data plot of continuous water temperatures graphed with the EMDS temperature ratings.

The cumulative distribution of the same raw data is depicted in Figure 3. This type of plot is used to determine the percentage of time that particular criteria or levels are met or exceeded. In this example, water temperatures are within the EMDS “suitable” ranges about 3 percent of the time, in the “undetermined” area about 7% of the time, in the “unsuitable” ranges about 90% of the time. The species is subjected to temperatures outside the “suitable” ranges about 97% of the time, but never exceeding the short-term maximum.

Table 1. Water quality criteria and Basin Plan objectives used in assessment of water quality data.

Water Quality Parameter	Basin Plan Objective	TMDL-type targets	Criteria from the literature, etc.	References
pH	6.5-8.5			Basin Plan, p 3-3.00
Dissolved Oxygen				
Warm water fisheries	5.0 mg/L			Basin Plan, p 3-3.00
Cold water fish rearing	6.0 mg/L			Basin Plan, p3-3.00
Cold water fish spawning	7.0 mg/L			Basin Plan, p 3-3.00
Cold water fish spawning at critical periods	9.0 mg/L		10 mg/L or 100% saturation, whichever is larger	Basin Plan, p. 3-3.00 NCRWQCB 2000, p. 19
Temperature				
No alteration that affects BUs [1]				Basin Plan, p 3-3.00
No increase above natural > 5 F				Basin Plan, p 3-4.00
Cold water fish rearing		64 F MWAT [2]		NCRWQCB 2000, p.37
Cold water fish rearing		75 F daily max		NCRWQCB 2000, p. 37
Cold water fish spawning at critical periods		56 F MWAT		NCRWQCB 2000, p. 37, 38
Sediment				
Settleable matter	not to cause nuisance or adversely affect BUs			Basin Plan, p 3-2.00
Suspended load	not to cause nuisance or adversely affect BUs			Basin Plan, p 3-2.00, 3-3.00
Turbidity	no more than 20 percent increase above natural occurring background levels			Basin Plan, p 3-3.00
Percent fines <0.85 mm in fish-bearing streams [3]		<14%		Garcia TMDL, p. 2
Percent fines <6.5 mm in fish-bearing streams		<30%		Garcia TMDL, p. 2
V* in 3rd order stream with slopes 1-4 %		<0.21 (mean) <0.45 (max)		Garcia TMDL, p. 2
% of Stream Length in Riffles (in reaches <2% slope)			<30%	NCRWQCB 2000, p. 54
Median particle size (d_{50}) in 3rd order streams with slopes 1-4 %		>69mm (mean) >37mm (min)		Garcia TMDL, p. 2
Thalweg Profile		Increasing variability about the mean		Garcia TMDL, p. 2
Pool depth – 1st, 2nd order streams			>0.5 meters	NCRWQCB 2000, p. 54
Pool depth – 3rd, 4th order streams			>1 meter	NCRWQCB 2000, p. 54
Pool depth – 5th order and higher			>1.5 meters	NCRWQCB 2000, p. 54

[1] BUs = Basin Plan beneficial uses

[2] MWAT=maximum average weekly temperature, to be compared to a 7-day moving average of daily average temperature

[3] fish-bearing streams=streams with cold water fish species

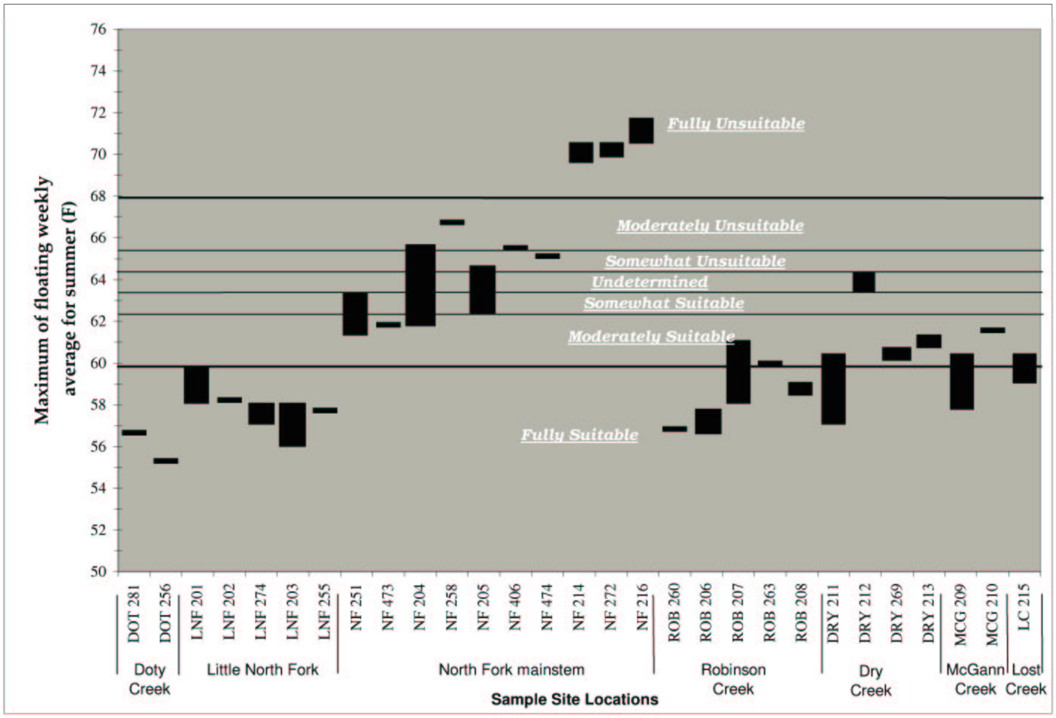

Figure 1. Summary of MWAT values for the North Fork Gualala River Subbasin

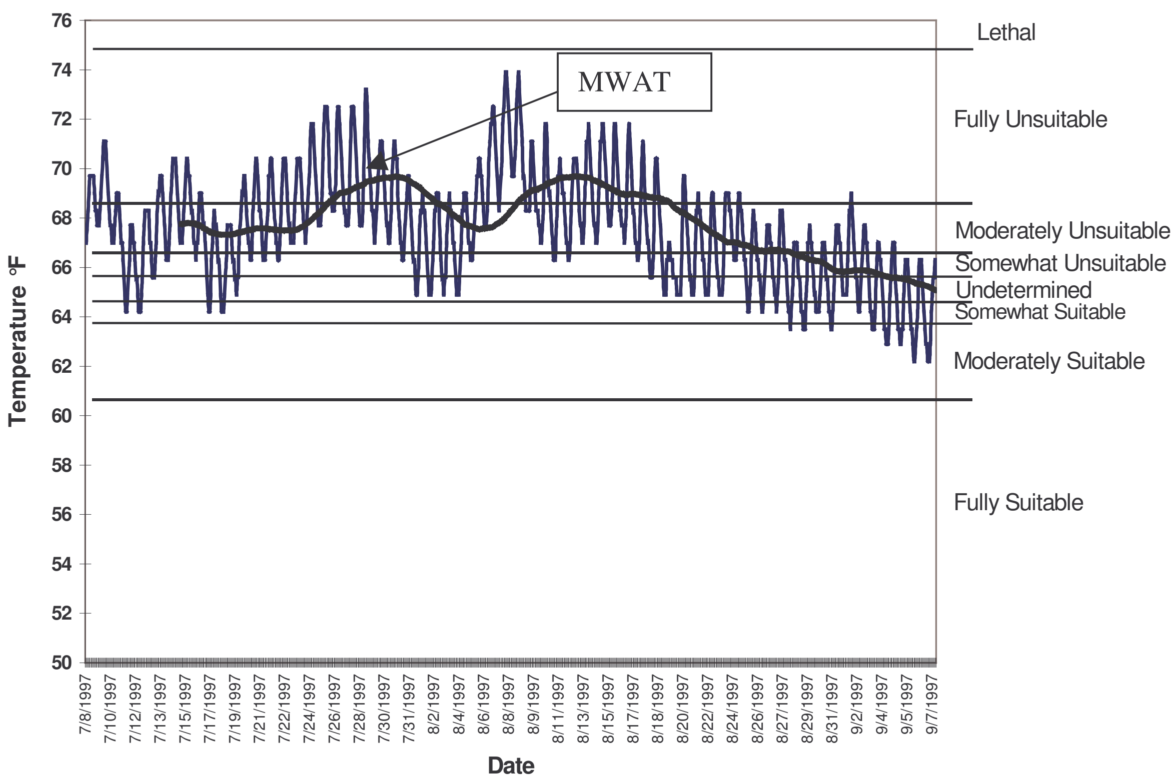

Figure 2. Raw Data Plot of Continuous Water Temperatures with EMDS Ratings

Other water quality parameters (including flow and diversion information) are subjected to similar analyses using raw data plots and cumulative distribution plots, as well as statistical methods (e.g., nested analysis of variance to analyze data from stations in different sub-watersheds).

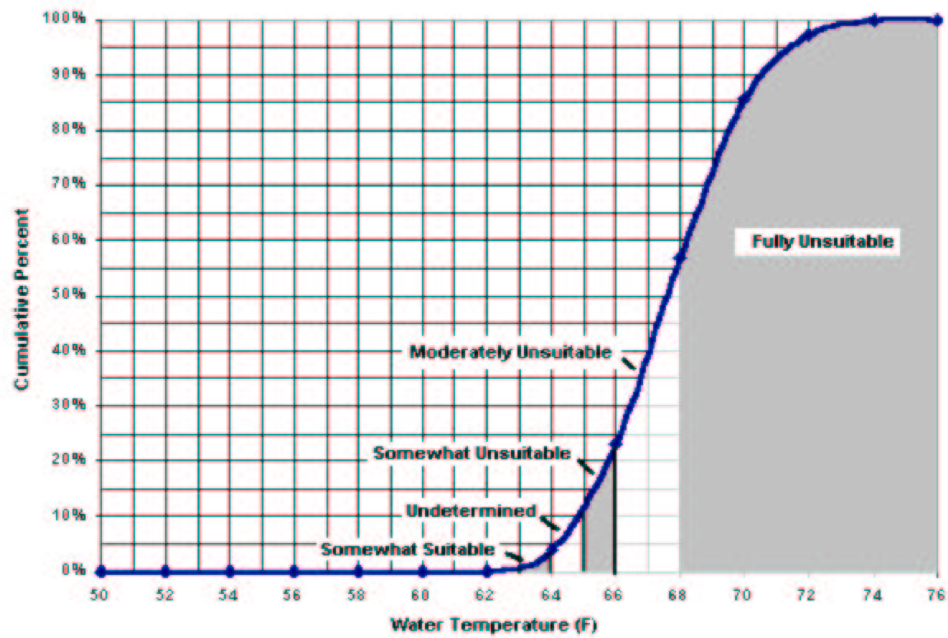

Figure 3. Cumulative Distribution of Water Temperature Data with EMDS Ratings

Limitations

The usefulness of these data is limited by the clarity of connections among watershed perturbations and the stream. Temporal considerations come into play in those links, with some current physical conditions the result of past disturbance in the watershed. Likewise, short-term disturbances not measurable today, may have translated to effects in the stream that are evident from distribution, diversity, and abundance of the biota.

Other factors that limit water quality assessments include the numbers and spatial density of measurements, the time frame for assessment (shorter equates to less detailed analysis), and limitations on access for data collection due to landowner concerns.

Data Quality Categories

General data quality categories apply to data gathered from other sources as well as new data collected by the program. We identified four categories of data quality for the program:

A. **Excellent** (suitable for the highest detail and most robust analysis)
B. **Good** (suitable for most watershed assessment needs, characterizes a process or condition providing proof from which to draw specific conclusions)
C. **Fair** (characterizes a process or condition on a broad basis to provide a perspective)
D. **Poor** (useful for screening or broadly qualified statements)

The criteria considered in assigning a data quality category are:

- Purpose/objectives
- Sampling design
- Reliability
  - Resolution
  - Precision and accuracy
  - Measurement method
  - Representativeness
  - Documentation
  - Verification (QA feedback on "certified" collectors, etc.)
- Robustness (number of measurements or density of data)

The relative importance of the factors and the scheme for assigning existing data to categories (and designing a program to meet a specified level with new data) are presented in a matrix, Table 2.

Quality Assurance/Quality Control
Quality assurance combines training and feedback with quality control checks for accuracy and precision. Samplers will be trained and their work checked on a routine basis. Data sheets and checklists will facilitate training and provide consistency to the collection of new data under SWAMP, as well as provide important documentation for meta-data needs.

Quality control involves checks on accuracy and precision with procedures to follow when a measurement does not fall within acceptable ranges. Strict QA/QC procedures call for pre- and post-run calibration and routine precision checks. Meters are calibrated prior to sampling. Accuracy is checked at the end of a sampling run or every five samples, whichever is more frequent. A duplicate sample is collected at the first station in a sampling run and analyzed for pH, conductance, and turbidity at the end of the run, to provide information on overall precision. All data are recorded on waterproof data sheets. Meter calibrations, precision checks and accuracy checks are documented. The SWAMP Quality Assurance Project Plan can be downloaded from the State Water Board's website at: http://www.swrcb.ca.gov/swamp /qapp.html.

Report Generation
A report describing water quality data and assessing those data with regard to current Basin Plan water quality objectives and other references is generated for each watershed. Graphical representations accompany those descriptions. Raw data are provided in electronic form and actual data tables included in each report to the extent it is reasonable (size limited).

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Table 2. Preliminary data quality categories for the NCWAP and SWAMP programs.

Attribute or criterion	Poor	Fair	Good	Excellent
Purpose/Objectives				
Broad	X	X		
Specific			X	X
Sampling Design				
density not sensitive to tribs, etc.	X			
density sensitive to tribs, etc.		X	X	
density sensitive to specific problem			X	X
seasonality not addressed	X			
seasonality addressed		X	X	X
statistical design incorporated			X	X
Reliability				
Detection limit & resolution				
Low	X			
Medium		X		
High			X	X
Precision				
+/- 50%	X			
+/- 20%		X		
+/- 10%			X	X
Accuracy & closeness to MDL				
@ MDL	X			
< 2x MDL		X		
>2x MDL			X	X
Measurement Method (tied to accuracy)				
"Litmus"	X			
pocket meter		X		
good field meter			X	X
lab quality meter				X
Representativeness				
streamside collection (mixing unverified)	X	X	(depends on parameter)	
centroid, well-mixed streamside		X	X	X
other factors (swimmers, etc.)	X	X		
Documentation (relative to the category)	X	X	X	X
Verification				
no calibration or not documented	X			
calibrated at start		X		
post-calibrated as well			X	
QC records			X	X
trained personnel		X	X	
OJT checks			X	X
Robustness (depends, but …)				
< 5 samples	X			
5-10 samples		X		
10-20 samples			X	
> 20 samples				X

ATTACHMENT A

Surface Water Ambient Monitoring Program – Data Collection Protocols
September 24, 2003

INTRODUCTION

The Surface Water Ambient Monitoring Program (SWAMP) has a two-pronged approach: 1)long-term monitoring sites for trend analysis, and 2)rotating intensive basin surveys. SWAMP has significant interface with other programs in the Region, most notably are the North Coast Watershed Assessment Program (NCWAP) and the TMDL development program. Both of those programs benefit from the data collected through SWAMP. Due to the interdependency of those programs, with NCWAP feeding information into TMDL development, the SWAMP rotation schedule was closely tied to the NCWAP assessment schedule to provide additional and current information on water quality parameters to the NCWAP assessment.

SWAMP parameters include: bioassessment of instream macroinvertebrates, water chemistry and heavy metals (minerals, nutrients, pH, dissolved oxygen, conductance, temperature, metals scan), chlorophyll-a, vitellogenin screening for endocrine disrupting compounds, channel geometry, sediment transport, turbidity, bacterial analyses, and MtBE and BTEX analyses in selected lakes. SWAMP also includes funding for stream flow gage installation that is being coordinated with Dept of Water Resources and U. S. Geological Survey. Multi-parameter data loggers are used at selected sites for "round-the-clock" monitoring of DO, pH, specific conductance, and temperature.

SITE SELECTION

Sampling design is stratified by sub-watershed and tempered by local knowledge and access concerns. Site selection is based on SWAMP needs and goals as well as any special NCWAP needs that were identified. Basically, we wish to characterize water quality for a reach or subwatershed. Generally, data collection stations are at the terminus of a subwatershed.

For the rotating intensive basin surveys, additional considerations are the known or suspected pollution problems, and the location of reach surveys by other agencies. The intent is to cover suspect areas as well as be responsive to opportunities with other agencies.

Permanent stations are left behind as a rotation occurs, and receive quarterly sampling every year. Rotation back into a watershed is planned on a five-year basis. The rotation schedule is:

Fiscal Year	Watershed Management Area (WMA)	WMA Description
2000-01	North Coastal WMA	Coastal streams not included in other WMAs, like Smith R, Mattole R, etc.
2001-02	Humboldt and Eel WMAs	Redwood Cr south to include the Eel R
2002-03	Klamath WMA	Klamath R watershed, except Trinity R
2003-04	Trinity WMA	Trinity R watershed
2004-05	Russian/Bodega WMA	Russian R watershed and streams south to include Stemple Cr
2005-06	North Coastal WMA	Coastal streams not included in other WMAs

FIELD OBSERVATIONS

Sampling Site Observations

Site conditions including location, access, special considerations, photos, and sampling point location(s), as well as climatic and hydrologic variables are documented on waterproof forms. This allows standardization of information, and ensures that all variables are recorded. Flow measurements are obtained when possible and according to the methods described by USGS (1999).

Strict QA/QC procedures call for pre- and post-run calibration and routine precision checks. Meters are calibrated prior to sampling. Accuracy is checked at the end of a sampling run or every five samples, whichever is more frequent. A duplicate sample is collected at the first station in a sampling run and analyzed for pH, conductance, and turbidity at the end of the run, to provide information on overall precision. All data are recorded on waterproof data sheets. Meter calibrations, precision checks and accuracy checks are documented.

Grab Sample Collection

Samples are hand-collected from the centroid of flow at mid-depth where possible. When flows are too high for wading, we use a thief-type sampler (Kemmerer bottle or equivalent) suspended into the centroid of flow from bridge crossings, and select well-mixed locations to collect from shore in other locations. Grab samples for contract laboratory analysis are collected in appropriate containers prepared by the laboratory, labeled, preserved, transported, and analyzed according to SW-846 protocols (USEPA 1998) and USGS (1999).

Water quality data from field instruments are collected as above along with grab samples. Meters are calibrated prior to sampling and accuracy checked at the end of a sampling run or every five samples, whichever is more frequent. A duplicate sample is collected at the first station in a sampling run to be analyzed for pH, conductance, and turbidity at the end of the run, providing information on overall precision.

All data are recorded on waterproof data sheets and meter calibrations, precision checks and accuracy checks documented. In the event a measurement exceeds a QC warning or control limit, we follow the procedures outlined in the SWAMP Quality Assurance Project Plan, available at: http://www.swrcb.ca.gov/swamp /qapp.html.

Chemical constituents for contract laboratory analysis include: standard minerals, nutrients, total organic carbon, heavy metals, chlorophyll, pesticides/herbicides.

Field parameters, beyond basic observations, include: pH, dissolved oxygen, water and air temperatures, specific conductance, turbidity, relative humidity, wind speed, flow rate.

Biological Sample Collection

Macroinvertebrate samples are collected using "D" nets per the *California Stream Bioassessment Procedure* (CDFG 1999) Attachment A-1. Sampling sites will be selected according to guidance provided in those protocols as well as knowledge of the watershed and land uses upstream of the site.

Qualitative observations of algal growths are supplemented by grab samples. Identification of algal assemblages are performed at the Regional Water Board laboratory, delineating types by relative abundance in a sample.

Other interesting, descriptive, or unusual biota are noted at the time of sampling to provide additional qualitative information on the relative health of the waterbody.

Automated Sample Collection

Data loggers are effective in collecting physico-chemical measurements on short time intervals over many days without constant staff oversight. Data are stored on internal memory chips and downloaded to a computer in the field or office for further data analysis.

Temperature

We use temperature loggers manufactured by Onset® Corp., programmed to sample at least every 96 minutes. With 8K of internal memory, a full summer of data can be collected. Additionally, the 96 minute sampling interval is the minimum specified in the cooperative effort developed by the Forest Science Project (FSP 1998) to detect daily maxima. A multi-agency temperature monitoring consortium in the Russian River watershed modified the FSP protocol and standardized data downloading from remote loggers. We use that protocol in the SWAMP and other temperature sensor deployments (Attachment A-2).

Basic considerations for site selection are presented in the modified protocol. The primary use of the data is for characterizing a stream reach, so placement is in a well-mixed flowing section of the stream that is representative of a reach. Data sheets for calibration, deployment, and site conditions accompany the data for each deployment.

Analysis of continuous temperature data with other watershed-level data occurred as part of the NCWAP and TMDL development efforts. We process the data to provide temporal and cumulative distribution plots, frequency of exceedances of objectives or criteria for beneficial uses, daily excursions, and time spent above an objective or criterion.

However, TMDL level of analysis is not conducted with the SWAMP nor NCWAP: that is, the methods presented in the next paragraph are for TMDL development by the TMDL team and not specifically for the SWAMP nor NCWAP assessments.

TMDL methods include modeling and sensitivity analysis to focus on determining factors, then GIS to portray those factors' effects on the stream temperature. That level of analysis was expected nor intended for the NCWAP. For informational purposes, the methods used for the Navarro River TMDL are summarized in Attachment A-3.

In addition, we are developing a monitoring design and GIS-based database for water temperatures on a regional basis.

Multi-parameter

Multi-parameter dataloggers are an efficient means of gathering basic physico-chemical water measurements on a semi-continuous basis over a period of many days or weeks. The loggers are calibrated and pre-programmed to collect conductance, pH, dissolved oxygen, temperature, depth, and other parameters on a predetermined interval, placed in the waterbody, and left to record the data on internal memory. Once the sampling period is complete, they are returned to the lab for post-calibration checks, and the data downloaded and imported into a spreadsheet for analysis. Typically, the probes need servicing every three or four days, depending on the waterbody. A four day deployment can accommodate sampling at 15-minute intervals, providing a dense data set around the clock.

The data are first plotted to observe diel periodicity and attainment of various maximum or minimum water quality objectives. Cumulative distribution plots are used to derive percentiles pertaining to other water quality objectives, and to determine the percentage of time a particular objective is met or not. In addition, the magnitude and shape of the curves for daily fluctuations of dissolved oxygen and pH provide valuable information on primary productivity in the waterbody.

The methods to calibrate, program, deploy, service, retrieve, download, and post-calibrate are per the manufacturer's instructions for the particular instrument. Data sheets for calibration, deployment, and site conditions accompany the data for each deployment as with the temperature loggers.

Actual deployment on a site takes into account a combination of factors, striving to place the instrument in a well-mixed flowing section of the stream, while protecting it from vandalism. Deployment on or in close proximity to patches of algae, sandy areas, or other micro-habitat influences are avoided—we attempt to find a spot representative of a reach of stream and uninfluenced by local anomalies. To the extent possible, we follow the published guidelines established by the USGS (2000).

When special circumstances warrant more focussed study on primary production or oxygen demanding sediments, we can deploy a logger within a Plexiglas dome covering a portion of the area under study as well as one outside the dome. Comparison of conditions within the dome (say over a clump of algae) are compared to ambient conditions in the stream. These studies are generally associated with problem areas, and are not part of an ambient monitoring program nor watershed assessment unless modeling is anticipated.

Channel Measurements

Stream channel and streambed metrics, such as V*, D_{50} ,substrate cores, etc. collected under the SWAMP are coordinated with the other agencies', landowners', and watershed groups' efforts to avoid duplication and enhance the overall data collection effort. These types of measurements have utility in describing channel conditions, sediment movement and recent events, but also in describing quality of cold water fish habitat.

Analysis of those data with other watershed-level data occurred as part of the NCWAP, and support the TMDL development effort. However, TMDL level of analysis is not expected with the SWAMP nor NCWAP; that is, the methods presented in the next paragraph are for TMDL development by the TMDL team and not specifically for this program nor the NCWAP assessments.

By way of information, the methods of analysis employed by the Regional Water Board and USEPA for sediment TMDLs include sediment source categorization, estimates of delivery rates from air photo analysis with some gound truthing, and comparison to the literature for other watersheds in the north coast and elsewhere. The methods employed in the Navarro River TMDL are described in a methods summary taken from the TMDL (Attachment A-4). Methods for the Van Duzen TMDL were somewhat different, are more preferred, and are described in that attachment as well.

The following descriptions are summaries of the measurements with reference to specific literature. Specific methods and the actual references for these metrics are presented in Attachment A-5, *Stream Sediment Monitoring and Assessment Protocols*.

Percentage of Residual Pool Volume Occupied by Fine Sediment Deposition (V-star or V*)

The volume of fines deposited in a pool can be used to evaluate and monitor channel condition and sediment sources. Pool volume has consistently been identified as an important aspect of pool habitat and appears to be vulnerable to increased sediment loads from watershed disturbances. Reductions in pool volumes reduce summer and winter holding capacities for salmonids (Stuehrenberg 1975, Klamt 1976, Bjornn et al 1977). Bjorn et.al (1977) found that the effect of introducing enough fine sand into a 3rd order stream pool to reduce its volume by half (a V* of .5) caused fish numbers to decline by two-thirds. Since pool habitat has often been correlated with the size and volume of pools (Heifetz, et. al. 1986 and Lau 1994) it follows that decreasing a pool's volume by introducing excess sediment will simplify pool habitat, also resulting in decreased substrate diversity. If pool habitat is limited in a given stream then this will translate into reductions in overall stream productivity and adverse impacts to the survival of cold-water fish.

V* is the volume of sediment in residual pools divided by the residual scoured pool volume and was developed to assess the supply of fine sediments being transported in a stream system (Lisle and Hilton, 1992). The method cross-section measurements to define the area and depth of the pool, with probing of the sediment in the pool to determine both the existing water depth and the depth to the residual pool (the pool without the sediment). The resulting metric is a decimal between 0 and 100, with 0 being no sediment, and 100 being 100% of the residual pool volume occupied by fresh sediment.

Sampling protocols on the North Coast for V* pool selection target pool-rifle channels with a 2-4% gradient in Rosgen B-3 channel types. These criteria were selected because they provide much of the spawning and rearing habitat for anadromous fish (Knopp, 1994). V* was found to have utility in other Rosgen B and C gravel channel types. Bedrock-boulder channels were found to give mixed results and may not be reflective of upslope land use and natural disturbance activities in a particular watershed (Lisle and Hilton, 1993).

Specific methods and the actual references for V* procedures are presented in Attachment A-5, *Stream Sediment Monitoring and Assessment Protocols*.

Channel Cross-sections

Channel cross-section measurements provide valuable information on the shape and dimension of a stream channel and its relationship to the flood plain. Coupled with other measurements, cross-sections provide valuable information on the transport and storage of sediment in the stream channel. Common parameters include width/depth ratio, gradient (slope), bankfull depth, flood prone area, and sinuosity. For utility and ease of reference, other parameters, such as scour chain and bank pin placement (for monitoring changes in depth and fill and bank stability, respectively), pebble counts, riparian canopy measurements, LWD surveys, etc., can also be combined and conducted at cross section locations.

Monitoring the long term changes in cross sectional data can provide insights into channel bed and bank stability, and relationships between sediment transport and discharge (Beschta and Platts 1986).

Shifts, such as decreasing cross sectional area, are often associated with decreasing thalweg depth, widening of the channel width, increasing bed elevations and overall streambed aggradation. Channel incision and downcutting may be indicative of a return to more "natural" conditions from previous management and/or natural catastrophically related impacts (McDonald, et al., 1991).

A typical study design can have as few as three, or as many as 15-20 cross sections located in a study reach. A reach has been variously defined as 20-50 bankfull flow widths (Kondolf and Micheli), a thousand meters (Knopp, 1993), or a predetermined length based on the geomorphic characteristics of the watercourse under study. For example, Madej and Ozaki, defined a study area as 26 kilometers long in Redwood Creek from its confluence with the Pacific Ocean to a slope-determined end point. Within the study area the 26 km stream segment was divided into three interconnected reaches, an upper, middle, and lower reach. A total of 58 cross sections were nested within the three reaches. The end points of each reach were determined by major breaks in stream gradient.

A cross sectional profile is developed by measuring points along a tape measure stretched across the stream and recording the distance, surface water, and stream bed elevations at each specific point along the tape. Stream bed characteristics, such as changes in bottom elevations, the position of the field estimated bankfull height, riffle crests, breaks in slope, and the deepest points in the particular channel feature being measured are recorded. The end points of the cross section are arbitrary, but they should extend at least above the estimated bankfull stage and preferably beyond the current floodplain.

More detailed descriptions of methods and quality control conditions are presented in Attachment A-5, *Stream Sediment Monitoring and Assessment Protocols*.

Thalweg profiles

The amount of variability in thalweg along a longitudinal axis in the stream is a good measure of complexity of the wetted stream channel. Pools, logs, boulders, riffles, etc. add complexity to the channel that affect sediment transport, channel form, and fish habitat. Changes in the thalweg profile reflect overall changes in the channel complexity, which are a result of channel-forming forces in the stream. Reduction of complexity occurs with excessive sediment introduction. Increased complexity indicates a recovery from such a condition. Thalweg profiles provide information on existing conditions, but are useful in trend analysis over the long term.

Strictly implemented, a thalweg profile or survey, as mentioned above, measures the elevations along the water surface and the thalweg of the stream, taking particular care to measure all breaks-in-slope, riffle crests, maximum pool depths, and pool tail-outs. Concurrently, while the tapes, levels, etc., are set up for measuring thalweg profiles, the locations of transects for cross sections are also usually documented and measured (Madej and Ozaki 1996 and Ramos, 1996). Since it is practically impossible to uniformly arrange the longitudinal tape exactly over the thalweg, measurements should be perpendicularly referenced to the centerline tape, and read to within one-tenth of meter. Ramos suggests that as thalweg measurements intersect the point of a designated cross section, the thalweg should be measured at the intersection first, then the cross section is surveyed before proceeding upstream. In addition to water surface and thalweg elevations, other variables, such as bar height, substrate size, high water marks, and comments on local channel features such as pools, riffles, runs, and the presence or absence of large woody debris can also be recorded. Subsequent analysis of the profile allows the detection of changes in the vertical dimensions of channel features. Depending on the data obtained from the thalweg survey, standard parametric and non-parametric statistical methods can be applied to more fully interpret survey results.

Depending on the study's intent, the reach length surveyed in a thalweg profile may vary from 20 to 50 channel widths. Rather than channel widths, surveys can also be modeled around a specific number of meander segments, generally three to four, within a reach (Madej and Ozaki 1996; Trush 1997; Rosgen 1996). The important consideration in selecting a specific length for a reach to conduct thalweg profiles is the ability of the study design to answer any questions or hypotheses proposed, whether it is to detect changes over time in channel aggradation or degradation, or to inventory available pool and riffle habitat for salmonids and other instream biota.

Pebble counts

One of the most widely used methods of sampling grain size from a streambed is the pebble count technique (Wolman, 1954). It can be used as a simple and rapid stream assessment method that may help in determining if land use activities or natural land disturbances are introducing fine sediment into streams (Potyondy and Hardy, 1994). Pebble counts are routinely used by geomorphologists, hydrologists and others to characterize bed material particle size distributions of wadable, gravel bedded streams. The procedures have been adapted in fisheries studies as a preferred alternative to visually characterizing surface particle sizes commonly used during instream flow studies (Kondolf and Li, 1992). The methodology is best applied in gravel and cobble streams with a single channel and are not applicable to lower gradient, sand-bed dominated channels.

Pebble counts are conducted by randomly collecting, counting and measuring the intermediate diameter (b-axis) of 100, and up to 200 (Kappesser, 1993) particles from the surface of a given streambed. Riffles deemed suitable for spawning salmonids are the preferred location for sampling efforts (Schuett-Hames, et al., 1999). Pebbles are collected along transects at measured points following a predetermined grid pattern, or by walking the streambed and picking up individual pebbles at the toe of a boot along a toe-to-heel, zigzag pattern. Whether the structured grid pattern or the toe-to-heel method is used, all transects should traverse the stream channel from the estimated bankfull to bankfull stage.

After at least 100 pebbles are sampled cumulative size distribution curves can be developed for the D50, median particle size, the diameter at which 50% of the particles are finer, and the D16 and D84, the diameters at which 16% and 84% of the particles are finer. Other analyses that may be applied are the geometric mean diameter: dg = D84 x D16)0.5 and the geometric sorting coefficient: sg = (D84/D16) 0.5 (Kondolf and Li, 1992). As mentioned, it has been shown that shifts toward the lower end of the pebble count cumulative frequency curves may be indicative of significant increases in streambed fines from accelerated natural and or land-use disturbances. Conversely, a progressive coarsening of streambed surface particles may indicate improving conditions from past upstream and/or upslope disturbances.

Specific methods and the actual references for pebble count procedures are presented in Attachment A-5, *Stream Sediment Monitoring and Assessment Protocols*.

Streambed Cores

The only way to determine the composition of the streambed below the surface is to take a core and analyze for particle size distribution. Several methods of core sampling are available, and include McNeil style core samplers, freeze-core samplers, and a shovel. We use the methods described in Valentine (1995), included in Attachment A-5. Basically, a sample is removed from the streambed and run through sieves to determine amounts of material within certain particle size categories. When done in the field, the samples usually are wet-sieved and the fractions measured by volumetric displacement. A set of samples is also taken back the lab for drying and analysis by weight to provide conversion factors for volume to weight for the particular geology. Samples can also be removed wet to the laboratory and analyzed dry by weight.

Data are expressed as percent of the core within size classes, allowing one to characterize the streambed particle distribution to relate to sediment transport mechanisms and suitability for salmonid spawning and egg incubation.

References Cited

Full literature citations are contained in the individual Attachments as referenced in the above protocols.

ATTACHMENT A-1

CALIFORNIA STREAM BIOASSESSMENT PROCEDURE

CALIFORNIA DEPARTMENT OF FISH AND GAME WATER POLLUTION CONTROL LABORATORY AQUATIC BIOASSESSMENT LABORATORY REVISION DATE - MAY, 1999

(Protocol Brief for Biological and Physical/Habitat Assessment in Wadable Streams)

Non-point Source Sampling Design

There will be no obvious perturbations or discharges into the stream with non-point sources of pollution. This sampling design is appropriate for assessing an entire stream or large section of stream. The sampling units will be riffles within a reach of stream. The stream reach must contain at least 5 riffles within the same stream order and relative gradient. One sample will be collected from the upstream third of 3 randomly chosen riffles.

Sampling Design for Assessing Ambient Biological Conditions

Assessment of ambient biological condition utilizes both the point and non-point source sampling designs to cover an entire watershed or larger regional area. Ambient bioassessment programs are used to evaluate the biological and physical integrity of targeted inland surface waters. Stream reaches should be established in the upper, middle and lower portions of each watershed and above and below areas of particular interest. Quite often bioassessment is incorporated into an existing chemical or toxicological sampling design. In most cases, the water quality information is being collected at a particular point on the stream. Although there will be the tendency to use the point source design, try to convert to a non-point reach design for biological sampling.

Measuring Physical/Habitat Quality

The physical/habitat scoring criteria is an EPA nationally standardized method. It is used to measure the physical integrity of a stream and can be a stand-alone evaluation or used in conjunction with a bioassessment sampling event. DFG recommends that this procedure be conducted on every reach of stream sampled as part of a bioassessment program. Fill out the Physical/Habitat Quality Form for the entire reach where the BMI samples were collected as part of a non-point source sampling design. Some of the parameters do not apply to a single riffle, so this procedure is usually not performed as part of the point source sampling design. This procedure is an effective measure of a stream’s physical habitat quality, but requires field training prior to using it and implementation of quality assurance measures throughout the field season. A detailed description of the scoring criteria is available through the California Aquatic Bioassessment Web Site.

QUALITY ASSURANCE (QA) PROCEDURES FOR THE FIELD AND LABORATORY

QA for Collecting BMIs

The CSBP is designed to produce consistent, random samples of BMIs. It is important to prevent bias in riffle choice and transect placement. The following procedures will help field crews collect unbiased and consistent BMI samples:

1. In using the CSBP, most sampling reaches should contain riffles that are at least 10 meters long, one meter wide and have a homogenous gravel/cobble substrate with swift water velocity. There are approved modifications of the CSBP when these conditions do not exist. Contact DFG or visit the California Aquatic Bioassessment Web Site for methods to sample narrow streams, wadable streams with muddy bottoms and channelized streams.
2. A DFG biologists or project supervisor should train field crews in the use of the BMI sampling procedures described in the CSBP. Field personnel should review the CSBPs before each field season.
3. During the training, crew members should practice collecting BMI samples as described in the CSBP. The 2 ft 2 area upstream of the sampling device should be delineated using the measuring tape or a metal grid and the collection effort should be timed. Practice repeatedly until each crew member has demonstrated sampling consistency. Throughout the sampling season, assure that effort and sampling

area remain consistent by timing sampling effort and measuring sampled area for approximately 20% of the sampling events. The results should be discussed immediately and need not be reported.

QA for Measuring Physical/Habitat Quality

Physical/habitat parameters are assessed using a ranking system ranging from optimal to poor condition. This rapid ranking system relies on visual evaluation and is inherently subjective. The following procedures will help to standardize individual observations to reduce differences in scores:

1. A DFG biologist or a project supervisor should train field crews in the use of the EPA physical/habitat assessment procedures. Contact DFG or visit the California Aquatic Bioassessment Web Site for a detailed description of the procedures. Field personnel should review these procedures before each field season.
2. At the beginning of each field season, all crew members should conduct a physical/habitat assessment of two practice stream reaches. Assess the first stream reach as a team and discuss in detail each of the 10 physical/habitat parameters described in the EPA procedure. Assess the second stream reach individually and when members are finished, discuss the 10 parameters and resolve discrepancies.
3. Crews or individuals assessing physical/habitat quality should frequently mix personnel or alternate assessment responsibilities. At the end of each field day, crew members should discuss habitat assessment results and resolve discrepancies.
4. The Project Supervisor should randomly pre-select 10 - 20% of the stream reaches where each crew member will be asked to assess the physical/habitat parameters separately. The discrepancies in individual crew member scores should be discussed and resolved with the Project Supervisor.

From: California Department of Fish and Game 1999. California Stream Bioassessment Procedure: Protocol Brief for Biological and Physical Habitat Assessment in Wadable Streams. California Department of Fish and Game, Water Pollution Control Laboratory, Aquatic Bioassessment Laboratory, Revision Date, May, 1999.
Available on the Web at *http://www.dfg.ca.gov/cabw/cabwhome.html*

CALIFORNIA STREAM BIOASSESSMENT PROCEDURE
CHAIN OF CUSTODY (COC) RECORD

Project Name: ________________________________ Date/ Time: ________________________
Watershed Name:________________________________ bioassessment Lab: ___________________

Sample Number	Lab Number	Sample Date	Sample Description

Sampled by: (sign and date)	Relinquished by: (sign and date)	Received by: (sign and date)
Received by: (sign and date)	Received by: (sign and date)	Received by: (sign and date)

Address of Sampler: ____________________________________

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Address of Project Advisor: ____________________________________

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CAMLnet Short List of Taxonomic Effort

This is a working list defining standard levels of taxonomic effort to be used when following the California State Bioassessment Procedures for laboratory analysis. This is a companion document to other CAMLnet resources that are or will be available on the CABW website.

PHYLUM ARTHROPODA	
Class Insecta	
Coleoptera	Identify to genus
Diptera	Identify all to genus except in the following cases:
Canacidae	Identify to family
Chironomidae	Identify to subfamily or tribe
Dolichopodidae	Identify to family
Phoridae	Identify to family
Scathophagidae	Identify to family
Syrphidae	Identify to family
Hemiptera	Identify to genus
Megaloptera	Identify to genus
Odonata	dentify to genus
Lepidoptera	Identify to genus
Ephemeroptera	Identify to genus
Plecoptera	Identify to genus
Trichoptera	Identify to genus
Subphylum Chelicerata	
Class Arachnoidea	
Acari	Identify to family
Subphylum Crustacea	
Class Brachiopoda	
Notostraca	Identify to Genus
Cladocera	Identify to Family
Class Copepoda	Identify to Subclass
Class Malacostraca	
Amphipoda	Identify to genus
Decapoda	Identify to genus
Isopoda	Identify to genus
Mysidacea	Identify to genus
Class Ostracoda	
Ostracoda	Identify to family
PHYLUM COELENTERATA	
Class Hydrozoa	Identify to genus
PHYLUM MOLLUSCA	
Class Gastropoda Identify to genus except in the following cases	
Hydrobiidae	Identify to family
Physidae	Identify to genus except for Physa/ Physella
Class Bivalvia Identify to genus	
PHYLUM NEMATODA	Identify to phylum
PHYLUM TARDIGRADA	Identify to phylum
PHYLUM PLATYHELMINTHES	Identify to family
PHYLUM ANNELIDA	
Class Hirudinea	Identify to genus
Class Branchiobdellida	Identify to genus
Class Oligochaeta	Identify to family
Class Polychaeta	Identify to genus
PHYLUM NEMERTEA	
Class Enopla	Identify to genus

NOTE: Other data sheets from CA Bioassessment Procedure are in pdf files on the website, and include:

- macro metrics.pdf
- macro wksheet.pdf
- macro habitat form.pdf

ATTACHMENT A-2

Water Temperature Monitoring – Data Loggers

INTRODUCTION

1.1 Background

This protocol has been adapted in large part from the Forest Science Project's Protocol (FSP 1998). Stream temperature is one of the most important environmental factors affecting aquatic ecosystems. The vast majority of aquatic organisms are poikilothermic--their body temperatures and hence their metabolic demands are determined by temperature. Temperature has a significant effect on cold-water fish, both from a physiological and behavioral standpoint. Below is a brief list of the physiological and behavioral processes affected by temperature (Spence et al., 1996):

- Metabolism
- Food requirements, appetite, and digestion rates
- Growth rates
- Developmental rates of embryos and alevins
- Timing of life-history events, including adult migrations, fry emergence, and smoltification
- Competitor and predator-prey interactions
- Disease-host and parasite-host relationships

This protocol sets forth a sampling approach that will provide consistent data that can be used to address stream temperature issues at broad regional scales, i.e., watershed, basins, and regions.

1.2 Scope and Application

The field methods described in this protocol are for obtaining representative stream temperatures from perennial streams for regional monitoring. The field methods are specifically applicable for the deployment of continuous monitoring temperature sensors (e.g., Hobo Temps, Temp Mentors, Stowaways, etc.) for the purpose of identifying diurnal changes in temperature, seasonal changes in thermal regime as well as seasonal changes. Possible interferences in the accurate and precise measurement of stream temperature include: 1) exposure of the sensor to ambient air, 2) improper calibration procedures, including date and time settings, 3) improper placement of the sensor in the stream, 4) low battery, 5) inherent malfunctions in the sensor or data logger, and 6) vandalism.

1.3 Summary of Method

All continuous stream temperature monitoring sensors should be calibrated against a National Institute of Standards and Technology (NIST) traceable thermometer. Sensors not meeting precision and accuracy data quality objectives should not be used. Sensors should be placed in a well-mixed zone, e.g., at the end of a riffle or cascade. Monitoring location should represent average conditions — not pockets of cold water refugia or isolated hot spots. Location of sampling points should either avoid or account for confounding factors that influence stream temperatures such as:

- confluence of tributaries
- groundwater inflows
- channel morphology (particularly conditions that create isolated pools or segments)
- springs, wetlands, water withdrawals, effluent discharges, and other hydrologic factors
- beaver ponds and other impoundments

The sensor should be placed toward the thread or thalweg of the channel. Keep in mind that flow will decrease throughout the summer resulting in an exposed sensor. The thermistor portion of the device should not be in contact with the bottom substrate or other substrate that may serve as a heat sink (e.g., bridge abutment or boulder). Secure the sensor unit to the bottom of the channel with aircraft cable, surgical tubing, rebar, or diver's weights. The sensor should be set to record temperatures at sampling intervals that should not exceed 1.6 hours (96 minutes).

2.0 EQUIPMENT AND SUPPLIES

2.1 Calibration and Standardization

Prior to deployment of sensors, calibration of each sensor must be performed. The following is a list of equipment and supplies for calibration:

- NIST traceable thermometer - resolution of 0.2□C or better, an accuracy of ±0.2□C or better.
- controlled-temperature water bath, or water-filled thermos or
- ice chest
- laboratory notebook
- ice

2.2 Field Measurements

There are several useful materials and pieces of equipment that should be taken to the field to install or service temperature sensors. These include:

- securing material such as zip ties, bailing wire, aircraft cable, surgical rubber tubing, locks, rebar, cinder blocks, large rocks with drilled holes, diver's weights
- GPS w/extra batteries
- surveyors marking tape or flagging
- sledge hammer (e.g., two-pound)
- wire cutters and/or pocket knife
- thermistor equipment items (silicone rings, submersible cases, silicone grease, silica packets)
- portable computer or interface for data downloading and launching
- backup batteries and thermistors
- timepiece/watch
- Rite in the Rain field book w/ extra field sheets
- NIST-traceable auditing thermometer
- waders
- camera and film
- brush removal equipment (e.g., safety axe)
- maps and aerial photos
- first aid kit
- spray paint, rags and clean up cloths
- metal stakes or spikes, rebar

3.0 PRE- AND POST-DEPLOYMENT CALIBRATION AND STANDARDIZATION

A. A NIST-traceable thermometer must be used to test the accuracy and precision of the temperature sensors. The NIST-traceable thermometer should be calibrated annually, with at least two calibration points between 10C (50F) and 25C (77F). Calibrations should be performed using a thermally stable mass of water, such as a controlled-temperature water bath, or water-filled thermos or ice chest. The stable temperature of the insulated water mass allows direct comparison of the unit's readout with that of the NIST-traceable thermometer. Accuracy of the NIST-traceable thermometer must be within ±0.5C.

B. Prior to use, all continuous monitoring devices should be calibrated at room temperature (~25C, 77F) and in an ice water bath to insure that they are operating within the accuracy over the manufacture's specified temperature range. Calibrate all continuous monitoring devices with a NIST-traceable laboratory thermometer at two temperatures, room temperature (i.e., ~77F, 25C) and near the freezing point of water as follows:

1. When calibrating and prior to deployment, set all units to the same current date and synchronize all devices using an accurate watch/clock that will be used to time the recording intervals of the reference thermometer. Call for the correct time.

2. Set the record interval of each thermograph to a short period, six to 30 seconds.
3. Record the date, sensor serial number, data logger serial number, and analyst's name in a laboratory notebook. Table 1 is an example of a format that can be used for data collection. The same sensor and same data logger should be deployed in the field as they were paired together during calibration.
4. Place the reference thermometer and the continuous monitoring devices in a five-gallon pail filled with about three gallons of water that has reached room temperature overnight or in a controlled-temperature water bath that has reached room temperature (~77F, 25C). Make sure the casings of all continuous monitoring devices are completely submerged. Stir the water, just prior to, and during the calibration period to prevent any thermal stratification.
5. After allowing 10 to 20 minutes for the continuous monitoring devices to stabilize, begin recording data for a 10-minute interval. Record the time, the reference thermometer temperature, and the continuous monitoring device temperatures measured at the predetermined sampling frequency (e.g., 6 second, 10 second) used during the 10-minute interval. After all readings are completed, calculate the difference between the reference thermometer and each of the continuous monitoring devices for each reading and calculate the mean difference. Record the data using a format similar to that shown in Table 1.

Table 1.Example of Calibration Data Collection Table

4/12/98	**Sensor Serial Number = 10043** **Data logger S.N. = 2S256S**	**Analyst: Joe Celsius**	**Reference Thermometer No. 412**
Time (sec)	**NIST Thermometer Reading (C)**	**Device Reading (C)**	**Difference (C)**
0	25.0	24.8	-0.2
10	25.1	25.0	-0.1
20	25.0	24.9	-0.1
30	25.2	25.0	-0.2
40	25.0	24.6	-0.4
Etc.			
		Mean = 24.9 S.D. = 0.16	Mean Diff. = -0.16

C. Any continuous monitoring devices not operating within their specified accuracy range should be thoroughly scrutinized. If a particular device returns readings that are outside of the manufacturer's accuracy limits, but is still precise, then a correction factor (addition and/or multiplication) can be applied to the data. Precision should be within 0.2 standard deviations (S.D.) of the mean. Acceptable precision should be observed over the range of temperatures that will be experienced in the field. The correction factor, when applied over the calibration range, should give temperature values that are within the accuracy limits of the device. If units are inaccurate and imprecise they should not be used.

D. Using the same water bath, add enough ice to nearly fill the bucket and bring the temperature down to nearly freezing. Stir the ice bath to achieve and maintain a constant water temperature. Place the reference thermometer and the continuous monitoring devices in the water bath or five-gallon pail. Again, make sure that the casings are completely submerged.

E. Repeat steps 2B-D with ice water bath.

F. Also confirm that thermograph batteries have sufficient charges for the entire monitoring period (will the length of the upcoming field season fit into the life expectancy of the unit's lithium batteries?).

G. Calibration should also be repeated when sensors are retrieved at the end of the sampling season (post-deployment calibration). Repeat steps 2A-F.

4.0 QUALITY ASSURANCE AND QUALITY CONTROL

4.1 Laboratory

Precision and accuracy should be 0.2 SD and ±0.5C, respectively for each continuous monitoring device.

Monitoring equipment with detachable sensors must be marked in order to match the sensor with the data logger. This allows instrument and sensor to be calibrated and tested prior to deployment, and also makes malfunctions easier to diagnose and correct. A logbook must be kept that documents each unit's serial number, calibration date, test results, and the reference thermometer used (Table 1).

4.2 Field

In addition to laboratory quality control checks, temperature monitoring equipment should be audited during the field season if possible. A field audit is a comparison between the field sensor and a hand-held NIST-traceable reference thermometer. The purpose of a field audit is to insure the accuracy of the data and provide an occasion for corrective action, if needed. A minimum of two field temperature audits should be taken during the sampling period — one after deployment when the instrument has reached thermal equilibrium with the environment, and ideally one prior to recovery of the device from the field. Reference thermometers used for field audits must meet the same specifications as those used for laboratory calibrations: accuracy of ±0.5C, resolution of 0.1C. Exercise caution with mercury thermometers in the field.

A field audit is performed as follows:

1. Place the reference thermometer in close proximity to the continuous monitoring device.

2. Record the reference thermometer temperature and the sensor temperature in a field notebook. A stable reading is usually obtained within 10 thermal response units or time constants. For example, a reference thermometer with a ten-second time constant should give a stable reading in 100 seconds.

3. Most general purpose data loggers allow the user to connect a computer in the field and view "real-time" temperature data without disrupting the data logger's scheduled sampling schedule. This feature allows immediate comparison of the data logger's reading with the reference thermometer's reading. Real-time audit accuracy must be within ±1.0 C.

> Response time (time constant) is the time required by a sensor to reach 63.2% of a step change in temperature under a specific set of conditions. Response time values should be provided by the manufacturer. Five time constants are required for the sensor to stabilize at 100% of the step change value. Ten time constants are recommended to insure that the reference thermometer has reached equilibrium with the stream temperature.

4. Conversely, most brands of miniature data loggers interrupt data collection when the unit is connected to a computer. With this type of unit, field audit data can only be applied by "post-processing", i.e., the stored data are downloaded and later compared to audit values. This does not permit on-site corrective action if the sensor is not within accuracy specifications. For this type of data logger, auditing times should be scheduled reasonably close to the data loggers download time. Otherwise, the sensor/data logger equipment may fail the audit criteria due to rapidly changing water temperatures. Post-processing audit accuracy must be within ±0.5 C .

5. Data loggers typically set date and time based on the set-up computer's clock. It is important that field personnel synchronize their watches to the computer clock's time. Prior to the field audit the computer clock should be set to the correct date and time by calling for the correct time.

5.00 PROCEDURES

Water temperatures vary through time and space. The temporal and spatial aspects of deploying stream temperature monitoring devices is discussed in the following sections.

5.1 Temporal Considerations of Sensor Deployment

5.1.1 Sampling Window

Launch sensors to capture the hottest period of the field season, which will vary with watershed location. Coastal streams in Humboldt and Del Norte Counties require deployment at least during July, August, and September; whereas Mendocino County and more inland streams may require longer recording periods (June-October) (FFFC, 1996). For consistency it is recommended that the sampling window be from June 1 to October 1. This sampling window will ensure that the highest temperatures during the summer will be captured in the data set.

5.1.2 Sampling Frequency

The time interval between successive temperature readings can be adjusted from every few seconds, to every few hours, to every few days, for most continuous monitoring devices. Table 2 shows some of the typical sampling frequencies and the number of days the device can be left in the field prior to data downloading. In most monitoring activities, the primary objective is to determine the highest temperatures attained during the year. Thus, one of the deciding factors in setting the sampling frequency on a device will be to ensure that the daily maximum temperature is not missed.

The more frequent the monitoring, the more precisely the duration of daily maximum temperature can be characterized. The disadvantage of frequent data collection is reduced number of days of data storage and increased number of data points to be analyzed. Some agencies and other groups have found that an 80-minute sampling interval still captures the daily maximum stream temperatures for sites (OCSRI, 1996). If a less frequent sampling interval is desired, then a pilot study must be performed with monitoring at 30-minute intervals over a one to two week period during the hottest time of the year to determine how rapidly stream temperatures change. Pilot study information can provide information on the time interval most appropriate for capturing the daily maximum.

Table 2. Typical Sampling Frequencies and Storage Capacity of a Hobo® Data Logger Used for Stream Temperature Monitoring

2K Memory / 1,800 Meas.	8K Memory / 7,944 Meas.	32K Memory / 32,520 Meas.	Sample Frequency
37.5 days	165 days	677 days	30 min
45 days	198 days	813 days	36 min
60 days	264 days	1084 days	48 min
75 days	331 days	1355 days	1 Hr
90 days	397 days	1626 days	1.2 Hr
120 days	529 days	2165 days	1.6 Hr
150 days	662 days	2710 days	2 Hr
180 days	799 days	3270 days	2.4 Hr
240 days	1050 days	4300 days	3.2 Hr
360 days	1590 days	6540 days	4.8 Hr

Note: BoxCar® and LogBook® software's launch menu allows the user to choose from 42 intervals ranging from 0.5 seconds to 4.8 hours. The table shows the most likely settings that may be used for stream temperature monitoring. Mention of trade names does not denote endorsement by the Fish, Farm, and Forests Community Forum, the Forest Science Project, or any of their cooperators.

Selection of appropriate sites for monitoring is dependent upon the purpose and monitoring questions being asked. There are two scales of consideration for the appropriate monitoring site: selection of a sample point or location in the stream which provides representative data and the broader strategy of selecting sites that can provide useful information to answer the questions being asked.

5.1.3 Data Downloading

It is preferable to have the data cover the entire monitoring without interruptions. However, if data must be downloaded during the monitoring period due to insufficient data logger memory, record the date and time the sensor was removed from the stream and the date and time when it was returned to the stream. Some models may allow for downloading of data without interruption or removal of the sensor from the stream. Be sure to return the sensor to the same approximate location and depth after downloading. During a field visit for data downloading or auditing, record in the field notebook whether the sensor was exposed to the air due to low flow, discontinued flow, or vandalism. This information will be valuable for verification and validation of the data in the office.

5.1.4 Mid-Season Field Audit/Calibration Check

If data downloading is performed in mid-season, an opportunity for a mid-season field audit and calibration check presents itself. See Section 4.2 for mid-season field audit and calibration procedures.

5.2 Spatial Considerations of Sensor Deployment

5.2.1 Stream Sample Point Location

The simplest and most specific scale is a sampling point on a stream. Here, the focus is on sample collection methods that will reduce variability and maximize representativeness.

Monitoring must record daily maxima at locations which represent average conditions - - not pockets of cold water refugia or isolated hot spots. Measurements should be made using a sampling protocol appropriate to indicate impact to beneficial uses (OCSRI, 1996). Thus, location of sampling locations should be done in a manner that is representative of the waterbody or stream segment of interest. In order to collect representative temperature data, sampling site selection must minimize the influence of confounding factors, unless the factor is a variable of interest. Some confounding factors include:

- confluence of tributaries
- groundwater inflows
- channel morphology (particularly conditions that create isolated pools or segments)
- springs, wetlands, water withdrawals, effluent discharges, and other hydrologic factors
- beaver ponds and other impoundments

5.2.2 Site Installation

Unless study design dictates differently, all sensors should be placed in the thalweg of riffles to insure a complete mixing of the water and to maintain sufficient water depth for the duration of the sampling window. Alternatively, if riffles are too shallow place the sensor in a pool or glide that exhibits well-mixed conditions. Do not place the sensor in a deep pool that may stratify during the summer, unless this is the objective of your study. This measure insures that sensors are not selectively placed in cooler areas such as stratified pools, springs, or seeps or in warm, stagnant locations (hot spots) that would misrepresent a stream reach’s temperature signature. A hand-held thermometer can be used to document sufficient mixing by making frequent measurements horizontally and vertically across the stream cross section. If stream temperatures are relatively homogenous (±1-2 C) throughout the cross section during summer low-flow conditions, then sufficient mixing exists.

Monitoring devices should be installed such that the temperature sensor is completely submerged, but not in contact with the bottom. Place the sensor near the bottom of the stream by attaching it to a rock, large piece of woody debris, or a stake. Use zip ties, surgical tubing, or aircraft cable to attach the sensor to the bottom substrate. Rebar or diver’s weights can be used if no suitable fastening substrate is available. For non-wadeable streams, the sensor should be placed one meter below the surface, but not in contact with a large thermal mass, such as a bridge abutment or boulder (ODF, 1994). If the monitoring site is not in a heavily visited area, mark the location of the sensor by attaching flagging marked with the gauge number or site ID number to nearby vegetation.

Precautions against vandalism, theft, and accidental disturbance should be considered when installing equipment. In areas frequented by the public, it is advisable to secure or camouflage equipment. Visible tethers are not recommended because they attract attention. When equipment cannot be protected from disturbance, an alternative monitoring site should be considered. For external data loggers that are not waterproof, place them above the mean high water line to prevent loss during a freshet. Some data loggers must be housed in a waterproof metal or plastic box that should be locked and chained to a tree. Data logger boxes and cables should be covered with rocks, moss, and wood to hide equipment.

Install the sensor in a shaded location; shade can be provided by canopy cover or some other feature such as large woody debris. If no shaded locations are available, then it may be necessary to construct a shade cover for the sensor (e.g., using a section of large diameter plastic pipe.) The intention for this measure is to avoid direct solar warming of the sensor. The intent is not to suggest that sensors should be placed only in shaded thermal reaches.

Sensors should be located at the downstream end of a thermal reach, so as to characterize the entire thermal reach, as opposed to local conditions. Protocols for characterizing thermal refugia can be found in FFFC (1996).

The number of thermograph units deployed will vary with 1) drainage area of the watershed, 2) numbers and sizes of inflow tributaries or other transitions in riparian condition, 3) changes in elevation, and 4) proximity to coastal fog zone. In all circumstances, a continuous monitoring device should be located as far downstream as surface water flows during the summer. In watersheds with multiple sensors locate them in a lower/upper or lower/middle/upper distribution.

A ***thermal reach*** is a reach with similar (relatively homogenous) riparian and channel conditions for a sufficient distance to allow the stream to reach equilibrium with those conditions. The length of reach required to reach equilibrium will depend on stream size (especially water depth) and morphology (TFW, 1993). A deep, slow moving stream responds more slowly to heat inputs and requires a longer thermal reach, while a shallow, faster moving stream will generally respond faster to changing riparian conditions, indicating a shorter thermal reach. Generally, it takes about 300 meters (or 1000 feet) of similar riparian and channel conditions to establish equilibrium with those conditions in fish-bearing streams.

Mark all monitoring site locations on a USGS 1:24,000 topographic map, aerial photo, or GIS map. Clearly show the location of the site with respect to other tributaries entering the stream, e.g., above or below the confluence. Record measured distance to a uniquely distinguishable map feature (i.e., road crossing, specific tributary, etc.) Draw a diagram of the monitoring area. Include details such as: harvest unit boundaries, sensor location and thermal reach length, tributaries with summer flow, description of riparian stand characteristics for each bank, areas where portions of the stream flow become subsurface, beaver pond complexes, roads near the stream, other disturbances to the channel or riparian vegetation (heavy grazing, gold dredging, gravel mining, water withdrawals).

Record the serial number of each sensor/data logger combination at each monitoring site. Make an effort to deploy the same sensor/data logger combination at the same site each year.

Once a sensor/data logger combination has been deployed at a site, do not move the equipment to another location. Adjustments in sensor location may be necessary if the initial location ran dry, and the sensor must be moved to the active, flowing channel. This will necessitate a unique site_id for spatial statistical analysis. Make notes of such relocations in the field notebook.

If sensors are used to collect long-term baseline or trend data in specific watersheds, establish fixed-location monitoring stations so that data sets will be comparable.

5.3 Site-Specific Data Collection

Other site-specific data should be collected at the time of sensor deployment or retrieval. These additional attributes will greatly assist in post-stratification and interpretation of status and trends in stream temperatures.

5.3.1 Length of Thermal Reach or Stream Segment

The thermal reach extends 300-600 meters above the site, depending on stream size (TFW, 1993). With a hip chain or measuring tape, measure the length of thermal reach or stream segment (in feet). If the stream has more than one channel, measure along the channel that carries most of the summer flow.

5.3.2 Canopy Closure

Use a spherical densiometer at evenly spaced intervals to determine average canopy closure for the thermal reach above the monitoring site. Take canopy closure measurements at 50-meter intervals along the thermal reach. If the percent canopy cover varies by more than 20% between measurements, then take additional measurements at 25-meter intervals to more accurately determine the average percent canopy closure for the reach. In order to save time, it may be advantageous to determine canopy closure at 25-meter intervals from the start, thus avoiding the need to back-track in cases where the variability exceeds 20%. In addition to calculating the average canopy closure, keep a record in a field notebook of the percent canopy closure at each sampling interval and note the locations on a map or sketch of the reach to document how the shade level varies through the reach. At each 25- or 50-meter interval, stand in the center of the channel and measure canopy closure four times: facing upstream, downstream, right bank, and left bank. Average these four values to obtain canopy closure for the location.

5.3.3 Elevation

Determine the elevation at the midpoint of the thermal reach from a USGS topographic map, or altimeter and record on data sheet to nearest feet.

5.3.4 Average Bankfull Width and Depth

The width and depth of a channel reflect the discharge and sediment load the channel receives, and must convey, from its drainage area. Channels are formed during peak flow events, and channel dimensions typically reflect hydraulic conditions during bankfull (channel-forming) flows.

Bankfull width and depth refer to the width and average depth at bankfull flow. These dimensions are related to discharge at the channel-forming flow, and can be used to characterize the relative size of the stream channel. This characterization will be useful for later post-stratification and assessment of stream temperature data. In addition, the ratio of bankfull width to depth (width:depth ratio) of a stream channel provides information on channel morphology. Width:depth ratio is related to bankfull discharge, sediment load, and resistance to bank erosion (Richards, 1982). For example, channels with large amounts of bedload and sandy, cohesionless banks are typically wide and shallow, while channels with suspended sediment loads and silty erosion-resistant banks are usually deep and narrow. Changes in width:depth ratio indicate morphologic adjustments in response to alteration of one of the controlling factors (Schumm, 1977).

Refer to TFW Ambient Monitoring Manual (1993) for step-by-step procedures for estimating bankfull width and depth.

5.3.5 Average Wetted Width

Measure the wetted channel width at the location where the sensor is placed. This measurement should be collected at the time of deployment and at the time of retrieval. Change in wetted width over the field season will provide information on the change in flow during the monitoring period. Follow the method outlined in Flosi (1998). Figure 3 shows a comparison of wetted width and bankfull channel width dimensions.

5.3.6 Habitat Type

Record the habitat type in which the sensor was placed. Use the following codes for the habitat types:

riffle Shallow reaches with swiftly flowing, turbulent water
run Relatively uniform flowing reaches with little surface agitation
spool Shallow pools less than 2 feet in depth with good flow (no thermal strata)
mpool Mid-sized pools 2 to 4 feet in depth with good flow (no thermal strata)
dpool Deep pools greater than 4 feet in depth or pools suspected of maintaining thermal strata (possible thermal strata)

5.3.7 Stream Class

Record the stream classification as defined by the California Forest Practice Rules.

1 - ***Class I Watercourse:*** Domestic supplies, including springs, on site and/or within 100 feet downstream of the operations area and/or 2) Fish always or seasonally present onsite, includes habitat to sustain fish migration and spawning.

2 - ***Class II Watercourse:*** a) Fish always or seasonally present offsite within 1000 feet downstream and/or 2) Aquatic habitat for nonfish aquatic species. 3) Excludes Class III waters that are tributary to Class I waters.

3 - ***Class III Watercourse:*** No aquatic life present, watercourse showing evidence of being capable of sediment transport to Class I and II waters under normal high water flow conditions after completion of timber operations.

4 - ***Class IV Watercourse:*** Man-made watercourses, usually downstream, established domestic, agricultural, hydroelectric supply or other beneficial use.

For Class I watercourses make a concerted effort to collect fish presence/absence and/or abundance data in the same thermal reaches or stream segments where stream temperature data is being gathered. Conduct fish surveys during the period when stream temperatures are highest (July-August).

6.00 DATA FIELD FORM

To assist in the collection and organization the site-specific information described in Sections 5.3.1 through 5.3.7 a field data form has been developed by the Forest Science Project. The form can be found in Appendix A. Please reduce and photocopy the form onto Write-in-the-Rain paper for data collection activities. Please use a No. 2 pencil.

7.00 CALCULATIONS

It is recommended that only data that meets quality control requirements be used for statistical analyses. Data are considered valid if the instrument's pre- and post-deployment calibration checks are within ±0.5 C of the NIST-traceable reference thermometer, as described in Section 4, and the data are bracketed by field audits which meet the ±1.0 C accuracy criterion (Section 4).

7.1 Maximum Weekly Average Temperature (MWAT)

The seven-day moving average of the daily average and the daily maximum can be calculated with most spreadsheet, database, and statistical software. The seven-day moving average of the daily average is simply the sum of seven consecutive daily average temperatures divided by seven. For consistency, it is recommended that the first day's daily average can be used as the first seven-day moving average, the second day's moving average would be the average of day one and day two daily averages, etc. The seven-day moving average of the daily maximum is the sum of seven consecutive daily maximum temperatures divided by seven.

After all the seven-day moving averages have been calculated, the highest of all the moving averages is referred to as the Maximum Weekly Average Temperature (MWAT) for a given site. Different agencies and groups are comparing either the seven-day moving average of the daily average or the seven-day moving average of the daily maximum to various MWAT criteria. The MWAT threshold can be calculated using the following equation:
Where:

OT = a reported optimal temperature for the particular life stage or function, and
UUILT = the upper temperature that tolerance does not increase with increasing acclimation temperature.

If the OT is not known, Armour (1991) recommended using the midpoint of a preferred range. The MWAT is interpreted as the upper temperature limit that should not be exceeded during a one-week period in order to prevent chronic lethal effects.

Thus, according to Armour, the MWAT is the threshold against which weekly temperatures are compared. The weekly temperatures are not MWATs.
There is no agreed upon statistic adopted by California state and federal agencies at this time.

8.00 ACKNOWLEDGMENTS

This protocol is based on the FSP protocol which, in turn, is based on several existing stream temperature protocols. We would like to acknowledge the states of Oregon and Washington for providing stream temperature monitoring protocols for review and incorporation of sections into the FSP protocol. We would like to thank the Forest Science Project cooperators for their review and helpful comments of this protocol. Also, many insightful suggestions were provided by various reviewers from various state and federal agency personnel in California, Oregon, and Washington.

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ATTACHMENT A-3

Description of Approach and Methods for Development of the Technical Basis for a Temperature TMDL for the Navarro Watershed

A series of modeling approaches was used to identify and analyze those factors having a significant influence on stream temperatures in the Navarro River watershed.

1. A deterministic model capable of predicting stream temperatures, SSTEMP, was applied to a reach of the Navarro as a screening tool to identify the most important factors affecting stream temperature.
2. Regression analyses using data gathered at 15 stations distributed throughout the watershed were used to confirm the SSTEMP results.
3. A GIS model was developed to portray shade conditions along the streams of the watershed both for current conditions and site potential vegetation conditions. Shade, air temperature, and wind speed were identified as the three most important factors affecting stream temperatures. The analysis focused on shade because it can be directly related to solar radiation, excess amounts of which constitute the 'pollutant' in the TMDL framework.

The following sections describe in more detail the modeling approaches, including the types of data required to perform the analyses.

<u>Sensitivity Analysis Using SSTEMP</u>

The various heat exchange processes affecting stream temperatures have different magnitudes and interact in different ways depending on site-specific conditions. These factors in turn are expressed through different values of variables in the mathematical equations that describe the heat exchange fluxes. To evaluate the relative significance of the variables that affect heat exchange rates for Navarro watershed streams, heat fluxes in a portion of the Navarro River were modeled. The model used, named SSTEMP, is intended for application to a segment or reach of a stream or river (Bartholow 1999). It is a simplified version of SNTEMP (Stream Network Temperature Model) (Bartholow 1989). SNTEMP can be used to model stream temperatures for an entire watershed. SSTEMP was used to perform a sensitivity analysis using ranges of values of parameters reflective of conditions in the Navarro watershed. Both SNTEMP and SSTEMP are public domain codes and are currently supported by the US Geological Survey (USGS). This is an attractive attribute for use in a TMDL as the model on which the analysis is based can be easily retrieved and applied by any members of the public with the interest in doing so.

The primary uses for sensitivity analysis in the Navarro temperature TMDL were: 1) to rank parameters according to effect on predicted stream temperatures, and 2) to identify the most important management-related parameters.

<u>Model Inputs</u>

Model input requirements are summarized in Table 1-1. The model requires input on both temperatures and flow for the date being modeled. This can be a significant limitation.

Table 1-1 SSTEMP Model Input Requirements	
Hydrology	Meteorology
Segment Inflow (cfs)*	Air Temperature (°F)*
Inflow Temperature (°C)	Relative Humidity (%)*
Segment Outflow (cfs)*	Wind Speed (mph)*
Accretion Temperature (°F)*	Ground Temperature (°F)*
	Thermal Gradient (j/m2/s/c)*
Geometry	Possible Sun (%)*
Latitude (°)	Dust Coefficient *
Segment Length (mi.)	Ground Reflectivity (%)*
Upstream Elevation (ft)	
Downstream Elevation (ft)	Shade*
Width's A Term *	
Manning's n	Time of Year (mm/dd)

* Input parameter that was varied as part of the sensitivity analysis.

<u>Analysis of Conditions at Selected Navarro Watershed Stations</u>

To investigate the SSTEMP screening results further, additional analysis was conducted using data collected at fifteen stations established in the watershed by the SWRCB in 1995. Available data at these stations included continuous temperature records and monthly streamflows through the summer. Flow measurement data sheets in turn included detailed measurements of wetted channel widths, depths, and velocities at the measured cross sections. Regional Water Board staff supplemented these data with effective shade measurements in reaches upstream of the previously monitored locations. A data collection protocol was developed for effective shade measurements using a Solar Pathfinder.

There often are not data of similar completeness available on the other parameters that may be important, e.g., air temperature, wind speed, and relative humidity. Sorting out the relative importance of the factors at play would require data on a variety of parameters at temperature monitoring locations. Temperature data without data on other characteristics of the temperature monitoring locations that can affect temperatures severely limits the possibility of demonstrating causal relationships between environmental conditions, management activities, and effects on stream temperatures.

<u>Development of Pollutant Loading Capacities and Surrogate Measures</u>

Under the TMDL framework, identification of the "loading capacity" is a required step. The loading capacity represents the total loading of a pollutant that a water body can assimilate while still meeting water quality objectives and protecting beneficial uses. For a temperature TMDL, the loading capacity is expressed as effective shade, a surrogate for solar radiant energy load.

A GIS model was used to develop the potential effective shade values that equate to the solar radiation loading capacity of the streams of the watershed.

Numeric Targets for Effective Shade and Temperature

The narrative water quality objectives described in the Basin Plan (see Section 3.2) state that "natural receiving water temperature shall not be altered unless…such an alteration in temperature does not adversely affect beneficial uses." Natural receiving water temperatures are considered to be the reference condition that would not adversely affect beneficial uses associated with salmonid use of the watershed. This reference condition was developed using the following approach:

- The Regional Board developed a GIS model capable of representing solar radiation, topography, stream locations and orientation, and the effects of vegetation near streams on stream shading for this TMDL. The model calculates the percent of possible solar radiation received at each location in the watershed, and the effective shade offered by topography and vegetation to the stream network. By relating effective shade to temperature, estimated temperatures in the streams for different shade conditions can be portrayed.

- The model was used to describe stream shade considering: 1) only topography (no vegetation), 2) with vegetation reflecting late-seral stage (fully mature) tree growth, and 3) with current vegetation conditions.

- Model results were then modified to an adjusted potential shade condition for use in developing target stream temperatures.

As a key step in model development, input on the vegetation type, height, and extent is required for both potential and current vegetation conditions. Vegetation information was developed from available GIS coverages, literature information on occurrence and characteristics of particular tree species, field observations in the watershed, and review of historic and recent aerial photos.

The Timberland Task Force (TTF) Klamath Province habitat database developed as part of the Klamath Region Vegetation Mapping Project was the primary source of distributed (watershed-scale) vegetation information. Particularly useful database fields included the vegetation classification by Wildlife Habitat Relationships (WHR) type, tree size classes (classified into dbh ranges), and estimates of percent conifer/percent hardwood for each polygon mapped in the coverage. To describe potential vegetation height conditions, the mature tree heights for hardwoods and conifers by vegetation class (WHR type) were combined with the polygon percent conifer and percent hardwood values to calculate polygon-specific potential vegetation heights. For current vegetation conditions, an additional step was performed. Each polygon in the GIS coverage has an associated dbh class. Using conversions developed from the literature, dbh information was converted to estimated current vegetation heights for each polygon.

Topography

Topography was developed using 10m Digital Elevation Model (DEM) input acquired from CDF and developed by the U.S. Geological Survey). The DEM results in development of the hydrographic network and aspect of streams in addition to the topography of the watershed.

Vegetation Height Estimates for Current and Potential Conditions

As a first step, a summary of tree species occurring in the Navarro watershed was compiled from published reports (Griffin and Critchfield 1972) and field observations. For each species, reported heights of mature trees were compiled from a variety of sources (Burns and Honkala 1990; Fowells 1975; Hickman 1993; Munz 1968; Sudworth 1908; Whitney 1998). For each species, a typical mature tree height was selected from the compiled values. In addition, estimated tree heights associated with diameter at breast height (dbh) classes were developed (Burns and Honkala 1990; Fowells 1975) for later use in characterizing current vegetation height conditions. Next, key tree species associated with the Klamath Region Vegetation Mapping Project habitat database vegetation types were identified.

Examples of vegetation types are redwood forest, Douglas fir forest, and mixed hardwood-conifer forest. For each vegetation type, height values were developed for each dbh class for groupings of conifers and hardwoods.

Vegetation Extent

Vegetation extent near streams was handled differently for potential and current conditions. First, no attempt was made to separate Class I from Class II streams. As indicated in USEPA (1999), eliminating Class II streams from consideration in the vegetation and shade scenarios can result in significant underestimate of the potential suitable aquatic habitat in the watershed. For this analysis, all drainages shown on USGS 1:100,000 topographical coverages as blueline streams were included in the analysis. In addition, streams shown on USGS 1:24000 topographical coverages occurring within 300 meters of the 1:100,000 streams also were included in the analysis. The underlying stream network was developed from USGS topographic data, available as a 10m Digital Elevation Model (DEM) coverage.

For potential conditions, the unvegetated channel was defined using bankfull width, centered on the centerline of the stream channel. Bankfull widths were assigned using a relationship for the Mendocino Coast developed with techniques and equations described in Leopold, Wolman and Miller (1964) and stream channel geometry information (hydraulic geometry exponents needed for the equations) for Mendocino Coast streams developed by Leopold (2000) and as part of this analysis. For current conditions, aerial photographic coverage for the watershed flown in 1996 was reviewed and compared to current USGS topographic coverage representing the occurrence of trees and forested areas in the watershed. These results were used to identify the current occurrence of trees near streams. This analysis was limited to areas within 300 meters of the blue line streams mapped on USGS 1:100,000 topographic coverage.

Sun Track for Mean MWAT Date

The GIS model uses sun position in calculating shading from topography and vegetation. Equations presented in Boes (1981) were used to calculate hourly solar azimuths and altitudes for July 22, the mean MWAT date for the watershed. These values were then used as input to the ArcInfo HILLSHADE module. A HILLSHADE simulation was run for each hour of the MWAT date. The results then were weighted to reflect variations in solar intensity during the day, using the solar radiation intensity distribution for July from the Solar Pathfinder sunpath diagram for a horizontal collector at 37-43°N latitude. These results were summed to develop watershed-scale portrayals of shade conditions.

GIS Model

The GIS model consists of the combination as appropriate of coverages of current and potential vegetation heights and extent, topography, and sun track to estimate shading on the streams of the watershed for both current and an idealized potential shade condition. Potential shade conditions were reduced by 10% to represent an adjusted potential shade condition that was used in developing target stream temperatures.

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ATTACHMENT A-4

TMDL Sediment Source and Delivery Assessment Methods—Navarro and Van Duzen rivers.

The general approach taken by the North Coast Regional Water Quality Control Board (NCRWQCB) staff has been to:

1. Collect and review existing sources of data
2. Identify data gaps
3. Fill in the gaps, either by contracted or in-house analysis to the extent possible
4. Analyze processes, causes, and extent of sediment delivery

Our TMDL staff will soon be meeting with scientists from the Redwood Sciences Lab and Humboldt State University to discuss ways of improving collection and analysis of data.

The Navarro Approach

The Navarro River sediment source assessment provided an order-of-magnitude level analysis of sediment delivery in the Navarro Watershed, and represents the approach taken in a case of limited data, limited resources, and limited time. The analysis did, however, allow staff to make a sound judgement about the origin and nature of human-caused sediment delivery. In short, the analysis showed that roads are the primary anthropogenic activity causing increased sediment delivery. The coarse nature of the analysis, however, limited the ability of staff to draw specific conclusions.

A significant amount of information used in the sediment source analysis came directly from the Navarro Watershed Restoration Plan (NWRP). Estimates of sediment yield rates from hillslope and streamside processes reported in the NWRP were incorporated into the sediment source assessment. The rates reported in the NWRP were derived from field reconnaissance and measurements, as well as literature values taken from studies of similar watersheds.

Data describing current conditions of rural roads were obtained from Pacific Watershed Associates (PWA). The data are based on detailed surveys of forty miles of roads in the Mill and Dago Creek subwatersheds conducted during the summer of 1998. The data were assumed to reflect the typical conditions of rural non-industrial dirt roads in the Navarro River Watershed.

Information pertaining to sediment yield on industrial forestlands was taken from the Albion Watershed Analysis (Mendocino Redwood Company 1999) and the Garcia Watershed Analysis (Louisiana-Pacific 1998). Data describing rates of sediment yield from industrial timber roads, skid trails, and hillslope processes in the neighboring watersheds were used to estimate the sediment contribution from the same sources in the Navarro watershed. Data from the Garcia watershed were assumed to be an upper bound, and data from the Albion watershed a lower bound, based on the opinion of Chris Surfleet, Mendocino Redwood Company Watershed Hydrologist (Surfleet 2000).

Aerial photos taken in 1984 and 1996 were analyzed to quantify sources of erosion (shallow landslides, deep-seated landslides, new gullies, road surface area, etc.) and their associated land uses, to improve the road database, and to quantify the location and extent of lands under cultivation. The results of the exercise provided Regional Water Board staff with high quality estimates of the length of roads in the basin, the length of recently built roads, the frequency of use of those roads, and the magnitude of management-related mass wasting (not related to roads) in relation to natural mass wasting. This information was then multiplied by rates taken from other studies to generate estimates of sediment delivery scaled to the magnitude of processes in Navarro watershed.

Erosion features that existed on the 1996 photos but not on the 1984 photos were measured in order to gain information on the rate of erosional processes since 1984. The reasons for choosing the '84 to '96 time period were that it represented current land management trends, spanned a time period that included a variety of water years (normal, wet, and drought), and revealed the current extent of the road network. The areal extent of each erosional feature was measured and a depth assumed for each type of feature. Landslides were assumed to have a depth of 5.5 feet and road fill failures were assumed to have a depth of four feet, based on data from surveys conducted by Louisiana-Pacific in the Garcia River watershed.

For each erosion feature a determination was made as to whether or not the feature was related to a management activity. Features were determined to be management related if there was evidence of past ground-disturbing management activity. Examples of such cases include; road fill failures, gullies and shallow debris slides in vineyards, gullies originating from new roads, landslides in clear-cut timber harvest units, etc.

Rates of road-related sediment yield were developed from a variety of data. Rates of road-related surface erosion for non-industrial forest and rangeland roads were derived from combinations of locally collected data and a modified version of the Washington Forest Practices Board's (WFPB) watershed analysis methodology. Values of average road width and hydrologic connectivity provided by PWA were combined with aerial photo data to provide information required for road surface erosion estimates via the modified WFPB methodology

A map of the road network was created based on interpretation of aerial photos. The study period used to characterize the road network was from 1984 to 1996. Roads were categorized as being built before or after 1984 and as either primary, secondary, or as recently abandoned / rarely used. Roads that existed in the past but were un-drivable in 1984 were not recorded. It was assumed that these roads have not contributed a significant quantity of sediment since 1984. This assumption was based on observations that on these roads many stream crossings had already failed, unstable fills had already caused debris slides, and the gullies originating from these roads appeared to have stabilized.

The categorization of roads by use level was a subjective process. In most cases, the level of use a road received was apparent; roads that lead to residences can be categorized as primary with a high level of confidence, as can roads that are rarely used. Categorization of secondary roads was more uncertain. Generally speaking, roads were categorized as secondary when they appeared to receive frequent use (i.e. no vegetation on road surface) but did not lead to primary structures, such as houses and farming facilities. When roads led to small cabins or barns, which are often only used seasonally, a subjective judgement was made whether the road was primary, secondary, or rarely used. In cases where staff felt uncertain, the higher use level was assumed.

Stream crossing erosion yields were estimated by combining information from surveys of 109 stream crossings in the Navarro Watershed (Hagans 2000) with detailed stream crossing erosion data collected after large flood events in Washington, Oregon, and Northern California (Furniss et al. 1998). Rates of stream crossing erosion associated with large storms were estimated by applying the rate of failure and distribution of fill volume erosion reported by Furniss et al. to the average volume of stream crossing fill in the Navarro River watershed.

The approach assumes that the rate of stream crossing failure (68%) reported by Furniss et al. (1998) is representative of the rate of failure resulting from large storm events in the Navarro watershed. Regional Water Board staff then used information describing the proportion of stream crossings failing by a given percentage reported by Furniss et al. (1998) coupled with the average fill volume of stream crossings in the Navarro River watershed, to estimate the amount of sediment eroded from stream crossings during large storm events. Regional Water Board staff conservatively used the upper bounds of fill volume erosion. This may tend to overestimate the true rate of delivery, however the lack of accounting for stream diversion at failed crossings leads to an underestimate. Regional Water Board staff assumed that these two factors roughly cancel each other.

Large storms triggering stream-crossing failures were assumed to occur every ten years, twice since 1980. The assumption that storms triggering stream crossing failures occur once every ten years on average seems reasonable given the flood record. The analysis assumes that the processes that led to stream crossing failures on the road networks surveyed by Furniss et al. (plugging by woody debris and sediment, debris torrents, and hydraulic capacity exceedance) are the same processes at work in the Navarro River watershed. This is reasonable given the similar vegetation, climate, and geology.

Rates of road-related mass wasting on rural non-industrial forest and rangeland roads were estimated from the estimated landslide yield per mile of road reported by PWA. The landslide delivery PWA reports is not time specific. In order to estimate an annual delivery rate, the landslide yield was assumed to be delivered during large storm events. The estimated landslide delivery then was divided by ten years, the estimated rate of occurrence of storm events triggering landslides.

Road-related gully erosion was estimated by best professional judgement based on on-the-ground-observations, aerial photo observations, and the judgement and experience of Pacific Watershed Associates (Hagans 2000). The road-related gully contribution was estimated to be approximately equivalent to the road-stream crossing erosion contribution. The estimated volume of sediment delivered to streams due to failed stream crossings was divided by the total length of roads. The resulting average stream crossing delivery per mile of road was then applied to the length of roads in each subwatershed to estimate the contribution of road-related gullies. The resulting estimate is likely an overestimate of the true rate of delivery associated with road-related gullies. This conservative estimate is incorporated into the margin of safety.

Very little information describing rates of soil loss from vineyards was available for estimating soil loss from vineyards. The two documents that reported estimates of vineyard erosion simply stated that rills develop and soil loss becomes noticeable when erosion reaches 15 tons/acre/year (White 1986) and 8-15 tons/acre/year (Sotoyome Resource Conservation District 1999). Observations made by Regional Water Board staff indicated that conservation practices used by vineyards (cover cropping, buffer strips, terracing, etc.) are variable. Vineyards with active erosion occurring, as well as vineyards with no soil exposure, were observed. Rate of sediment yield from vineyards was estimated to be 5 tons/acre/year by assuming that the average rate of soil loss is 10 tons/acre/year and approximately 50% of eroded soils reach the stream network. Regional Water Board staff acknowledges the considerable uncertainty of the estimate, however in the absence of better information, estimates erring towards protection of the resource are required. The estimated rate of sediment yield associated with vineyards is assumed to slightly overestimate the true delivery rate, this conservative estimate is incorporated into the margin of safety.

Estimated rates of sediment delivery attributed to shallow debris slides were taken from values reported in the NWRP and modified based on aerial photo analysis. Entrix et al (1998) estimated the long-term rate of shallow debris slide delivery associated with natural processes by applying results of studies conducted in similar watersheds. Entrix et al (1998) did not estimate rates of shallow debris slides caused by management activities. To address rates of management-related shallow debris slides, Regional Water Board staff analyzed aerial photos and estimated the ratio of anthropogenic-to-natural shallow debris slides. The results indicate that sediment yield associated with management related shallow debris slides (not including road-related slides) is approximately 32% of the yield associated with shallow debris slides attributed to natural processes.

Rates of sediment yield from erosion of stream banks and near-stream shallow debris slides were also taken from the NWRP. Entrix et al (1998) estimated long-term rates of bank erosion for first and second order channels by applying rates of soil creep reported in studies of similar geologic terrain to the channel network. The analysis assumes that rates of bank erosion in these small sub-basins are currently in equilibrium with rates of soil production.

Entrix et al (1998) used studies of gully erosion in similar watersheds to estimate the sediment yield of gullies in the Navarro River watershed. They used measurements of gully expansion from the Willow Creek watershed in Sonoma County and the Lacks Creek watershed in Humboldt County to estimate gully yields in the melange terrain of the Navarro watershed. Rates of gully erosion in the semi-coherent Coastal Belt geology were approximated from sediment yield studies of Lone Tree Creek in Marin County and Redwood Creek in Humboldt County. Regional Water Board staff compared aerial photos of Lacks Creek, Redwood Creek, and Lone Tree Creek to aerial photos of areas of the Navarro to verify the applicability of measured rates. Comparison of the photos supports the applicability of gully erosion estimates from the studied watersheds to the Navarro River watershed. These photos show that the size, extent, and density of gullies are similar in the reference watersheds when compared to the respective areas of the Navarro watershed.

Sediment yields attributable to erosion of skid trails was also estimated from data reported in the Garcia and Albion Watershed Analyses. The average rate of skid trail erosion per square mile of areas harvested by tractor yarding in the Garcia and Albion watersheds was applied to the area harvested by tractor yarding in the Navarro River watershed. The assumption is that tractor yarding practices employed on L-P's Garcia and Albion properties has resulted in nearly the same rate of sediment delivery as tractor yarding practices on timberlands in the Navarro watershed.

The uncertainty of the sediment yield estimates highlights the need for higher quality data, as well as the need for revision of the TSD as new data becomes available. Multiple data collection and analysis efforts are currently underway in the Navarro River watershed. As these data become available in the next few years, the Navarro Sediment TMDL should be revised to reflect the new information.

Despite the uncertainties of sediment yield estimates, the source analysis and data presented in the summary of water quality impairments supports the following points:

1. Sediment yields in the Navarro River watershed have been dramatically increased by human activities, primarily the construction and existence of roads.

2. Salmonid habitats have been significantly degraded as a result of excess sediment loads, particularly fine sediments.

3. Most human-induced processes attributed to increased sediment yields are easily prevented and corrected.

The Van Duzen Approach

Although the Van Duzen River (VDR) Sediment TMDL was prepared by USEPA, it represents what NCRWQCB staff believes is the best approach taken thus far for providing the information required to complete a sediment TMDL. We anticipate applying the methodology developed in the VDR Sediment TMDL to the Mattole River Sediment TMDL. A more detailed description of the methodology is available in the VDR TMDL document at http://www.epa.gov/region09/water/tmdl/vanduzen.pdf

The following excerpts from the USEPA VDR TMDL document summarize the approach:

> The sediment source analysis consisted of five main components or tasks conducted by Pacific Watershed Associates (PWA), for use in developing the VDR TMDL:

1) a review of previous studies which quantified or discussed past sediment production and yield in the VDR:
2) an aerial photo analysis of large landslides throughout the VDR;

3) a field inventory of 80 randomly selected 41.8 acre parcels to measure all past erosion and sediment yield;
4) extrapolating results from the randomly-selected sample plots to the remainder of the watershed; and
5) an analysis of regional literature to quantify earthflow sediment production processes.

PWA, with assistance from statistician Jack Lewis (U.S. Forest Service, Redwood Sciences Laboratory), developed a statistically valid, stratified, random sampling scheme to estimate total past erosion and sediment yield to the Van Duzen River and its tributary streams. The approach relied on extensive field inventory and aerial photographic analysis throughout the VDR in order to estimate the magnitude of past erosion and sediment yield, and to determine what percent of the past erosion and yield has some association with the variety of land management practices occurring in the watershed.

A total of eighty (80) plots, each totaling 41.8 acres in area, were randomly located throughout the basin, and "weighted" according to predicted rates of sediment delivery from the five main terrain types (i.e., stratum or general bedrock types as depicted in the Van Duzen River Atlas (DWR 1975). The sediment yield rates were based on estimates made by Kelsey (1977) from the upper 60% of the watershed through 1975. Table 4.1 identifies the terrain type, the area of the basin each covers (in square miles and percent), percent of the total predicted sediment yield from each terrain type and the associated number of field plots for PWA's study. A higher proportion of plots were located in terrain types consisting of higher estimated percent sediment yield, in order to increase the accuracy in quantifying total sediment yield. For example, 25 random plots were selected for the "sandstone, potentially unstable and active slides" which had a projected sediment yield of 40%, compared with only 4 plots located in the "melange, generally stable, serpentine, alluvial terrain which had a projected yield of 3% of the total.

In addition to the field plots, PWA conducted an analysis of aerial photographs for selected years throughout the watershed in order to accurately account for the large debris slides which constitute a small area of the basin but a high rate of sediment delivery. In the lower 40% of the watershed (205 mi^2), PWA (1998) previously analyzed sediment production through 1994 using aerial photographs. For this study, PWA further analyzed 1997 aerial photos for the same lower basin area to document all landslides greater than 5000 yds^3 in size. Likewise, for the upper 60% of the watershed, where landslide histories have been compiled by Kelsey through 1975, PWA analyzed either 1984 or 1988 and 1997 aerial photos to update the occurrence of landslides larger than 5000 yds^3 throughout the watershed. Features smaller than 5,000 yds^3 were accounted for through the field plot samples.

This approach is favored by NCRWQCB staff for the following reasons:

1) The approach allows for statistical estimates of confidence,
2) It quantifies volumes of small erosion features through on-the-ground surveys,
3) It identifies and verifies all of the largest erosional features (debris slides and other large mass wasting features),
4) It can easily integrate mass wasting data generated by Division of Mines and Geology,
5) It integrates existing information,
6) It is cost effective, and
7) It generated great support by landowners.

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ATTACHMENT A-5

STREAM SEDIMENT MONITORING AND ASSESSMENT PROTOCOLS

Background
This protocol presents sampling methods for V*, thalweg and cross-sectional profiles, pebble counts, and sediment cores for surface and subsurface sediment quantity and quality measurements in select stream reaches and rivers of Northern California. The procedures have been adopted from assessment and monitoring techniques that characterize fine sediment distribution in pools and riffles. Excessive fine sediment deposition in either pools or riffles is believed to reduce the overall suitability of instream habitat for aquatic organisms, particularly critical life stages of cold-water anadromous fish. Fine suspended or settled sediment can have negative impacts on cold-water fish during critical life stages. Suspended sediment blocks light affecting feeding and movement of fish and can cause gill damage that may increase mortality at high concentrations. Settleable sediment in the instream environment may physically prevent fry emergence, reduce or prevent proper redd aeration, hinder dissolved oxygen exchange to incubating eggs and the removal of metabolic wastes from developing embryos. Other effects of excessive sediment include fatality, stress, altered behavior, and reductions in growth and abundance (University of California Extension, Harper, et al. 1998).

V-Star (V*)

V* measures the volume of sediment in residual pools divided by the residual scoured pool volume and was developed to assess the supply of fine sediments being transported in a stream system (Lisle and Hilton 1992). The volume of fines deposited in a pool can be used to evaluate and monitor channel condition and sediment sources. Pool volume has consistently been identified as an important aspect of pool habitat and appears to be vulnerable to increased sediment loads from watershed disturbances. Reductions in pool volumes reduce summer and winter holding capacities for salmonids (Stuehrenberg 1975, Klamt 1976, Bjornn et al 1977). Bjorn et al (1977) found that the effect of introducing enough fine sand into a 3rd order stream pool to reduce its volume by half (a V* of 0.5) caused fish numbers to decline by two-thirds. Since pool habitat has often been correlated with the size and volume of pools (Heifetz et. al 1986 and Lau 1994) it follows that decreasing a pools volume by introducing excess sediment will simplify pool habitat, also resulting in decreased substrate diversity. If pool habitat is limited in a given stream then this will translate into reductions in overall stream productivity and adverse impacts to the survival of cold-water fish.

Sampling protocols on the North Coast for V* pool selection targeted pool-rifle channels with a 2-4% gradient in Rosgen B-3 channel types. These criteria were selected because they provide much of the spawning and rearing habitat for anadromous fish (Knopp 1993). V* was found to have utility in other Rosgen B and C gravel channel types; bedrock-boulder channels were found to give mixed results and may not be reflective of upslope land use and natural disturbance activities in a particular watershed (Lisle and Hilton 1993). Surveying from the top of a reach of approximately 1,000 meters a minimum of six pools, as they are encountered, is selected based on the following criteria:

- The pool should have a nearly horizontal water surface (slope <0.05) during low flow (a smooth water surface will suffice).
- The pool should occupy the main part of the channel.
- The pool should have a maximum residual pool depth (below the riffle crest), equal to twice the riffle crest depth, as measured through the sediment to the scoured pool bottom.
- The pool should not be formed as a result of woody debris. Wood in the pool is acceptable, but it should not be the pool-forming mechanism.

After pool selection the riffle crest is determined by probing a ½-inch stainless steel rod at the lower edge of the pool as it transitions to a riffle. The riffle crest determination is important because this depth determines the residual pool volume (volume of a pool filled to the point of spilling at the riffle crest). If the riffle crest is obvious, one or two probes is usually sufficient to determine the depth. If the riffle crest is indistinct several measurements should be taken across and above and below the apparent riffle crest, and then averaged to estimate the pool's riffle crest. The rod should firmly penetrate any loose sediment until an armor layer resists further penetration. Loose gravel should be probed through, but cemented or otherwise armored gravel should be measured as the riffle crest depth.

Next, transects are located to characterize the pool's morphology and sediment deposits. Visually surveying the pool before disturbing bottom sediments helps determine likely transect locations. A transect tape is anchored across the chosen pool cross section and is referenced to a longitudinal tape anchored at the pool head and tail (meter tapes should be used for ease of data analysis and adherence to uniform field protocols). The longitudinal tape remains in place during transect measurements. Usually a minimum of four transects is necessary for simple pools; more complex pools may require eight or more transects.

Penetration rod sampling across a transect varies at about 0.5 meter intervals, measuring ten or more points across a transect. Sample points should include bottom profile breaks and sediment measurements as necessary to best define the pool's sediment cross-section. Measurements are taken from bank-to-bank at all points that are less than or equal to the pool's riffle crest. Often sediment deposits extend to and above the banks of a pool, or are elevated above the pool surface but the probe can still reach water within the pool. This water and sediment is considered within the pool up to the point where the water measured under the sediment is less than or equal to the riffle crest depth.

All data measurements are entered in a field data sheet that includes the stream name, pool number and its distance from the start of the reach, riffle crest depth, pool length, transect intersects, etc.

Depending on the intent of the monitoring study, the pool location should be surveyed to a known monument or geo-referenced with a GPS receiver to a GIS database. An accurate drawing that includes the major features of a pool (such as the locations of LWD, rock outcrops, sediment deposits, thalweg, etc.) and/or photo documentation of each pool should be completed and included in the data file. Drawings and photographs can provide a visual snapshot of changes in a pool's morphology and sediment load over time and are also helpful when used in conjunction with GPS coordinates upon returning to a location for repeat assessments or long term trend monitoring.

Refer to Hilton and Lisle (1993) for a more detailed description of field techniques for measuring and calculating V*.

Pebble Counts

One of the most widely used methods of sampling grain size from a streambed is the pebble count technique (Wolman 1954). It can be used as a simple and rapid stream assessment method that may help in determining if land use activities or natural land disturbances are introducing fine sediment into streams (Potyondy and Hardy 1994). Pebble counts are routinely used by geomorphologists, hydrologists and others to characterize bed material particle size distributions of wadable, gravel bedded streams. The procedures have been adapted in fisheries studies as a preferred alternative to visually characterizing surface particle sizes commonly used during instream flow studies (Kondolf and Li 1992). The methodology is best applied in gravel and cobble streams with a single channel and are not applicable to lower gradient, sand-bed dominated channels.

Pebble counts are conducted by randomly collecting, counting and measuring the intermediate diameter (b-axis) of 100, and up to 200 (Kappesser 1993) particles from the surface of a given streambed. Riffles deemed suitable for spawning salmonids are the preferred location for sampling efforts (Schuett-Hames, et al. 1999). Pebbles are collected along transects at measured points following a predetermined grid pattern, or by walking the streambed and picking up individual pebbles at the toe of a boot along a toe-to-heel, zigzag pattern. Whether the structured grid pattern or the toe-to-heel method is used, all transects should traverse the stream channel from the estimated bankfull to bankfull stage. Transects should encompass a relatively homogeneous gravel bed surface, and are spaced to encompass the upstream, mid- and downstream extent of the habitat unit being surveyed. Distinct populations of heterogeneous bed material, such as gravel-cobble, finer grained gravel, and sand-gravel mixtures in a sampling unit can also be adapted to pebble techniques by stratifying distinct sample size populations and then developing size distribution curves for each distinct population on the streambed (Lisle 1989 and Kondolf and Li 1992).

After the pattern of transects is determined (grids or zigzags) sampling involves selecting individual pebbles by the sampler as he/she places a finger at the boot toe for each step taken. The sampler should avert or close the eyes at the last minute to lessen bias toward selecting larger or more distinctive particles. To further eliminate sampler bias it has been suggested that a fixed point on the boot and pointing finger should be used for each pebble encountered (Kondolf and Li 1992, Potyondy and Hardy 1994). Samples are tallied into size classes using the Udden-Wentworth scale as less than 2mm, 2-4mm, 4-8mm, 8-16mm, 16-32mm, 32-64mm, 64-128mm, 128-256mm, 256mm-512mm, and 512mm-1024mm. Some researchers count large particles for as many times as the toe encounters it, placing them in the larger size classes (Kappeser 1993). As mentioned, Schuett-Hames, et al. do not count non-spawning habitat within the sampling unit, this would eliminate counting large substrate particles, such as buried boulders and bedrock bottoms within the bankfull channel. However, those structures are noted on the field forms when encountered.

After at least 100 pebbles are sampled cumulative size distribution curves can be developed for the D50, median particle size, the diameter at which 50% of the particles are finer, and the D16 and D84, the diameters at which 16% and 84% of the particles are finer. Other analyses that may be applied are the geometric mean diameter: dg = D84 x D16)$^{0.5}$ and the geometric sorting coefficient: sg = (D84/D16)$^{0.5}$ (Kondolf and Li 1992). As mentioned, it has been shown that shifts toward the lower end of the pebble count cumulative frequency curves may be indicative of significant increases in streambed fines from accelerated natural and or land-use disturbances. Conversely, a progressive coarsening of streambed surface particles may indicate improving conditions from past upstream and/or upslope disturbances.

Channel Cross Sections

Channel cross sections (cross sections) are a relatively simple and inexpensive method for determining the topographic profile of the bed and banks of a stream along a transect perpendicular to the direction of flow. Cross sectional data, when used in conjunction with velocity-area measurements are necessary to accurately calculate stream discharge, and is extensively employed for this purpose at stream gauging stations worldwide. Additionally, cross sections can be integrated with other instream sampling parameters (see below) to more fully characterize channel attributes.

Within a reach a single cross section at a point in time and not associated with other stream assessment parameters is relatively useless. Generally, more information can be gathered over multi-year sampling events when a stream reach contains several cross sections. For utility and ease of reference, other parameters, such as scour chain and bank pin placement (for monitoring changes in depth and fill and bank stability, respectively), pebble counts, riparian canopy measurements, LWD surveys, etc., can also be combined and conducted at cross section locations.

Monitoring the long term changes in cross sectional data can provide insights into channel bed and bank stability, and relationships between sediment transport and discharge (Beschta and Platts 1986). For example, at Redwood National Park cross sections have been used to document and follow channel responses to sediment movement down Redwood Creek for a period of twenty years (Madej and Ozaki 1996). During this study cross sectional analysis showed that as the sediment wave moved downstream, the channel responded by widening or narrowing in relation to channel aggradation or degradation, respectively. Shifts, such as decreasing cross sectional area, are often associated with decreasing thalweg depth, widening of the channel width, increasing bed elevations and overall streambed aggradation. Channel aggradation and widening along with decreasing water depths can trigger a chain of events, including decreasing riparian canopy and associated water temperature increases, decreases in the abundance and quality of in- and near stream cover, and changes in available quality spawning habitat for resident and anadromous fish species. The aforementioned consequences could be indicative of upslope natural events or management induced impacts affecting the beneficial uses of water quality.

Conversely, changes such as increases in channel depth, channel narrowing, incision, and increasing cross sectional area may indicate overall channel degradation accompanied with its own set of beneficial or detrimental impacts to water quality. For example, channel incision and downcutting may be indicative of a return to more "natural" conditions from previous management and/or natural catastrophically related impacts (McDonald, et al. 1991). Channel downcutting may also result in bank failures and the toppling of riparian vegetation into stream channels. Other effects of changes in channel cross sectional area, whether reflected by channel aggradation or degradation, may be shifts in biological dynamics, such as macroinvertebrate and algal population increases or decreases and, possibly, species displacements due to loss and/or gains in available niches.

Depending on the variables measured, cross sections should be located in response to riffle-pool sequences or meander bend spacing, with replicates for similar morphological units within a study reach (Kondolf and Micheli 1995). Cross sections within a riffle-pool sequence can be further stratified to characterize spawning habitat (e.g. at the break from a pool tail to the head of a riffle), at numerous points across a riffle to stratify pebble count measurements, or within pools. Pools and riffles can also be further stratified by situating cross sections as a single transect, or in a grid pattern to more fully characterize any major features or sampling design characteristics (Hilton and Lisle 1993, Knopp 1993).

A typical study design can have as few as three, or as many as 15-20 cross sections located in a study reach. A reach has been variously defined as 20-50 bankfull flow widths (Kondolf and Micheli 1995), a thousand meters (Knopp 1993), or a predetermined length based on the geomorphic characteristics of the watercourse under study. For example, Madej and Ozaki (1996) defined a study area as 26 kilometers long in Redwood Creek from its confluence with the Pacific Ocean to a slope-determined end point. Within the study area the 26 km stream segment was divided into three interconnected reaches, an upper, middle, and lower reach. A total of 58 cross sections were nested within the three reaches. The end points of each reach were determined by major breaks in stream gradient. The proposed Garcia River TMDL (Lundborg and Manglesdorf 1997) uses Rosgen's protocols for identifying survey units within a reach (Rosgen 1996). Briefly, it defines a reach as 20-30 bankfull widths long in Class I and Class II streams. Three transects are then established across the bankfull channel in each survey unit where evenly spaced measurements of the depth to channel bottom are surveyed.

As can be seen above, there appears to be no standard methodology for establishing the length of a reach or the number of cross sections/transects within a reach. In general, protocols chosen should be chosen based on the variables to be measured, the geomorphic features of the stream segment, and the time frames allotted or deemed necessary to obtain valid sample results that will scientifically characterize the intent of the sampling design.

A cross sectional profile is developed by measuring points along a tape measure stretched across the stream and recording the distance, surface water, and stream bed elevations at each specific point along the tape. Stream bed characteristics, such as changes in bottom elevations, the position of the field estimated bankfull height, riffle crests, breaks in slope, and the deepest points in the particular channel feature being measured are recorded. The end points of the cross section are arbitrary, but they should extend at least above the estimated bankfull stage and preferably beyond the current floodplain. Cross section end points are often permanently monumented by driving pins or spikes in tree trunks that will not be subject to felling or damage, locating reinforcing bars or rods and/or brass plates set in excavations filled with concrete, chiseling marks into immovable boulders and bedrock, or other permanent marking methods unlikely to be modified or damaged by natural events, animals, trespassers, management activities, etc. The transect's end point with the zero measure should consistently be measured from the right bank or the left bank, depending on sampling protocols. When laying out cross sections, whether for riparian canopy surveys that may extend beyond the streams bed and banks, or for instream monitoring, the transect is always surveyed from a line established perpendicular to stream flow.

If change over time is to be monitored, the elevation data must be related to a permanent benchmark or other monument (McDonald, et al. 1991). Quite often cross sections are referenced to a permanent bridge (if available), permanently monumented end points of a referenced reach, base lines, or other known markers such as USGS gauging stations and topographic survey benchmarks. The monumented cross section should also be referenced to at least two other triangulation points.

Because field conditions may change from year to year to ease identifying specific cross section during future sampling events, the survey monuments should be photo documented from a prominent point within the unit while attempting to include other visible or nearby unique features. A site sketch, when used in conjunction with photographic prints or transparencies of surveyed monuments are also helpful upon return visits. After all reference points are established, photographed and documented, individual points along the cross section can be surveyed using traditional surveyor's transits, automatic levels, or total station theodolites sited to stadia rods.

Depending on the time frames of the study design, cross sections can be measured on an annual basis, after major floods (Madej and Ozaki 1996), other catastrophic events, such as landslides, or as a post and preproject assessment tool.

The Gualala River Watershed Council's 2001 quality assurance guidelines for cross sections are presented below as an example.

Parameter	Time scale	Spatial scale	Endpoints/units	Tolerated error	Supporting documentation	Prep by professionals
Cross-sections	1/yr (summer) or more frequently, depending on objectives	3 per 1000 ft reach is conventional; sites initially selected are likely spawning sites defined as riffles located at pool tails.	Elevation observations at inflections points with at least one intervening point between inflection points The most important features to measure are; riffle crests, breaks in slope and deep points of pools. Average spacing between observations equivalent to < 10% of bankfull width.	Measure elevation (± 0.02'). Survey closure within 0.01 ft for each turning point, plus 0.01 ft for each 500 ft of linear distance	Notes on how to locate beginning and ending points of reach, associated long-profile data	Survey-ing techniques, site selection

Sediment Core Sampling

The McNeil sampler and methods (McNeil and Ahnell 1960) are commonly used in the North Coast for stream substrate sampling and analysis for size composition. The basic approach is to excavate a streambed substrate core, then sieve the sample. The various size fractions in a geometric progression are measured by volume or weight and percent materials in each size class determined. Statistics from those measurements can be compared to values in the literature for suitability of spawning gravels for various species. The analysis also allows determination of D16, D50, and D84 values for the substrate beneath the surface of the streambed, useful in understanding sediment transport dynamics.

Valentine (1995) produced a perpetual draft procedural guide, which is attached to this section for reference to specific concerns regarding sampling location and sample handling and analysis.

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STREAM SUBSTRATE QUALITY FOR SALMONIDS:

GUIDELINES FOR SAMPLING, PROCESSING, AND ANALYSIS

(Perpetual Draft--January 4, 1995)[1]
(Minor edits, conversion to MS Word – April 10, 2001)

Bradley E. Valentine
Regional Biologist

California Department of Forestry and Fire Protection
Coast Cascade Regional Office
P.O. Box 670
Santa Rosa, CA 95401
(707) 576-2937

1 I intend to continue refining and updating this document as new information becomes available. Citations should include the draft date.

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STREAM SUBSTRATE QUALITY:
GUIDELINES FOR SAMPLING, PROCESSING, AND ANALYSIS
(Perpetual Draft--January 4, 1995)

WHO & WHY?

Agencies mandated to 1) protect the beneficial uses of the state's waters (Regional Water Quality Control Board), 2) conserve the state's fish and wildlife (Department of Fish & Game), and 3) provide environmental protection oversight during timber harvests on private and state lands (California Department of Forestry) are concerned about land use practices that accelerate the rate at which upslope materials are introduced to streams during timber harvest activities. Private timber companies and independent operators own and conduct timber harvest on large areas draining into the state's spawning streams. The state's concern multiplies in highly erodible watersheds where there have been / are to be large portions harvested in short periods and / or the watershed is characterized by highly erodible materials, especially fine sediments.

To carry out the mission of the agencies mandated to protect the state's water-related resources from sediment impacts, the state may ask project proponents to assess the condition of a stream's salmonid habitat. The form of sediment impacts to watercourses from land use activities is heavily dependent on geology (Lisle, pers. commun.), and thus the potential impacts should be considered when deciding which measurement tools to use. Lisle and Eads (1991) review several methods to measure sedimentation of stream channels with special emphasis on spawning gravels. Recent research (Knopp 1993) has investigated new methods to evaluate the effects of forest practices on the structural conditions of habitat. His results indicate that the measures V-star (the amount of fine sediments accumulated in pools), RASI (Riffle Armour Stability Index, which measures the composition of riffle-surface sediments), and D_{50} (median particle size of riffle gravels) could distinguish between watercourses draining unharvested watersheds and all other categories of watershed disturbance. However, the variables were less able to discriminate among streamcourses draining watersheds harvested either 1) greater than 40 years ago with no intervening activity, 2) those harvested more recently under either moderate upslope disturbance, or 3) those harvested with heavy disturbance.

An older and more "standard" measure of the impacts of upslope disturbance to cold water fish habitat is an evaluation of the substrate's particle-size distribution, long known for its relationship to spawning success and productivity of aquatic macroinvertebrates. Agencies may ask landowners to perform this analysis when concerns are expressed, or landowners may want to develop their own monitoring program. The purpose of this document is <u>not</u> to support or reject any particular process to evaluate sediment impacts to streams. Rather, it is to provide guidelines to parties requested by the state (through review team or other functions) -- or who chose to do so on their own volition -- to evaluate or monitor the stream beds on lands they manage with a stream-bed, grab-sample approach. This guidance generally follows that of Klamt (1976).

HOW?

Sample Extraction

Bulk samples of the substrate are collected with a McNeil sampler (McNeil and Ahnell 1964). Because the potential for bias increases as the size of materials sampled increases, the diameter of the sampler's core should be 2-3 times the largest particle usually encountered (Shirazi et al. 1981); the 6 inch diameter of Fig. 1 should be considered a minimum. A second approach to evaluate the appropriateness of sampler size is to test that the largest particle is < 5% of the total sample (Lisle and Eads 1991). Reports should provide a description of the dimensions (diameter and height) of the sampler used.

Recent research in Wyoming has showed that a 20 cm wide, 24 cm long shovel performed equally well or better than other methods in portraying the known size distribution of gravel in laboratory conditions (Young et al. 1991) and field conditions (Grost et al. 1991). Until further evaluated by agency personnel on the North Coast of California, and this guidance document is amended, the McNeil sampler remains the recommended approach because of the need to retain comparability with historic values.

The sampling tube of the McNeil sampler is manually worked into the substrate until the bottom of sample basin contacts the channel. The contents of the sampling tube are removed by hand and placed in the basin. The water remaining in the tube contains suspended material and must be removed with the plunger. The cork is removed from the plunger, the water in the tube agitated with the hand, and the plunger pushed down to the metal stop-pins. The plunger is then tightened by turning the handle. The cork is replaced and the sampler removed from the streambed. The contents (including the water and fines in the tube) are transferred to a bucket pending sieve analysis.

Sieve Analysis

Particle size analysis of the sample can take several forms. Dry-sieving involves returning the samples to a lab and following its own protocol. Therefore, it is usually only performed when the highest control on measurement error is required; e.g., research situations. The more common method is wet-sieving in the field, which this guidance addressees. Older research employed fewer sieves of a wide variety of meshes, thus various particle sizes have been related to substrate quality. To help alleviate this variability, more recent research (Shirazi et al. 1981) has recommended using a series of sieves following a geometric progression (e.g., 128, 64, 32, 16, 8, 4, 2, 1, 0.5 mm). The upper limit (128 mm) approximates the largest size particle in which most salmonids will spawn (Platts et al. 1983). To facilitate comparison with much of the older research employed other sized sieves, other sizes may be added into the series (e.g., 0.85, 2.36, 3.35, and 4.75 mm), with especially the 0.85 mm sieve recommended. Alternatively, the values for these size classes can be determined either graphically by plotting the cumulative percent retained, or mathematically based on the assumption that stream sediments are log-normally distributed (Platts et al. 1979).

From the buckets, samples are passed through the series of sieves using hand shaking and washing with water. While agitating the sample by hand in a sieve is useful in the sorting activity, use care not to force materials through the sieve because you will bias your sample towards finer condition and may compromise the usefulness of the sieve if the mesh is permanently deformed. The trapped sediment on each sieve is allowed to drain and is poured into a partially-filled graduated cylinder. The volume of particles within that size range is the difference between the cylinder's volume before and after adding the particles.

The sediments passing through the finest mesh screen (into the "pan") are poured into Imhoff cones (many samples require as many as five cones to handle the samples water content) and the suspended material permitted to settle for exactly 10 minutes. The volume (ml) of fines is read directly from the cone. For convenience and to minimize the number of settling cones, the volume of water used to wash samples can be minimized by using that water collected with the sample.

Particles retained by the largest sieve (128 mm) are not included in the calculation of the sample's metrics. However, their presence or absence should be indicated. The reasons for excluding these larger materials are: 1) larger particles may exceed the size in which most salmonids will spawn (Platts et al. 1983), 2) the presence or absence of unusually large particles can greatly affect the relative proportions of the other size classes (Young et al. 1991), 3) calculation of the geometric mean particle size requires the calculation of a diameter midpoint for materials retained in a sieve -- without the upper limit, a size larger than the screen must be arbitrarily designated[2], and 4) larger particles can exceed the diameter of the graduated cylinders, thus requiring the particle to be broken in order to measure. Breaking the particle often induces loss of pieces when shattered, and thus adds variability to the measure.

Regardless of the size of the largest particles sampled, measure the length of the intermediate axis[3] of the three largest particles in each sample. This information enables an analysis of the adequacy of the sampler core. If the frequency of samples in which the intermediate axis of the largest particles are > 1/3 – 1/4 the diameter of the sampling core, a larger sampler is indicated.

Consistency in performing the sieving and measuring process is important in order that the variability is minimized (and thus the number of samples necessary to characterize the substrate). Following are some hints:

- Minimize the amount of water in samples by 1) using squirt bottles to help rinse particles from the sampler into the storage bucket and using sample-water to rinse particles through the sieves.

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2 An alternative approximation of the geometric mean (Shirazi et al. 1981), calculated as:

$$d_g = \sqrt{d_{84} * d_{16}}$$

where d_{84} and d_{16} = diameter at the 84th and 16th percentile, respectively, may avoid the problem if $d_{84} \leq$ the largest meshed sieve. However, if $d_{84} \geq$ the largest sieve used, its exact value is indeterminable also.

3 The intermediate axis is that which controls what mesh sieve the particle could pass. It is the widest dimension which is perpendicular to the particle's longest dimension.

- The volume of water can be reduced, and transporting sample buckets to a central processing location can be eased if --upon placing the sample into the bucket from the sampler -- the bucket is allowed to sit ≥ 30 minutes and then about 1/2 of the standing water above the gravel is carefully decanted off the sample.
- Each sample being processed should have its own "working area" to avoid interchange sub-samples between samples.
- Before performing any of the volumetric displacements of a sample, sieve the entire sample.
- Place each sieve with its collected sample at an angle. This accelerates drainage of excess water.
- Place the sieves as described above, as much as possible, in the sun.
- For materials < 4.0 mm, allow ≈ 10 minutes drip-drying time by allowing these sieves to stand for the entire 10 minute time required for the settling cones.
- Materials < 4.0 mm which still show excessive water retention after 10 minutes can be further drained by placing in a small plastic bag, hand condensed, and the water decanted.
- Use the smallest graduated cylinder that can handle the sample portion of interest.
- For samples with substantial loads of fines (that in the pan), hand spreading the settled fines between the number of Imhoff cones necessary to handle the water (as opposed to placing most of it in one cone) will reduce volume estimate errors by causing the fine/water zone of contact to fall within the region of the cone with the finest volume resolution.
- Having multiple sets of sieves can enhance the number of samples simultaneously processed.
- (An) Additional sieve(s) of the largest mesh can act as "extension walls" for sieves of smaller mesh when the volume of a given sample-fraction is larger than conveniently manipulated by the sieve alone.
- Having at least two sets of most of the items per sample processed at a time helps speeds sample processing.

The volume of each sample fraction is recorded on the data sheet, along with other supportive information. Comments on location, proximity to a suspected redd, sample point conditions (e.g., rooted aquatic vegetation, embedded woody material, presence of clay layers or rocks too large to sample) should be recorded, as well as stream, date, and sampler information.

WHAT?

Sample Metrics

The results of substrate sampling have several potential forms of expression. Older analysis presented the results as the percent of a sample less than a given size (e.g., Klamt 1976). Now, other metrics of substrate quality have gained favor (Platts et al. 1983, Chapman 1988, Young et al. 1990) because they 1) improve the ability to compare results among studies, and 2) provide a fuller measure of the substrate's physical conditions and biological functions. To facilitate comparison with older results, and to assure continued interpretation, the results should be expressed in three forms: 1) Percent finer, and graphically, 2) the Geometric Mean, and 3) the Fredle Index.[4]

The volume of materials collected on each sieve is determined and recorded on the data sheet (see Appendix 2). Within a sample, these are then summed and each sample fraction is divided by the total to derive that sieve's percent of sample retained.

Percent Finer.-- From the sample's volume-retained value by each sieve/pan, the percent finer for any sieve size employed is easily calculated by tabulating the cumulative percent of the sample passed figure (See Table 1 for an example). Such a table will explicitly indicate the percent of a sample finer than each sieve employed, enabling others to assess or use the information. The 0.85 particle size is frequently used to define "fines" and should be explicitly presented. When the sieve series employs the 0.85 mm sieve, the table will present the value measured. If the 0.85 mm sieve is not used, than the percent retained can be calculated mathematically by assuming the sample is log-normally distributed. If the full series of sieves is employed, a simple arithmetic extrapolation between the percent retained in the 0.5 and the 1.0 sieve will likely be accurate enough. Each sample should be graphed (see example in Fig. 1), and the percent finer than the 0.85 mm size can be estimated using a perpendicular triangle based at the desired size on the x axis.

Geometric Mean.-- The geometric mean is a measure of central tendency of the sample calculated using the size distribution of the entire sample. Following the methods described by Lotspeich and Everest (1981), the geometric mean is calculated as:

$$d_g = d_1^{w1} \text{ x } d_2^{w2} \text{ x } d_3^{w3} \text{ x} \ldots d_n^{wn}$$

where:

d_g = the Geometric mean,
d = midpoint diameter of particles retained by a given sieve and the next larger sieve,
w = decimal fraction by volume retained by a given sieve, and
n = the number of sieves used, inclusive of the pan.

Fredle Index.-- The Fredle Index (F_i) is a value which characterizes a sample by both its central tendency and a measure of its distribution. It is calculated following:

$$F_i = \frac{d_g}{\sqrt{\frac{d_{75}}{d_{25}}}}$$

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4 A BASIC computer program to calculate these values is available. To obtain a copy, contact the author on this report's title page.

where:

d_g = the geometric mean as calculated previously, and

d_{75} and d_{25} = the particle size diameters at which 75 or 25 percent, respectively, of the sample is finer on a volume basis, as estimated from the graphs or from a mathematical calculation assuming a log-normal distribution.

Correction Terms.--Some investigators have applied correction terms to the results of sample processing. This is due to 1) the fact that the amount of water retained in a fraction of a sample is negatively correlated with particle size and becomes significant below 4.0 mm, and 2) the spawning action of fish winnows fines from the substrate, thus resulting in a coarser gravel distribution in a redd as opposed to the adjacent streambed. Because 1) the correction factor required for water retention is dependent on rock type (e.g., the rock density, clay content, etc.), 2) the amount of cleansing accomplished by a spawning fish varies based on factors such as fish size, rock density, water velocity, and surrounding substrate conditions, and 3) many older research results did not subject their work data to correction factors, this guidance recommends that any results be presented without corrections, or if corrected, then both values presented. If corrected values are also presented, then the correction functions need to be clearly described and justified. To ensure comparability when comparing your results with other's data, report whether their results were corrected or not, and if so, what correction factors they used.

Statistics.

Sample metrics can be summarized using means, standard deviations, standard errors and/or confidence intervals. Differences among groups of samples (different streams, sites within streams, or years) can be determined following Analysis of Variance tests, or comparable non-parametric test (e.g., Kruskal-Wallis Test). Standard statistical texts can be consulted to direct hypothesis testing on sample metrics.

Number of Samples.

The number of samples necessary to characterize a stream or make comparisons is largely a statistical question, based on the sample's variance, how certain the agencies must be in detecting a difference, how much difference must be detected, and the significance level (α) desired for a test. At a minimum, 10 samples should be used. Standard statistical texts can be consulted on methods to evaluate sample size.

WHERE?

The question of "where" to sample must consider the "universe" to which the results are to apply, and how the results are going to be used. Defining the universe is important, as it determines what can be ascertained from the sampling efforts. Generally speaking, because sedimentation of fines is less of a problem as stream gradient increases, bulk sampling of the substrate should be limited to locations where both gross (as measured on a USGS quad) and site (as measured in the field with the sampling location 1/2 the distance between the upstream and downstream reach > 5x the full channel width) gradient are less than 3%. Streams to be sampled should be restricted to those that are 5*th* order or smaller, as ordered using bluelines on USGS quads. Examples of sampling universes for substrate characterization follow.

Entire Channel Conditions.

If the universe to which the results are to be applied is the entire stream bottom, then a random sampling scheme should be developed in which all of the bank-full channel is subject to sampling, regardless if the point is outside the water, in a pool, or in a riffle at the time of sampling. Such a scheme may tell much about the characteristics of the stream bottom in total, but will not be useful in evaluating spawning habitat conditions or to some extent, the amount of stream-generated food. This is because such sampling may occur in locations that either are infrequently wetted for a period adequate for fry to emerge, in locations in the channel in which salmon are unlikely to spawn (pools), and the invertebrates produced and available to salmon vary based upon aquatic habitat type and its frequency and duration of inundation. Use of the quality comparisons based on standards taken from redds is entirely inappropriate when this sampling universe is selected.

Redds

If the sampling universe is salmonid redds, then sampling should be conducted in randomly sampled redds after young have emerged. Because the size distribution of gravel can deteriorate substantially between egg laying and fry emergence (Lisle and Lewis 1992), waiting until emergence allows the conditions of the intragravel environment to be assessed. This will best allow statements about the quality of the spawning gravel as related to productivity. Waiting until after emergence further avoids unnecessary mortality. However, because of the inability to know when likely dates of emergence and variable flow conditions during that season, sampling redds is problematic. Sampling redds will best allow your sample to be compared with the results of others who have evaluated the relationship between substrate composition and survival to emergence. However, few local studies have done so. Use of the "relevance" section's quality indicators for samples from this universe is most appropriate.

Pool/Riffle Breaks

These guidelines recommend collecting one bulk sample from the thalweg (deepest part of the stream) at a point near where the water begins to accelerate as it passed from a pool into the head of a riffle. A random sampling criteria for selecting which pool/riffle break to sample would be statistically appropriate. However, due to the logistics of collecting and transporting samples to a processing station, some restriction to points of access (road crossings) is an acceptable deviation (this constraint applies to all sampling universes). The point of access can function as the center point, with samples being collected each n^{th} pool/riffle break upstream and downstream, where n is a random number between 0 and 5. This deviation from random sampling for logistic justifications may bias samples towards finer substrates if the roads are actively draining into the stream. In this case, comparing samples from downstream and upstream of the crossing may elucidate this potential problem.

Restricting the sampling universe to pool/riffle breaks is recommended because 1) salmonids preferentially select sites to spawn near the tail of a pool or at the head of a riffle (Fry 1979, Bjornn and Reiser 1991), 2) the water velocity is commonly greater at this point during low flow periods thus reducing the impacts of low-flow period sampling on summer accumulations of fines, and 3) for comparative purposes -- others have approximated it (Burns 1970, 1972) in regional studies. Thus, such a sampling scheme's results are related to conditions from which salmonids are likely to choose to spawn, but not to redds per se'. Randomization enables the results to be extended to all portions of the reach which meet the gradient and stream order criteria, as well as enhances the theoretical basis for statistical tests.

Sampling under this scheme will allow limited comparisons with other researcher's findings regarding the relationship between substrate condition and survival to emergence to a limited extent. Because this scheme does not sample from redds which would have some fines winnowed by the action of spawning, your samples' true value is likely to be greater than those of researchers who report on conditions within redds. Further restricting sample location to those used by spawning fish will make comparisons with research data more appropriate. For example, Reeves et al. (1989) indicate that coho salmon spawning habitat should be 1) dominant gravels between 1 and 20 cm (about pea to orange size) 2) of a contiguous area at least 2 m^2.

If the purpose of sampling is for monitoring, randomization of sampling points will alleviate possible sampling-induced alterations in the sampling universe (See discussion below under "When").

A final consideration for locating sampling stations is to attempt to associate the results with either historic sediment studies or with other projects. Co-locating your sediment sampling universe within stream reaches used by others (e.g., a fish population sampling station, Burns' study reaches) can provide useful information about fish habitat potential and how it has changed on-site. However, this criteria will limit the extent of the universe to which your results can be extended to the vicinity of that site. Extension to larger areas should be practiced with caution.

Whatever sampling universe you select, its clear definition in your report is very important.

WHEN?

If the sampling universe is the entire stream channel, samples should be collected during the summer low-flow period to minimize logistic and sampling difficulties associated with deep and fast flows.

If the sampling universe is redds, sampling should follow soon after young have emerged. Prior to that time, substrates should not be sampled to avoid unnecessary killing of fish, and to be able to evaluate conditions during the entire period of intragravel development.

If the sampling universe is the pool/riffle locations, sampling should be done during the summer low flow period. This timing avoids the high-flow problems. Late summer samples may be sensitive to sediment accumulation between fry emergence and sediment sampling. However, this condition is minimized because the pool/riffle interface is a hydraulic location of relatively high water velocity, even during the low flow period.

A final consideration in determining when to sample is the study's purpose. Timing may be less important if a one-time, snap-shot of sediment condition is the goal. If the results are to be compared to those of others, then you should attempt to sample during a similar portion of the hydrograph as did they. If your purpose is to monitor (evaluating trends over time [years]), then the sampling period should be repeatable at each time when sampling is projected. Frequency of sampling for a monitoring program should take into account annual variability and sediment loads in the stream in question; additional guidance should be sought from the responsible agencies. In evaluating the sampling frequency, the potential that sampling without replacement in stream systems which are supply-limited for gravel (>≈10 mm) could result in declines in the substrate's size distribution should be considered. This hazard would be greater in a sampling regime which sampled the same location each year for a number of years, and would be least important if the sampling regime was fully randomized.

Should shovels become the standard sampling tool, sampling during the extreme low-flow period is mandated because higher water velocity will bias the sample toward a higher than "true" average particle size (Grost et al. 1991, Young et al. 1991).

SO WHAT?

Research has shown that excessive erosion and land-sliding can limit fish populations -- most notably anadromous salmonids -- at several times in the species' life cycles. Among the impacts are 1) in-filling of pools which reduce the volume and quality of living space for over-summering parr, and 2) reduction in average size of stream substrate which reduces spawning success and restricts the fishes' food base. In particular, research has focused on the relationship between substrate particle size and egg-to-fry survival to emergence.

For your results to provide some relevance, they can be compared to the results of others. For percent fines, Lisle and Eads (1991) review of the literature notes that thresholds of concern fall most commonly around 20%. Drawing on the data of others, Chapman (1988) portrays the relationship between the survival to emergence of several salmonid species and the geometric mean (Fig. 3A) and the Fredle Index (Fig. 3B). Yet another method (Tappel and Bjornn 1980) is to use a graphical depiction based on the percent of a sample finer than two size intervals (Fig 5).

Most standards, including those described in the previous paragraph, are based on spawning environments. Therefore, any assessment of condition must recognize the difference between its sampling location protocol and the standards.

- Sampling from redds after emergence is the most applicable use of the standards.
- Using the standards to judge conditions when samples are collected from the pool / riffle juncture will provide a "worse case" assessment. The survival to emergence value from your samples when compared to the standards will be a conservative estimate of survival; i.e., if the estimate is 40%, the true value will be ≥ 40%.
- When sampling is fully randomized across and along the stream channel and is unrelated to spawning sites, the criteria provided above are not applicable. While coarser is better, the results of such a sampling scheme have not been related by research with any parameters of fish populations.

Two parameters of the substrate are important: condition and trend. The procedures provided in these guidelines, applied at a single time, enables reviewers to assess condition. Current condition can be variable due to localized natural geologic events, historic land uses, current land uses, and short- (1-5 year) to long-term (decade ±) climate conditions. Relative to land-use decisions, interpretation of the significance of "condition" is complicated by this inherent variability. Even short-term conditions may be critical when the population of a species (be it fish or of another taxa) which is sensitive to substrate character is extremely low. However, generally trend is of greater significance than a "snap-shot" of current condition. Repeated application of these guidelines over time will enable trend to be assessed.

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Table 1. Example of the cumulative percent table.

Sieve Size (mm)	SAMPLE A Retained Volume	%	SAMPLE B Retained Volume	%	SAMPLE C Retained Volume	%	SAMPLE D Retained Volume	%	SITE TOTAL Mean	Stnd. Dev.
STATION 1: xyz RIVER; Txxn,Ryyw,Szz; Downstream-most site.										
16.00					900	28.6	1255	65.6	23.6	31.1
12.50	1300	55.9	1300	76.2					33.0	39.0
4.75	410	17.6	150	8.8					6.6	8.4
4.00					1000	31.8	215	11.2	10.8	15.0
2.36	100	4.3	23	1.3					1.4	2.0
2.00					220	7.0	40	2.1	2.3	3.3
0.85	160	6.9	45	2.6	184	5.8	43	2.2	4.4	2.3
Pan	355	15.3	189	11.1	842	26.8	360	18.8	18.0	6.7
Total	2325	100.0	1707	100.0	3146	100.0	1913	100.0		
Dg		10.7		18.2		5.2		12.8	11.7	5.3
Fredle Index	3.8		10.6		3.0		5.0	5.6	3.4	
d75 B		30.0		38.0		23.0		38.0	32.3	7.2
d25 B		3.8		13.0		7.6		5.8	7.6	4.0
%< 3.3 B		23		14		39		23	24.8	10.4
STATION 2: xyz RIVER; Txxn,Ryyw,Szz; Upstream-most site										
16.0					910	39.8	775	40.6	20.1	23.2
12.5	1175	71.5	1400	44.1					28.9	35.2
4.75	160	9.7	330	10.4					5.0	5.8
4.00					540	23.6	325	17.0	10.1	12.0
2.36	21	1.3	155	4.9					1.5	2.3
2.00					128	5.6	78	4.1	2.4	2.9
0.85	30	1.8	320	10.1	126	5.5	118	6.2	5.9	3.4
Pan	258	15.7	967	30.5	585	25.6	615	32.2	26.0	7.4
Total	1644	100.0	3172	100.0	2289	100.0	1911	100.0		
Dg		15.0		5.4		6.5		5.4	8.0	4.6
Fredle Index	7.0		0.8		1.1		0.7	2.4	3.1	
d75		36.0		25.0		28.0		30.0	29.8	4.6
d25		8.0		0.5		0.8		0.5	2.5	3.7
%< 3.3		17		43		36		42	34.5	12.1

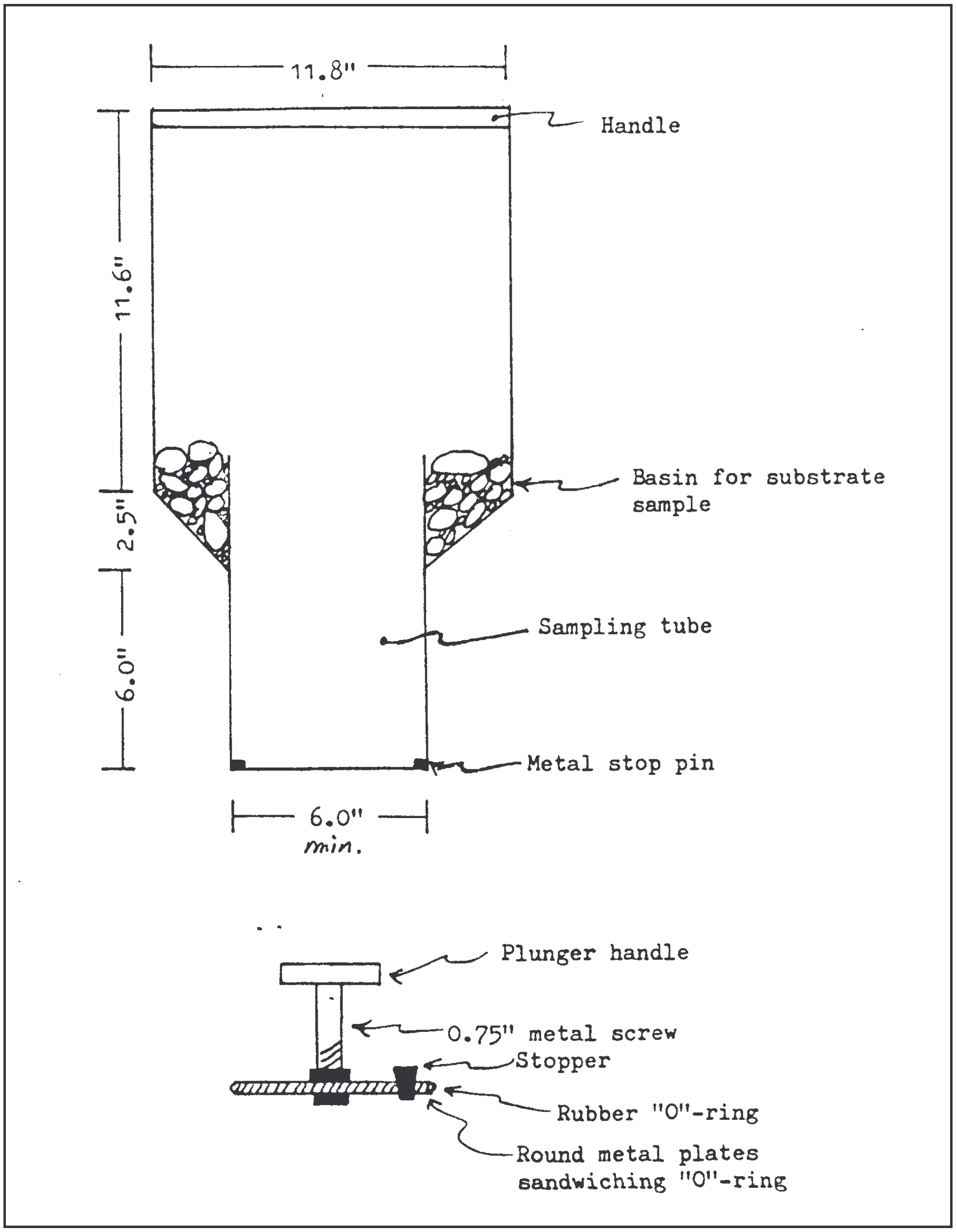
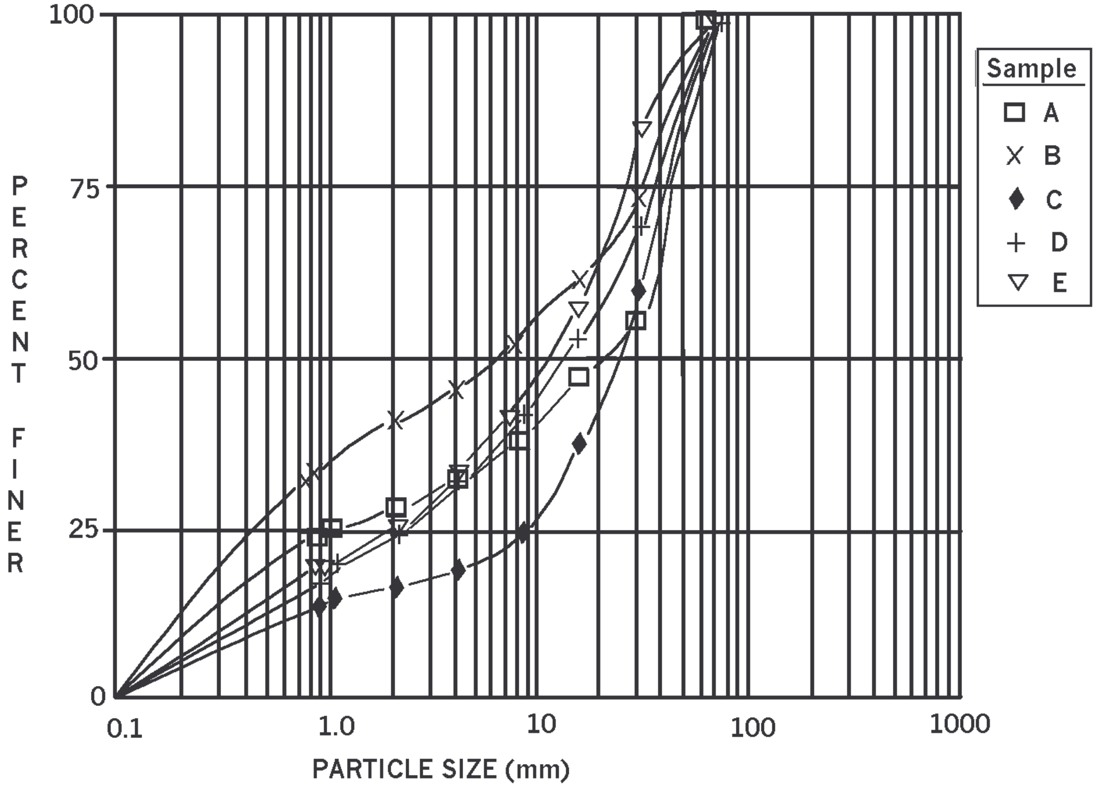


Fig. 1. The McNeil sampler (from Klamt 1976). The sampling tube of the main unit (upper illustration) is inserted into the substrate until the bottom of the sampling basin (angle portion) hits the stream bed. Materials down to the stop pins are excavated from the sampling tube by hand into the basin. Water in the sampling tube is agitated by hand, the plunger (lower illustration) is placed into the sampling tube until it sits on the pins, the stopper is inserted to seal in the aqueous portion of the sample, and the sample is removed to a bucket. The 6 inch diameter for the sampling core is a minimum, some experts recommend 12 inch cores. When altering the design, the basin volume must be enlarged to the same capacity as the sampling tube.

Fig. 2. Example of particle-size distribution graph.



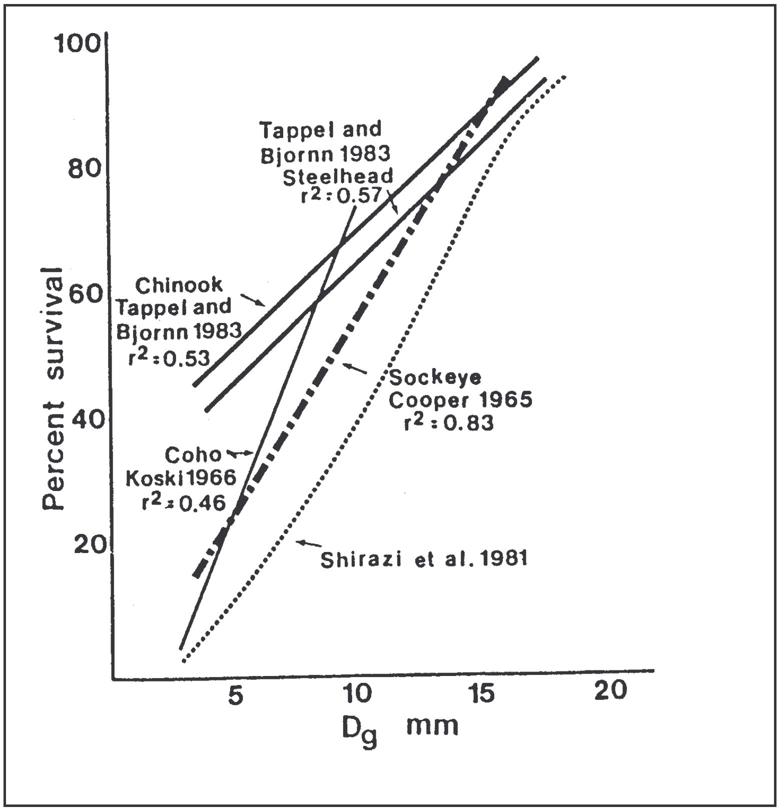


Fig 3. Survival of eggs to emergence based on substrate composition for several salmonid species. "A" is based on the substrate's geometric mean diameter, "B" is based on the Fredle Index. From Chapman (1988).

←A

B

↓

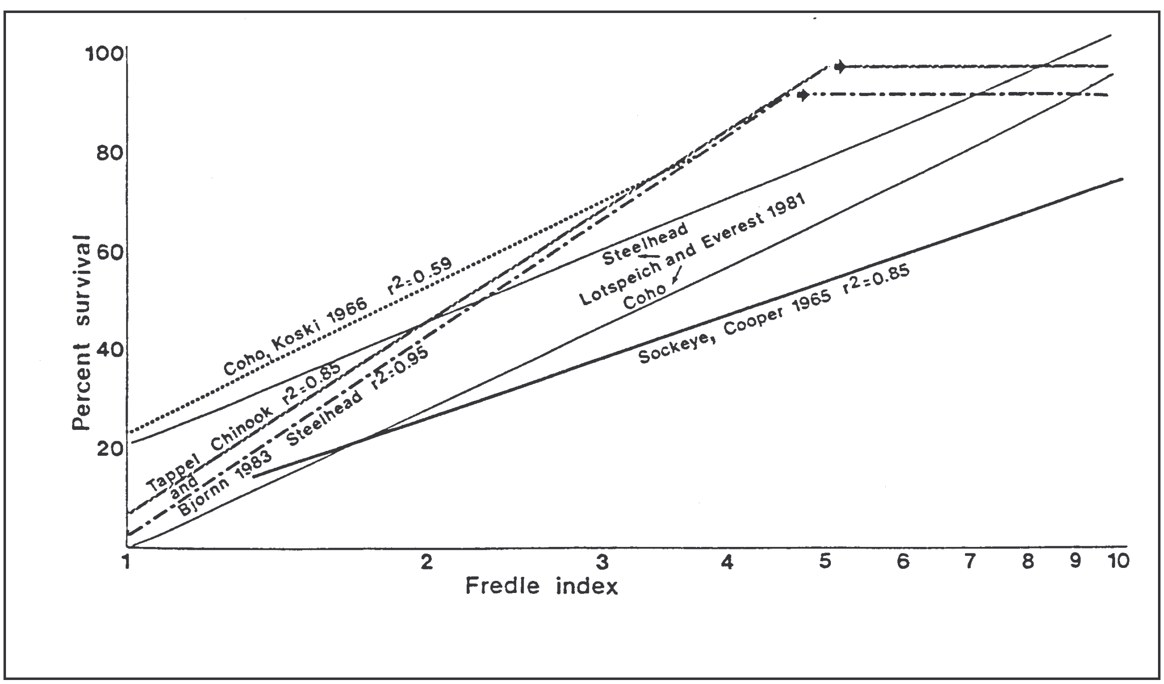
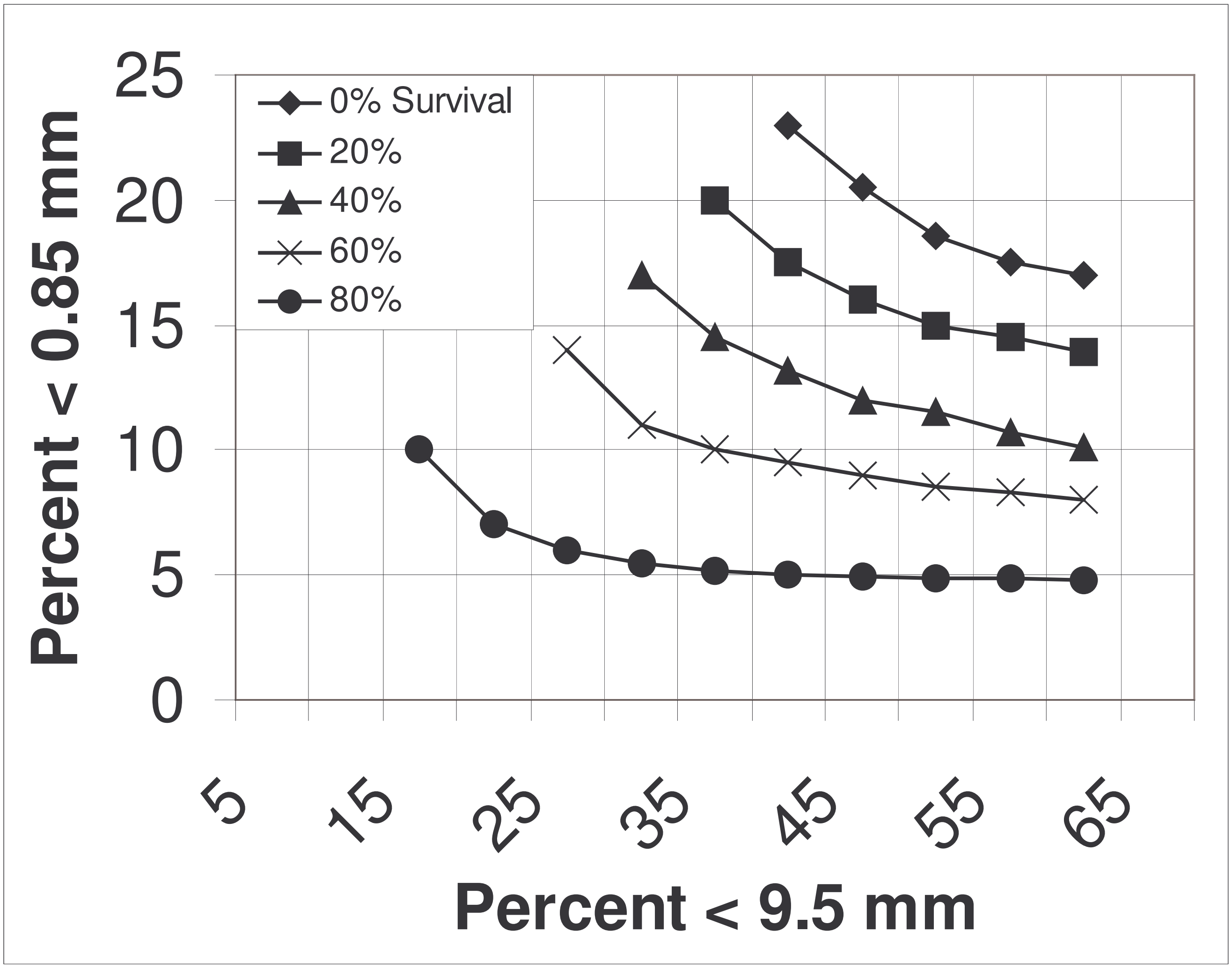


Fig. 5. Isoclines of the survival to emergence for Steelhead trout based on two data points (% < 0.85 and % < 9.5 mm) in the cumulative particle size distribution graph. Data is approximated from Tappel and Bjornn (1983).



APPENDIX 1
Recommended Supplies and Materials

The following supplies and materials are recommended for each sample processing crew. One person is able to process a sample, but an additional person can accelerate the processing time.

Data Sheets (helpful if on waterproof paper) Maps/Clipboard/Indelible pen.
McNeil Sampler
Sieves (128, 64, 32, 16, 8, 4, 2, 1, <u>0.85</u>, 0.5, Pan): One set is minimal, two will help in achieving a quicker, more complete drying. A self-fabricated, 128 mm frame may be necessary as sieves that size are difficult to acquire. One additional sieve of the largest mesh used to employ as extension walls for smaller sieves retaining excessively large sample fractions.
Buckets (5 gal.) -- One/sample, for collecting and transporting samples.
Buckets (2.5 gal.) - Two, for collecting and holding clean, surface water for use in the graduated cylinders.
Large (dish)pans -- Two, for initial sample sorting.
Graduated Cylinders -- One ≥ 2 l, Two each 1000 ml, 500 ml, 100 ml.
Hammer & Heavy Cloth -- To break (and control the scatter of pieces) rocks that are too large to fit in graduated cylinder openings so that they can be measured.
Rule -- metric, for measuring the longest axis of each sample's three largest particles.
Imhoff Cones -- Five.
Imhoff Cone Holder -- One.
Plastic Cups -- Two; to assist in using sample water in washing particles through sieves.
Turkey basters & squirt bottles -- Two each; to help "zero" water levels in graduated cylinders, and to assist in washing particles through sieves.
Large tray (cafeteria type or cookie sheet, with raised edges) - two; to capture droppage while hand shaking or transferring particles from sieves to graduated cylinders.
10 minute timers (suggest digital with sound alarm) - one; for standardizing settling time for fines in Imhoff cones.
Plastic Bags (1 gallon size) -- for decanting excess water from finer sample portions.
Camera - If desired; (a 4 ft x 4 ft sheet of plywood makes a convenient display surface for placing a sample's fractions on for photographic purposes).
Funnels, scoops -- various, to assist in transferring material from sieve to cylinder.

PARTICLE SIZE ANALYSIS

Watercourse:_____________________________Study Reach[3]:________________________

Date:________________ Sampled by (association):________________________________

Sampler core diameter:__________cm, depth_________cm.

Sieve Size[1]	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G	Sample H	TOTAL
>2nd [2] axis of 3 big rocks									
128.0									
64.0									
32.0									
16.0									
8.0									
4.75									
4.0									
3.35									
2.0									
1.0									
0.85									
0.50									
PAN									
TOTAL									

[1]Line through sieve sizes not used. [2] 2nd axis is the widest axis perpendicular to the particle's longest axis. [3]No more than one study reach per page. Attach map. NOTES on sample locations, etc.: ( ) more on reverse of form?:

IDEAS ON SHOVEL SAMPLING:

Approximate quotes from Young et al. (1991) and Grost et al. (1991).

> "The shovel blade (20 cm wide, 24 cm long) was worked into the streambed to a target depth of 20 cm, levered until parallel to the water surface, and gently lifted from the stream. The sample was allowed to drain for 2-3 seconds before it was placed into a container."

I would add that the shovel should be inserted with the blade upstream of the sample to be excavated. This would assure that what current is present will minimally affect the sediments in the sample.

I believe that it is likely that the relationship between the largest particle size collected vs. size of sampler necessary found for McNiel Samplers will be similar with shovels; i.e., when sampling in substrates with particle sizes commonly larger than 1/3 the blade width, the shovel will be too small (will produce a biased sample).

SUBSTANTIVE CHANGES SINCE THE OCT 93 VERSION:

95I04 -- Change the axis measured for the three largest particles from their longest to intermediate axis -- that which controls which sieve it would be able to pass. This makes this measurement consistent with the measurements of other particles. That is, theoretically, particles are passed through a sieve if its narrowest cross section will enable it, not its longest cross section.

Lisle comments:

1. Added sentence re. the importance of considering geology when selecting a measurement tool.
2. Added second criteria for assessing adequacy of sampler size: i.e., that the largest particle should comprise < 5% of total sample.
3. eliminated the "0.85" from the quote previously attributed to Lisle and Eads, as he does not ascribe a single definition of fines.
4. Added figure and discussion from Tappel and Bjornn.

MINOR EDITS – April, 2001 (Robert Klamt, N. Coast Regional Water Quality Control Board

1. Converted to MS Word 98
2. Page numbers and Table of Contents changed
3. Spelling and format checked
4. Figures 2 + 5 redrawn for clarity

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