# *Watershed Assessment*

*and*

# *Cooperative Instream Monitoring Plan*

*for*

# *The Garcia River*

# *Mendocino County, California*

**Compiled for the**
**Mendocino County Resource Conservation District**
**and the**
**California Department of Forestry and Fire Protection**

**by**

**Forest, Soil & Water, Inc.**
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## Executive Summary

This report develops an Instream Monitoring Plan for the Garcia River watershed, Mendocino County, California. In so doing, it (1) estimates sediment sources through a remote analysis, (2) synthesizes impact and sensitivity data, (3) evaluates present information and data collection needs in the watershed, (4) proposes data collection protocols, an implementation plan and a budget, and (5) suggests sites for conjunctive hillslope-instream monitoring.

The report includes maps and tables of mass wasting and road-related sediment sources, based on aerial photography and Department of Forestry mapping, covering the entire watershed. Unadjusted estimated erosion rates range from 120 to over 800 tons per square mile per year. Mass wasting erosion was found to correlate at a greater than 99% significance to relative watershed relief. Sediment delivery rates for shallow rapid mass wasting features were assumed to be 50%, but may be higher.

Synthesis of watershed information found no areas of low sedimentation, some areas with no fisheries, and no areas insensitive to land management. Synthesis also found disagreement among evaluators about relative conditions and sensitivities of several watersheds for several factors, principally canopy and sediment effects. A number of tributaries were affected by deep sedimentation, presumably from logging and road construction in the 1950's and 1960's, to which the streams continue to respond. The San Andreas fault zone also exerts a significant influence on sediment condition in some subwatersheds.

Evaluation of data sources found that, while some streams had many studies and others had little effort at data collection, few studies were quantitative. Sites for instream monitoring were selected by evaluating where data are most critically missing, where further monitoring will build a useful record from past studies and where cooperative monitoring will be most effective.

Protocols selected were chosen to evaluate water quality, gravel quality, channel quality, riparian function, causal mechanisms and fisheries. The connection from stream to hillslopes, to determine the effectiveness of site controls in forestry practices, may best be found in watersheds with present and future timber harvest, the best fisheries and salmonid habitat, and the most clear examples of watershed problems. Control sites should also be established. Long-term analysis of the effectiveness of harvest controls, as measured through instream, airphoto and forensic methods, will work to validate present methods of understanding the watershed effects of logging.

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# 1. *Introduction*

The Garcia River watershed drains 113 square miles of rugged forest and grasslands in southwestern Mendocino County, California. Part of the Coast Range, the watershed includes the San Andreas fault zone, down which the Garcia and its South Fork run. The watershed contains over 150 miles of perennial streams, including 40 miles of the Garcia mainstem, and drains directly into the Pacific Ocean. There are more than 25 named streams within the watershed, draining individual watersheds of greater than one square mile each. The land is the setting for modern activities of timber harvesting, cattle ranching, dairy, gravel mining and residence, among other uses. Landowners include timber companies, independent ranchers, an Air Force base, a Rancheria, and residential and non-industrial holdings.

This report includes a watershed assessment and instream monitoring program (IMP) for the Garcia River. The goal of this project has been to develop an instream monitoring approach for the evaluation of hillslope conditions and actions, their causal impacts in receiving waters, and best management practices (BMPs) which reduce those effects. The targeted use of this report is the evaluation of California's Forest Practice Rules and their implementation in the Garcia River watershed.

This report has been prepared by Forest, Soil & Water, inc. of Healdsburg, California (FSW), under a contract with the Mendocino County Recourse Conservation District (MCRCD). The MCRCD itself has contracted with the State of California's Department of Forestry and Fire Protection (CDF) to implement a cooperative monitoring program on the Garcia, to assess "the effectiveness of ... [CDF's] Forest Practice Program... in protecting the beneficial uses of water." (MCRCD 1997)

The implementation of instream monitoring in the Garcia watershed is an outgrowth of the Department of Forestry's Monitoring Study Group (MSG) and its Pilot Monitoring Program (PMP). The PMP recommended a long-term monitoring program (LTMP) in order to:

- "Provide an ongoing assessment of the effectiveness of the [Forest Practice] Rules, as implemented, in protecting the most sensitive beneficial uses of water (i.e. coldwater fisheries and domestic water supplies) through implementation monitoring, effectiveness monitoring and project monitoring.
- "Provide the results to the BOF [Board of Forestry] and the public in a timely manner to contribute effectively to the BOF's program for reviewing and, where necessary, strengthening the Rules' performance as BMPs."

(Lee, 1997)

The Garcia watershed was selected as a site for the LTMP. Its landowners were willing, several of its subwatersheds are dominated by timber harvesting, and its history of impacts made it a good candidate for trend monitoring.

The urgency of developing monitoring protocols which fit the Garcia River and the North Coast is underscored by the listing process for coho salmon and steelhead trout currently underway for this region. The National Marine Fisheries Service (NMFS) has listed coho as *threatened* under the Endangered Species Act (ESA) south of the Mattole, and is expected to expand the listing of *threatened* to steelhead in the near future. This project is of the utmost urgency for regulatory implementation by the host of agencies who protect fisheries in the region, and for the adaptive management of land use impacts to reduce their causal effects on coho and steelhead populations.

The most important goals of this report are to articulate objectives for sampling, protocols to meet those objectives, and tributary streams which are priorities for evaluation. To do this, we have reviewed relevant literature, identified studies which have been conducted in the Garcia, calculated erosion rates for the watershed, synthesized impact and sensitivity data, and reviewed air photos. In this report, we identify who has conducted monitoring, what monitoring appears to be important for continuation, who should conduct that monitoring, and how and where it should be done.

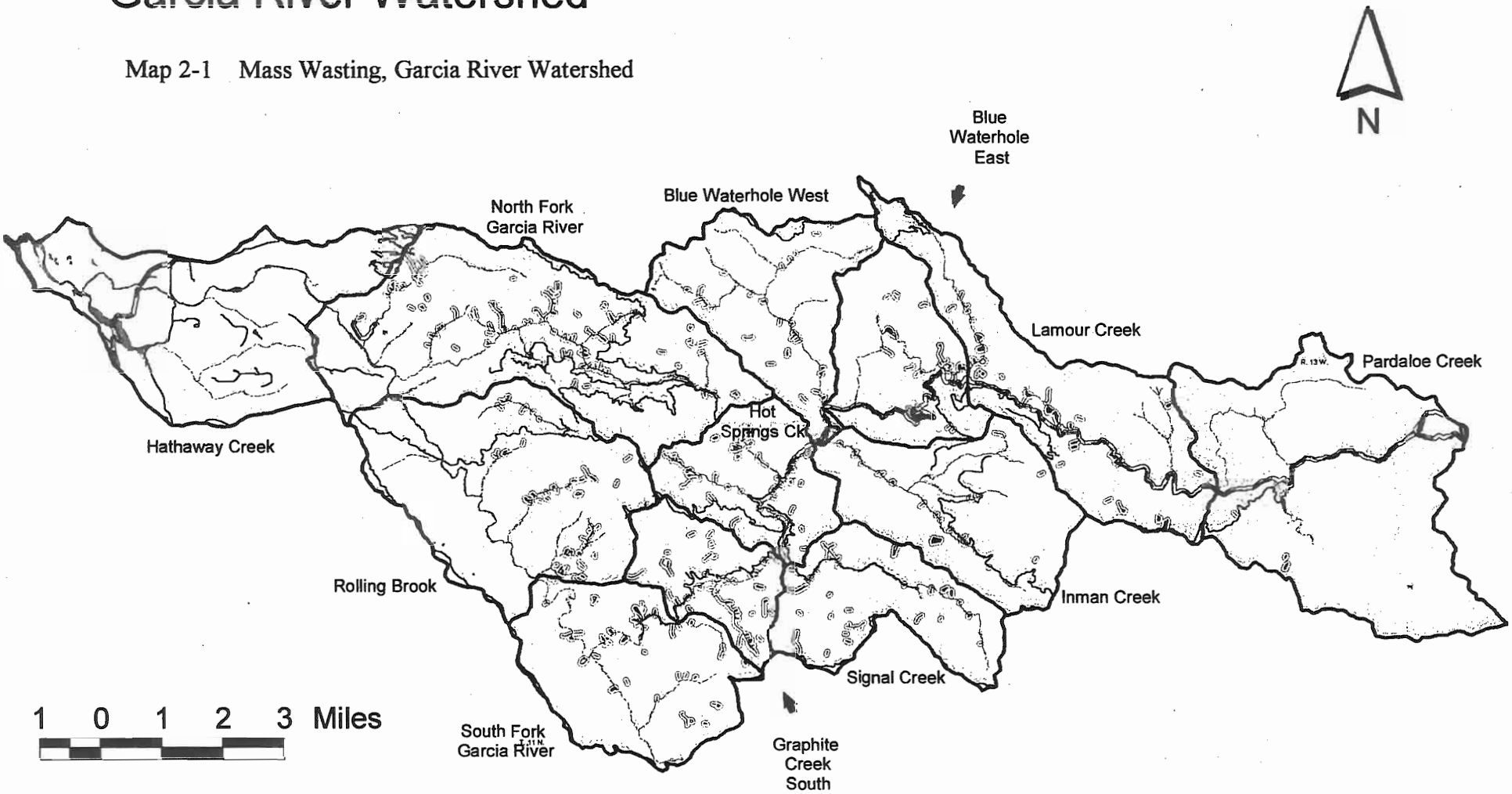
## 2. *Maps of Watershed Assessment Areas*

Maps of the watershed are included as Maps 2-1 and 2-2. Both maps are of the entire, 74,000 acre watershed. The whole watershed was included to assure uniformity in assessment, so that equal levels of effort and identical assessment processes were used for the development of Task 2, mass wasting and surface erosion modules.

Map 2-1 focuses on landslides, Map 2-2 on road systems. These data were included in Mass Wasting and Surface Erosion Modules, developed and put forth in Chapter 3.

# Garcia River Watershed

Map 2-1 Mass Wasting, Garcia River Watershed




## Legend

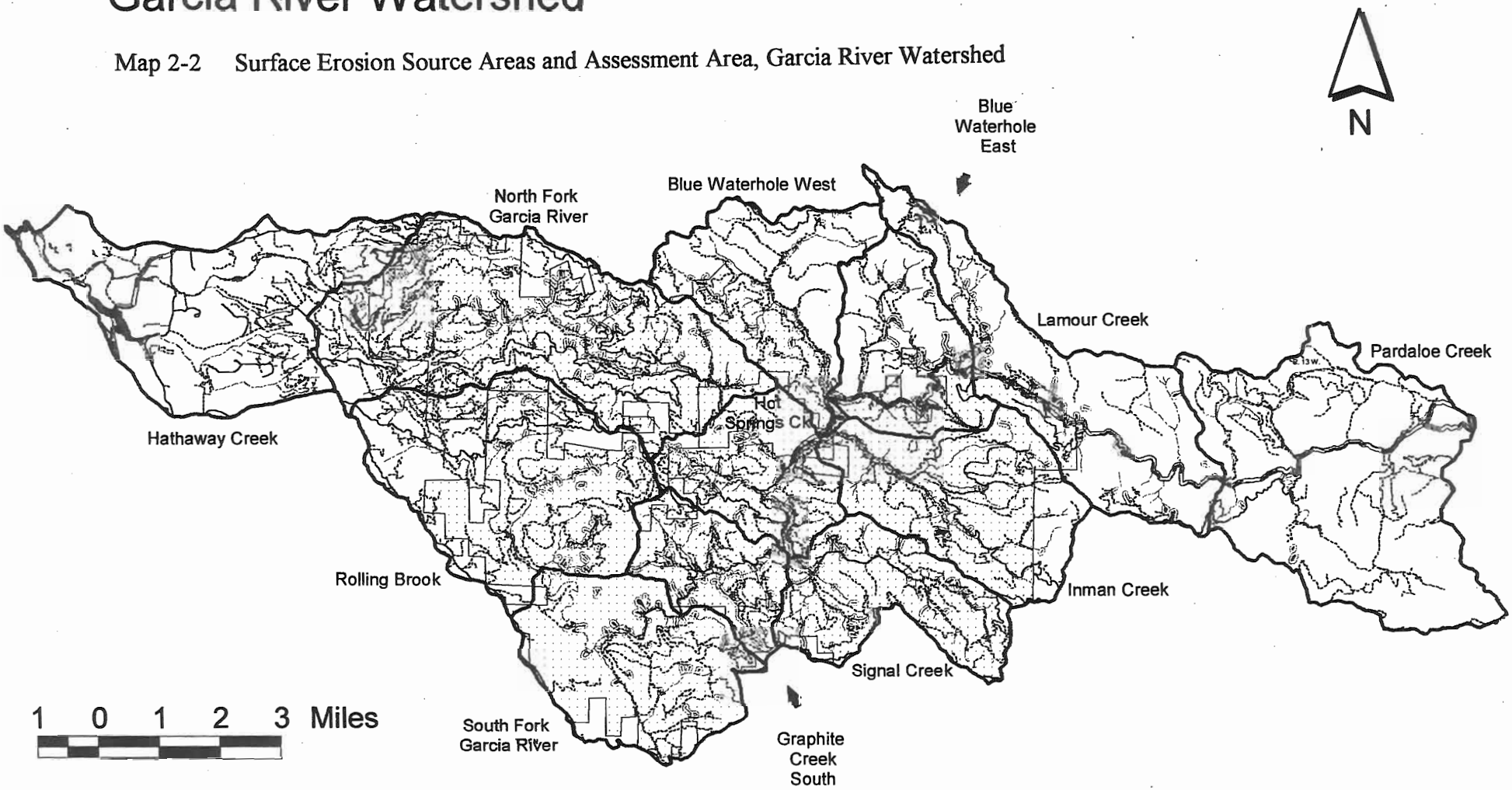
- Slide - Slidepo2
- Slide area - Slidebuf
- Primary road - Bigroads
- Major watercourse - Bigcreek
- Body of water - Hydropol
- Improved (rocked) road - Smlroads
- Calwater basin - Calwater
- 200' contour - Topo200
- 200' contour - Topoadd

Level I Mass Wasting Assessment
Prepared for Mendocino County Resource Conservation District
by
Forest, Soil & Water
East-West Forestry
O'Connor Environmental
December 1997

Sources: CDF GIS database (Santa Rosa) & field/aerial survey data by O'Connor Environmental, Inc.

# Garcia River Watershed

Map 2-2 Surface Erosion Source Areas and Assessment Area, Garcia River Watershed




## Legend

- Primary road - Bigroads
- Major watercourse - Bigcreek
- Body of water - Hydropol
- Class II watercourses Smlcreek
- Improved (rocked) road - Smlroads
- Slide area - Slidebuf
- Slide - Slidepo2
- Mapped unimproved & temporary roads - Tmproads
- Calwater basin - Calwater
- Assessed Area -- Coastal Forestlands - Cflbnd
- Assessed area -- Louisiana-Pacific - Lp

Level I Mass Wasting Assessment
& Areas Assessed by Other Parties
Prepared for Mendocino County Resource Conservation District
by
Forest, Soil & Water
East-West Forestry
O'Connor Environmental
October 1997

Sources: CDF GIS database (Santa Rosa) & field/aerial survey data by O'Connor Environmental, Inc.

## 3. *Mass Wasting and Surface Erosion Modules*

### *A. Mass wasting assessment*

#### i. Introduction

This analysis of mass wasting (landslide-related erosion) was conducted in accordance with guidelines of the Washington Department of Natural Resources (DNR) Standard Methodology for Conducting Watershed Analysis, Version 3.0 (WFPB, 1995). Under the terms of the contract with the Mendocino County Resource Conservation District, the analysis was conducted at "Level 1". This lower-level of analytic intensity, and the limited funds available for the analysis, provides only for preparation of a map of historic landslides based on aerial photo interpretation and development of estimates of historic sediment delivery to the Garcia River and its tributaries.

Some of the estimates presented in early sections of this assessment were revised on the basis of new data. These modifications are presented in the section of this assessment entitled "Suggestions for Further Work." Quantitative estimates of sediment production presented in that sections are considered likely to be more realistic. The prior estimates are preserved to record the assessment process and the impact of new data.

The initial Request For Proposal (RFP) and subsequent contract provided for an analysis to complement analyses prepared for the large commercial forest ownerships (MCRCD 1997). During the inventory phase of the project, the scope was expanded to include the entire Garcia River watershed.

#### ii. Limitations

This analysis was prepared to provide data on historic sedimentation and erosion in the Garcia River watershed. The method specified by the RFP is an established procedure of the State of Washington that has been used for watershed analysis in other western States, including Montana and Oregon. O'Connor Environmental, Inc., has performed two prior Level 2 mass wasting assessments in Washington, and is certified in Washington as qualified to perform the assessment. This assessment is not intended for purposes related to the prediction of future mass wasting or development of mass wasting hazard maps; the results of this assessment are only intended for the uses specified under the scope of the RFP. In addition, the scope of work for the project did not allow for significant field time to check the accuracy of photo interpretation. Therefore, conclusions must be regarded only as generalizations valid in the context of assessing erosion and sedimentation in the Garcia River watershed over a period of about the last 40 years.

#### iii. Watershed Conditions

The general history of land-use and past and present conditions in the Garcia River watershed have been described elsewhere. Among the previous sources reviewed during this assessment were geomorphic maps of portions of the watershed prepared by the California Division of Mines and Geology (CDMG, 1984), the Garcia River Watershed

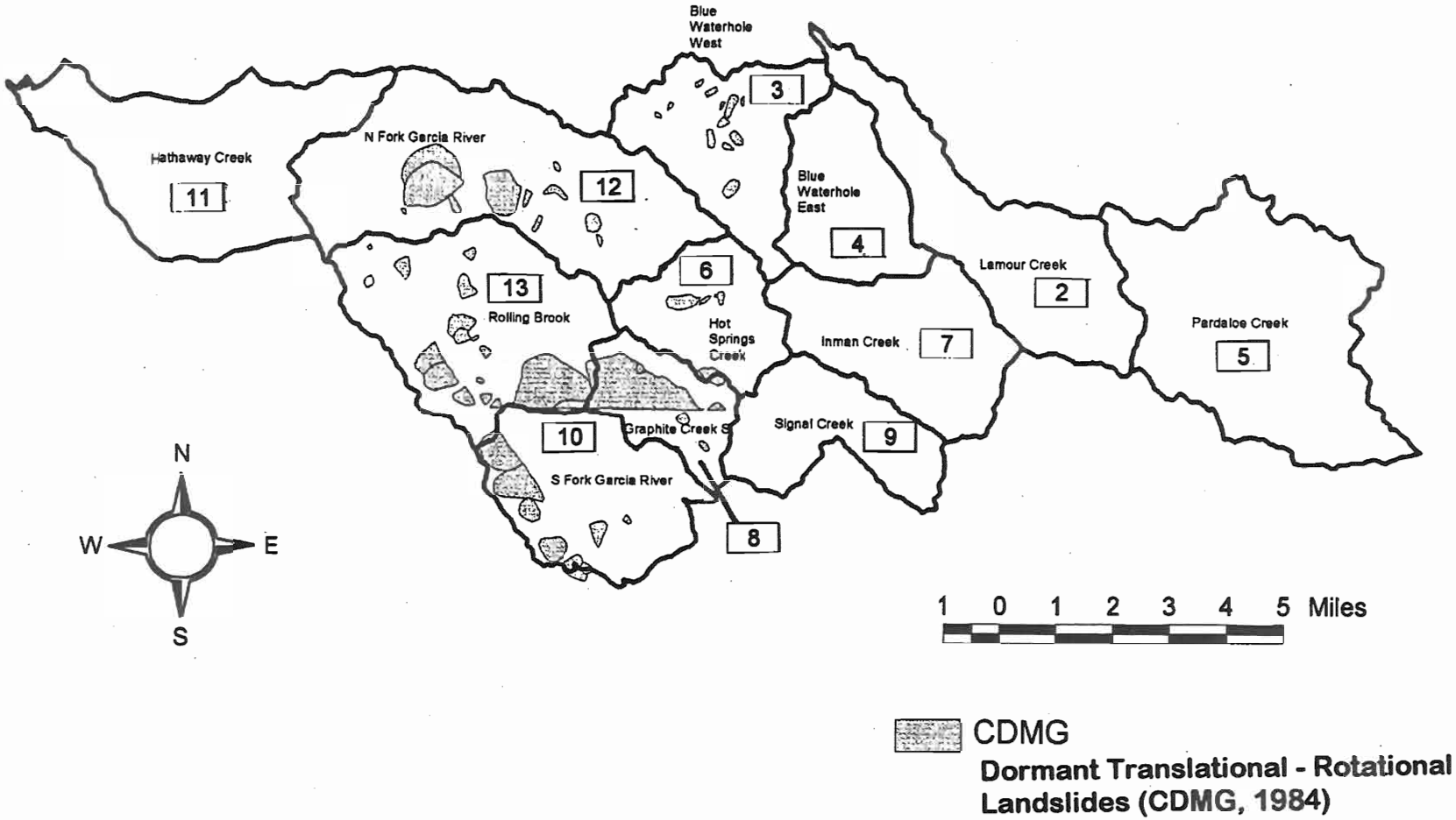
Enhancement Plan (MCRCD, 1992), the Garcia River Gravel Mining Plan (Philip Williams & Associates, Ltd., 1996), Sustained Yield Plan documents and other watershed assessments prepared by Louisiana Pacific Corporation and Coastal Forestlands, and published soil surveys for the region (USDA, 1972).

### iv. Methods

Historic erosion in the Garcia River watershed was assessed by an inventory of mass wasting sites visible on historic aerial photographs of the area. Photo sets utilized were from 1965, 1978, and 1996. All photography was black and white, and approximate photo scales determined by scaling photos to U.S.G.S. topographic maps were 1:20,000, 1:24,000, and 1:13,000. Aerial photos were inspected using a mirror stereoscope under 3x magnification. Mass wasting sites were mapped on U.S.G.S. topographic maps from the location of the site in relation to stream channels, valleys, ridges and roads visible in both the stereo image and the topographic map. In addition, transitional/rotational landslides and earthflows mapped by the California Division of Mines and Geology (1984a, 1984b) were considered in mapping mass wasting sites (Map 3-1).

Mass wasting processes at inventoried mass wasting sites were interpreted and classified in one of three types: shallow rapid, debris torrent, and persistent deep-seated. Shallow rapid mass wasting typically occurs in areas of shallow soil with a relatively impermeable substratum during rainstorms when soil pore water pressure rises rapidly. Where the topography concentrates subsurface water (e.g. convergent slope form), pore pressure tends to rise more rapidly, increasing the potential for mass wasting. These mass wasting events are more likely on steeper slopes, generally in excess of 60%. Under natural (unmanaged) conditions, shallow rapid landslides frequently occur on steep slopes on inner gorge landforms adjacent to stream channels, but may be found almost anywhere soils are present and slopes are sufficiently steep. Sediment production by shallow rapid landslides typically includes the material overlying the failure surface. Sediment flows downhill varying distances, typically on the order of hundreds of feet. Delivery of sediment to streams depends largely on the proximity of the mass wasting site to a channel and conditions of the intervening slope.

Debris torrents (also referred to as debris flows) are initiated by shallow rapid landslides (described above), but have the potential to scour additional material from steep stream channels and narrow headwater valleys, greatly enlarging the volume of sediment produced. Debris torrents typically are initiated near a channel head or adjacent to a headwater stream during rainstorms; the failure mechanism is similar to that of a shallow rapid mass wasting site. Debris torrents commonly originate on steep slopes with convergent topography that funnels failed material into a steep, narrow headwater valley. Most of the sediment is delivered to a stream channel, but much may also be deposited in channel margin terraces and in fan deposits at the mouth of tributaries.










Map 3-1. Garcia River Planning Watersheds and Large, Dormant Landslides

Persistent, deep-seated landslides are typically larger, deeper mass wasting features that are usually adjacent to stream channels. These mass wasting sites may be dormant for long periods, and can be reactivated or initiated when sufficient quantities of water enter the soil column, increasing pore pressure and weight, typically during relatively wet water years. Periods of high stream flow may undermine the toe of such landslides, triggering an episode of motion. Seismic events may also trigger or reactivate deep seated landslides. Typically, most of the material in a deep-seated landslide that moves remains on the slope, albeit displaced down slope. Erosion at the toe of deep-seated landslides usually accounts for most of the sediment delivered to stream channels.

A variety of other observations and interpretations were made for each identified mass wasting site. Confidence in interpretation of the mass wasting feature was stated as either definite, probable, or questionable. Whether sediment was delivered to a stream channel was assessed as affirmative or negative (no attempt was made to assess the proportion of delivery from the aerial photo image). The stream order to which sediment was delivered was estimated from the topographic map. Land use or uses associated with the mass wasting site were recorded as road-related (when the mass wasting site was adjacent to a road), harvest-related (when the site was in a recently-logged area, but the proximity of a road was not noted), or natural when evidence of neither road nor harvest was observed in the photo image. Harvest techniques in this watershed typically involve ground skidding of logs, so skid trails were abundant. It was not always possible to distinguish between mass wasting that may have occurred in relation to a skid trail from those related to harvest alone. Sites where a road bed or skid trail was clearly evident and proximate to the slide were attributed to roads, in part because it was not always possible to distinguish between roads and skid trails, and in part because landslide initiation mechanisms related to roads and skid trails would be expected to be similar. Harvest-related sites include an indeterminate number of sites attributable to skid trails. The shape of the slope in plan view at the top of mass wasting sites was observed and recorded as convergent, planar or divergent.

Finally, the size of each mass wasting site was either measured or classified according to size classes where small sites were <500 $yd^2$, medium were >500 and <2000 $yd^2$, large were >2000 $yd^2$ and <5000 $yd^2$, and extra large were >5000 $yd^2$. For debris torrents and deep-seated landslides, the areas of virtually all sites were measured on the photo, with dimensions of length and width transformed to estimate ground dimensions. For the more numerous shallow rapid mass wasting features, at least 20% of the mass wasting sites were measured (every fifth site). The purpose of measurements was to facilitate estimates of sediment production based on inventory data.

Mass wasting sites and other geomorphic features mapped by CDMG included shallow landslides and deep-seated (translational-rotational) landslides. The limited scope of this project made it infeasible to compare shallow landslides mapped by CDMG with shallow landslides mapped for this project. Larger, deep-seated landslides mapped by CDMG

were predominantly classified as "dormant;" no sediment production or delivery was estimated for these mapped sites.

To estimate sediment delivery from mass wasting sites to stream channels, it was assumed that mass wasting sites that did not appear to deliver sediment to stream channels delivered zero sediment. For the mass wasting sites where photo-interpretation revealed evidence of sediment delivery to stream channels, assumptions were made regarding the depth of soil material affected by mass wasting and the proportion of sediment delivery according to Table 3-1.

Depths were based on conservative assumptions. Typical soil profiles for the dominant forest soils in the Garcia range from 3 to 5 ft depth (USDA, 1972). For shallow rapid landslides, the depth of failure is typically to the soil/bedrock boundary. However, the assumed depths of failure are also applied to estimate erosion of soil on hillslopes below landslide initiation sites as well as erosion of headwater channels by debris torrents. Given the range in variation of soil depth, and prior experience regarding depth of erosion of hillslopes and channels, the conservative value of 3 ft was selected.

For persistent deep seated landslides, soil depths are generally several times greater than those found in areas with shallow soils underlain by bedrock. The assumed value of 15 ft is based on observed minimum heights of deep-seated landslide toes adjacent to stream channels in mountainous terrain. This height determines the assumed landslide geometry and resulting estimates of landslide volume; it generates a conservative, minimum estimate.

Delivery rates are based on previous experience with delivery rates for these mass wasting processes as observed in other watershed analysis projects (e.g. West Satsop Watershed Analysis, 1996), and are conservative. These delivery rates should be considered as contributing to a minimum estimate of sediment delivery from mass wasting sites observed on aerial photographs.

***Table 3-1. Assumed depth of soil material subject to mass wasting and assumed percentage of sediment delivered to stream channels by mass wasting process.***

| Mass Wasting Process | Assumed Depth of Mass Wasting (ft) | Assumed Delivery Rate (%) |
|---|---|---|
| Shallow Rapid | 3 | 50 |
| Debris Torrent | 3 | 75 |
| Persistent Deep Seated | 15 | 25 |

Sediment volumes delivered to stream channels were then calculated for each mass wasting site based on the measurements of surface area and the assumptions in Table 3-1. In cases where the area of the mass wasting site was not measured (i.e. it was classified according to size), the median area of mass wasting sites in that size class and process category was used as an estimate of area. In cases where a mass wasting site persisted from one set of photographs to the next, additional sediment production and delivery was

assumed to occur only if the size of the mass wasting site increased. If an increase in size occurred, sediment production and delivery was computed as the increment of increased mass wasting area.

The mass wasting sites were assigned to designated CALWAA subwatersheds. This allowed for sediment production from mass wasting to be estimated for smaller areas within the watershed.

### v. Results

Aerial photography revealed 447 mass wasting sites that were inventoried. Of these, 85% were classified as shallow rapid, 11% as debris torrents, and 4% as persistent deep-seated. One-third (33%) of the mass wasting sites were first observed on the 1965 photographs, while 40% first appeared on 1978 photography, and the remaining 27% were first observed in the 1996 photography. About 38% of the mass wasting sites first observed on 1965 photos remained visible in 1978 photos, and 7% remained visible in 1996 photos. Another 3% of sites first observed in 1965 photos were not visible in 1978 photography but reappeared in 1996 photography. Of the mass wasting sites first observed in 1978 photography, about 24% remained visible in 1996 photographs. About 83% of inventoried mass wasting sites were classified as delivering sediment to stream channels.

Among shallow rapid mass wasting sites, about 60% were associated with roads (i.e. they occurred near a visible road or skid trail), about 22% were associated with harvest (i.e. they occurred in an area where timber harvest had occurred, but were not near a visible road or skid trail), and about 18% were inferred to be of natural origin (they were not observed to be in close proximity to either roads or skid trails, nor did they appear to be in a previously-harvested area). The distribution of debris torrents was similar, with about 63% associated with roads, 16% with harvest, and 11% natural causes. Inferences regarding the influence of land management on persistent deep seated mass wasting sites are subject to greater uncertainty. About a quarter of observed active persistent deep seated landslides appeared to have occurred in areas where no recent management activities were evident, while the remaining three-fourths occurred in areas where roads and/or harvest had occurred. Note that the techniques used to inventory mass wasting sites did not include significant field observations, making inferences regarding cause and effect highly tentative.

Slope form at shallow rapid mass wasting sites was predominantly planar (42%) and convergent (41%), with distinctly fewer sites on divergent slopes (17%). Debris torrents occurred primarily on convergent slopes (64%), with a significant number occurring on planar slopes (31%), and few (4%) on divergent slopes.

Maps of inventoried landslides and inventory data are provided in map 2-1 and Appendix A. Roads are shown on Map 2-2. Full size maps also accompany the master of this report.

### vi. Sediment Delivery Estimate

As described in the methods section, the dimensions of a large number of mass wasting sites were measured on aerial photographs to estimate their area. Shallow rapid mass wasting sites were by far the most numerous; 34% of these features were measured on photographs. These data were then used to estimate the area of sites that were classified according to size, but not measured. In case of debris torrents and persistent deep-seated mass wasting sites, a much higher percentage of inventoried sites were measured (89% and 83%, respectively). Table 3-2 provides a summary of data used to estimate the area of mass wasting sites which were classified according to size but not measured.

Estimated sediment delivery was converted to units of tons (English) from units of cubic feet based on assumed average bulk density of 1.5 Tons/$m^3$. The sediment delivery estimates are reported for each CALWAA sub-basin; the sub-basins are shown in Map 3-1. The estimates are expressed in terms of total tons of sediment delivered in each time interval (Figure 3-1), and in terms of the sediment delivery rate in each time interval (Figure 3-2). The former provides perspective on the total sediment contribution by mass wasting process over the period of record. The latter provides a comparison of the intensity of mass wasting in each subwatershed.

***Table 3-2. Mass wasting site area sample statistics. The median area rather than the mean area was used to estimate areas of sites that were classified according to size, but not measured.***

| Process-Size | Number of Observations | Median Area ($ft^2$) | Mean Area ($ft^2$) | Coefficient of Variation (Std. Error/Mean) |
|---|---|---|---|---|
| SR-S | 17 | 3400 | 3400 | 0.053 |
| SR-M | 57 | 9450 | 10000 | 0.050 |
| SR-L | 46 | 25400 | 28500 | 0.045 |
| SR-XL | 9 | 55000 | 57100 | 0.052 |
| DT-S | 3 | 3700 | 3730 | 0.048 |
| DT-M | 14 | 9850 | 10800 | 0.110 |
| DT-L | 17 | 26000 | 27700 | 0.062 |
| DT-XL | 8 | 59900 | 61400 | 0.270 |
| PD-L | 4 | 37900 | 37900 | 0.016 |
| PD-XL | 11 | 87000 | 137000 | 0.300 |

To calculate rates, it was necessary to have a time period over which observed landslides occurred. For the first set of photos from 1965 it was assumed that mass wasting occurred beginning in 1957 (i.e. over a period of 8 years). For the 1978 photographs, the time interval between 1965 and 1978 (13 years), was used. Similarly, for the 1996 sets of photographs, the time interval of 18 years was used. The first interval of 8 years is a conservative estimate of the interval over which observed landslides occurred; it is likely that some of the observed sites were more than 8 years old. The 8 year period corresponds to the length of time required for half of the mass wasting sites that revegetated or became otherwise unnoticeable on aerial photos to attain that condition for the intervals between 1965-1978 and 1978-1996.

Figure 3-1 and Figure 3-2 suggest that mass wasting activity has abated significantly in the watershed as a whole since 1978, with subwatershed maxima occurring either in the interval prior to 1965 or the interval prior to 1978. Only in the case of Inman Creek did either the amount or rate of sediment delivery attain its maximum in the 1996 photo-interval.

Comparison of Figure 3-1 with Figure 3-2 highlights the differences between subwatersheds to which overall sediment delivery was high (Figure 3-1) with those in which the sediment delivery rate (Figure 3-2) was high. For example, the North Fork subwatershed has produced relatively high quantities of sediment in the 1978 and 1996 time intervals (Figure 3-1), but the rate of sediment delivery, which adjusts for both subwatershed area and the length of the time interval, is relatively low (Figure 3-2). In the case of subwatershed 8, which encompasses Eureka Hill on its northwest corner and Gualala Mountain on its southeast corner, the maximum sediment delivery rate by mass wasting occurred in the first time interval (Figure 3-2). In terms of the quantity of sediment delivered from sub- watershed 8, the amount was relatively large, but was exceeded in five cases (Figure 3-1).

Table 3-2 summarizes data from the mass wasting inventory over the full period of record, approximately 1957 to 1996. These data supplement Figures 3-1 and 3-2 and can be used to rank subwatersheds according to their contributions of sediment to the Garcia River watershed. For example, the three subwatersheds that have contributed the most sediment as the result of mass wasting are the North Fork Garcia, Larmour Cr., and #3. In contrast, the subwatersheds with the highest delivery rates are #8, #4, and #3. The subwatersheds with the lowest sediment delivery and delivery rates are the same: Hathaway Cr., Pardaloe Cr., and Signal Cr.

Figure 3-1. Volume of Sediment Delivery from Mass Wasting, by Subwatershed over Time.

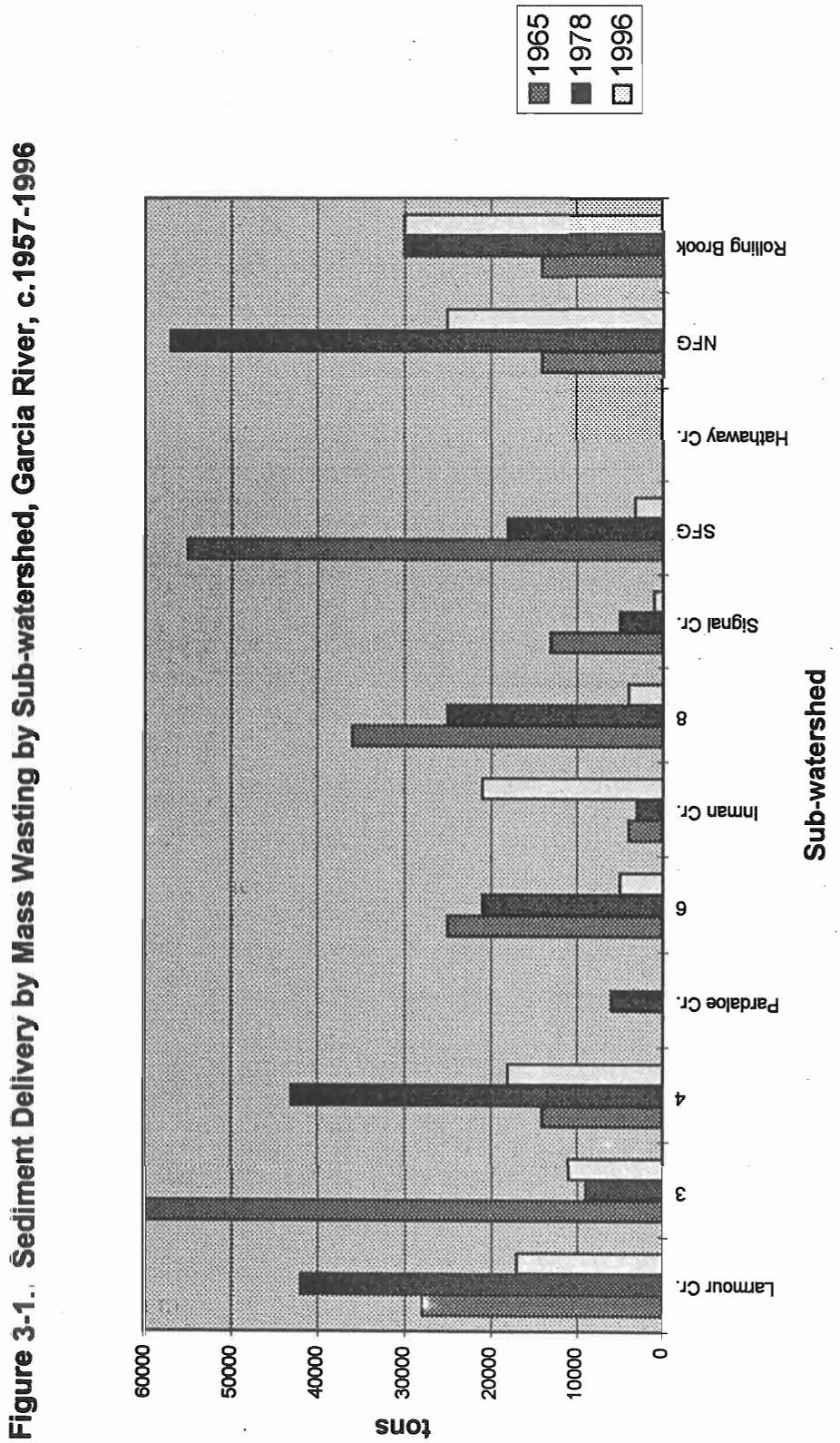


Figure 3-2. Rate of Sediment Delivery from Mass Wasting, by Subwatershed over Time.

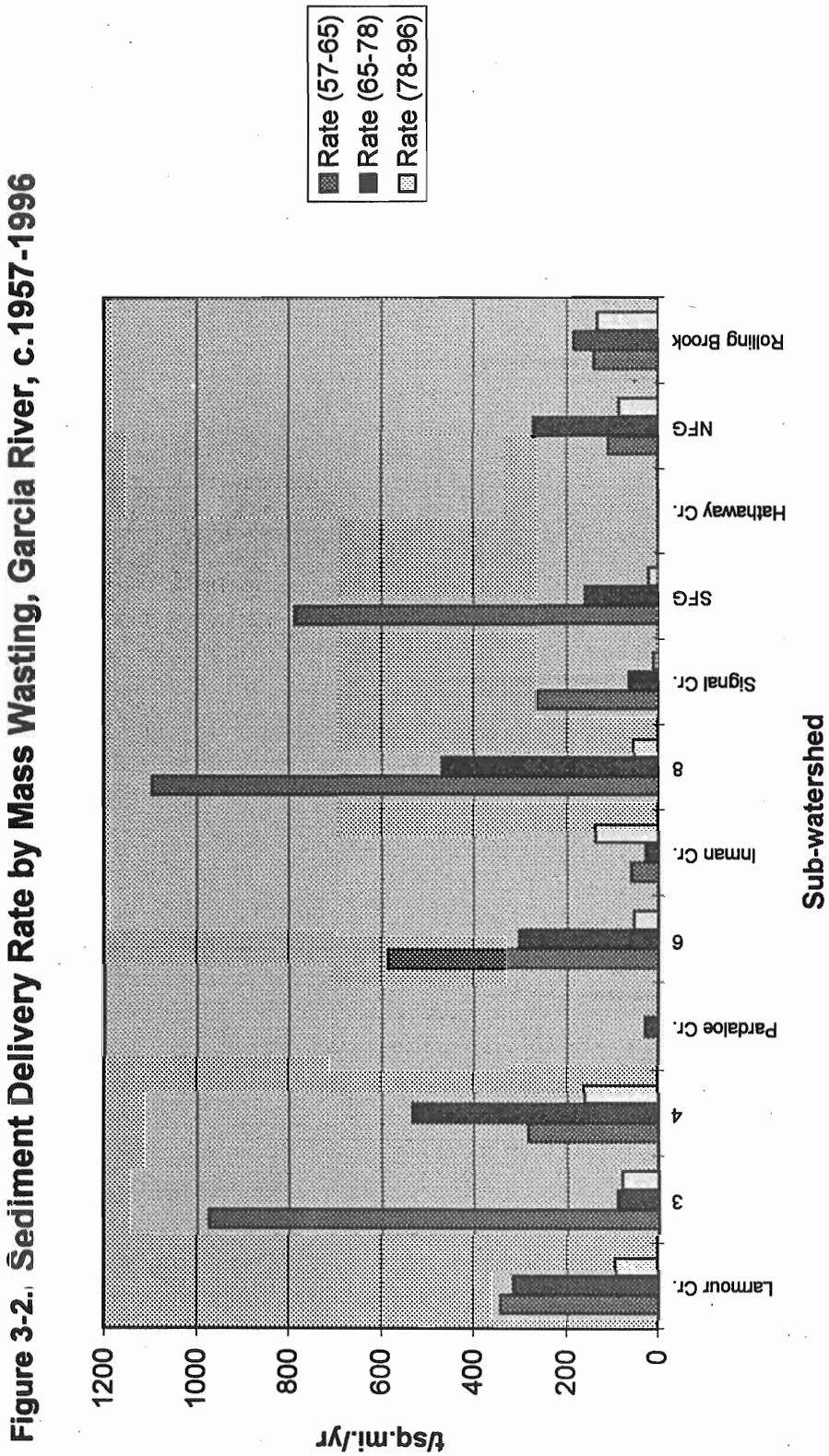


***Table 3-2. Estimated total sediment delivery and average sediment delivery rates from mass wasting over the period of record (approximately 1957 to 1996) for individual subwatersheds, Garcia River.***

| Sub-watershed | Area ($mi^2$) | Sediment Delivery (t) | Sed. Delivery Rate ($t/mi^2/yr$) |
|---|---|---|---|
| Larmour Cr. | 10.2 | 87,000 | 213 |
| 3 | 7.7 | 80,000 | 260 |
| 4 | 6.2 | 75,000 | 302 |
| Pardaloe Cr. | 16.4 | 6,000 | 9 |
| 6 | 5.4 | 51,000 | 238 |
| Inman Cr. | 8.6 | 28,000 | 82 |
| 8 | 4.1 | 65,000 | 396 |
| Signal Cr. | 6.2 | 19,000 | 77 |
| South Fork Garcia | 8.7 | 76,200 | 218 |
| Hathaway Cr. | 12.3 | 0 | 0 |
| North Fork Garcia | 16.2 | 96,000 | 148 |
| Rolling Brook | 12.5 | 74,000 | 148 |
| TOTAL | 114 | 657,000 | 144 (avg.) |

### vii. Interpretation and Implications of Results

The results reported above are put in context along with sediment delivery estimates from the Surface Erosion assessment in a subsequent section.

## *B. Surface Erosion Assessment*

### i. Introduction

This analysis of surface erosion was conducted in accordance with guidelines of the Washington Department of Natural Resources Standard Methodology for Conducting Watershed Analysis, Version 3.0 (WFPB, 1995). Under the terms of the contract with the MCRCD, the analysis was conducted at "Level 1". This lower-level of analytic intensity, and the limited funds available for the analysis, allowed only for preparation of a generalized road erosion assessment, and rough estimates of potential past and present skid trail erosion. The assessment was based largely on road data in a Geographic Information System (GIS) maintained by the CDF, shown in map 2-2, and information regarding skid trail density derived from aerial photographs. These data were used to assess erosion from existing and historic roads over a period of the past 40 years. It should be noted that the Washington Methodology (WM) only requires an evaluation of the existing road system, and does not specify that an assessment of historic roads be performed.

The initial RFP and subsequent contract provided for an analysis to complement analyses prepared for the large commercial forest ownerships. During the inventory phase of the mass wasting assessment, the scope was expanded to include the entire Garcia River watershed.

### ii. Limitations

This analysis was prepared to provide data on historic sedimentation and erosion in the Garcia River watershed. The method specified by the RFP is an established procedure of the State of Washington that has been used for watershed analysis in other western States, including Montana and Oregon. O'Connor Environmental, Inc., is certified in Washington as qualified to perform the assessment. The results of this assessment are only intended for the uses specified under the scope of the RFP. In addition, the scope of work for the project did not allow for significant field time to check the accuracy of assumptions required to complete the assessment. Therefore, conclusions must be regarded only as generalizations valid in the context of assessing erosion in the Garcia River watershed over a period of about the last 40 years.

### iii. Watershed Conditions

The history of logging in the Garcia River watershed is summarized in the Garcia River Watershed Enhancement Plan (Monschke and Caldon, 1992). Early logging (c. 1900) occurred in much of the North Fork watershed, and to a limited extent further upstream. The next major period of logging began in the 1950's when the use of caterpillar tractors allowed for what was primarily selective harvest in the more rugged terrain in the middle and upper watershed. Selective logging using tractors and skid trails has continued to the present. A few subwatersheds, however, were much less extensively logged, namely Hathaway Creek at the mouth of the watershed and at the easternmost headwaters in Pardaloe and Mill Creeks. Extensive networks of skid trails were visible in aerial photographs from 1965 and 1978 in much of the remaining area. Skid trails have, in general, been re-used during successive entries to the watershed for timber harvest. Beginning in 1974, forest practice rules restricted the locations in which skid trails could be used to yard logs. In recent years, skid trails have been excluded from stream channels (including the smallest Class III channels), and slopes > 65%.

### iv. Methods

The Surface Erosion assessment module of the Washington Forest Practices Board (1995) provides a detailed method for estimating sediment production from roads under a variety of conditions and use levels. The following discussion summarizes this method and highlights the key assumptions required to perform the assessment.

Road data were obtained in a GIS format from the CDF. This data set was generated from both existing road maps and Timber Harvest Plan (THP) maps. Roads were classified by CDF as secondary paved roads, gravel roads (both classified as "permanent roads" in the Forest Practice Rules (FPRs), seasonal roads (as defined by the FPRs), and temporary/4WD roads ("temporary roads" in the FPRs). Skid trails are not mapped. The GIS was used to compute the length of each type of road within each CALWAA sub-

basin. Road length data are the primary data used to estimate sediment production (erosion) from roads. In addition, the GIS computed the length of mapped stream channel in each CALWAA sub-basin. These data are used to estimate the "background" or "natural" erosion rate caused by hillslope creep processes that deliver sediment to stream channels. Hillslope creep processes include various forms of gravity-driven, small-scale sediment delivery, for example, soil-throw by the root mass of fallen trees, spoils from animal burrows (Reid and Dunne, 1996; WFPB, 1995).

According to the WM, the erosion potential for roads is a function of the relative area of road in each component of the road prism (tread, cut slope, and fill slope), the inherent erodibility of the parent material (rock type or sediment type upon which soil forms and on which a road is constructed), and the protection from erosion provided by vegetation and surfacing materials. Actual erosion is a function of actual or assumed road conditions and the proportion of eroded sediment delivered to streams. Delivery is controlled by factors such as road drainage design and proximity of roads to stream channels.

Erosion potential calculations begin with selection of the appropriate basic erosion rate (Table B-5 in the WM, reproduced here as Table 3-4). The bedrock east of the San Andreas Rift Zone, which coincides with the Garcia River between the North Fork Garcia and the South Fork Garcia, is predominantly marine sedimentary rock of the Coastal Belt Franciscan Formation (Wagner and Bortugno, 1982). A northwest southeast-trending belt of Franciscan Complex melange about 2 miles wide runs parallel to and just to the east of Inman Creek. West of the San Andreas Rift Zone, marine sedimentary rocks of the German Rancho Formation, the Gualala Formation and the Gallaway-Schooner Gulch Formation are found. These rocks have been subjected to extensive faulting, folding and uplift. Annual rainfall is greater than 50 inches. Soils of the region, particularly those used for commercial forestry, are predominantly of the Hugh-Josephine complex which, on steeper slopes (> 30%), are generally described as having high to very high erosion hazard (USDA, 1972).

Given the foregoing bedrock and soil conditions, the most appropriate choice for the basic erosion rate in the WM is "highly weathered sedimentary" parent material, which is grouped in the high erosion potential category. According to the WM, the erosion rate is 110 metric tons/acre of road prism per year for the first 2 years following construction. Thereafter, the erosion rate declines to 60 metric tons/acre/year.

Because of the age of most of the road network in the Garcia River watershed (most logging roads were constructed in the 1950's), calculations of estimated sediment production were based only on the lower (> 2 year following construction) basic erosion rate. This simplified the calculations significantly, and reduced estimated erosion from road prisms by about 5% over the 40 year period for which sediment production was estimated. In addition, it was assumed that the calculated erosion rates for the presently existing road network are representative of past erosion rates, thereby providing a means to estimate sediment production from roads over a period comparable to the mass wasting inventory.

***Table 3-4. Basic erosion rates as described in Table B-5, Washington Methodology. Erosion rate is given in metric tons per acre of road prism per year. For the Garcia River, the "high" erosion rate category was chosen on the basis of bedrock geology and general descriptions of soil erosion hazard.***

| | | Erosion Rate (T/ac/yr) | |
|---|---|---|---|
| **General Rate** | **Parent Material** | **Road Age 0-2 Years** | **Road Age > 2 Years** |
| High | Mica schist, volcanic ash, highly weathered sedimentary | 110 | 60 |
| High/Mod. | Quartzite, coarse-grained granite | 110 | 30 |
| Moderate | Fine-grained granite, moderately weathered rock, sedimentary rocks | 60 | 30 |
| Low | Competent granite, basalt, metamorphic road, relatively unweathered rocks | 20 | 10 |

The 60 T/ac/yr (about 66 t/ac/yr) of potential erosion is then apportioned to the constituent components of the road prism for further adjustments. For the typical, or "reference" road 40% of the erosion is derived from the tread, 40% from the cut slope, and 20% from the fill slope. The reference road has the following characteristics:

- insloped road tread with inboard drainage ditch
- native surface road tread
- general duty traffic (mostly pickups and sedans)
- cutslope gradient of 1:1 and fillslope gradient of 1.5:1
- initial ground cover density of zero on cut and fill slopes
- grade of 5-7%
- cross-drain spacing of 500 ft.

Discussions with forest managers and field observations indicate that these assumptions are not valid for all roads. The limited scope and resources for this Level I assessment do not allow refinement of these assumptions at this time.

Road length is converted to road prism area, distributed in the road tread, the cut slope and the fill slope, based on widths assumed to be representative of each component. The assumed typical road prism cross section contains 10 horizontal feet of fill slope, 16 feet of road tread, and 14 horizontal feet of cut slope, for a total of 40 ft. Thus for each 1,000 ft length of road, it is assumed that there is 40,000 $ft^2$ (0.92 acres) of road prism. These dimensions are likely to either underestimate or overestimate road prism area for some roads. Some of the oldest roads constructed in the 1950's may have had tread widths of 24 ft (Spittler, 1998).

For an acre of road prism, the WM assumes that sediment production from the road tread accounts for 40% of the base erosion rate, that is, 40% of 60 T/ac/yr, or 24 T/ac/yr.

Similarly, the base erosion rate is apportioned to the cut slope (40%) and the fill slope (20%). These rates are then adjusted using correction factors as described below.

It was assumed that the vegetative cover for the cut slope and fill slope averaged 50%. Limited field observations suggest that the cover density is higher in some areas, and lower in others. Adjustments to this assumption are beyond the scope and resources of the current project. Table 3-5 shows the correction factor used as a multiplier of the basic erosion rate that corresponds to different levels of vegetative cover.

***Table 3-5. The correction factor for vegetative ground cover on cut and fill slopes reduces erosion as the percentage of cover increases. When cover is zero, the correction factor is 1 and the base erosion rate for cut and fill slopes is not modified by the cover factor. This corresponds to Table B-6 in the WM.***

| Ground Cover Density | Correction Factor |
|---|---|
| >80% | 0.18 |
| 50% | 0.37 |
| 30% | 0.53 |
| 20% | 0.63 |
| 10% | 0.77 |
| 0% | 1.00 |

The correction factors for the road tread component of the prism include a surfacing factor (Table 3-6) and a traffic/precipitation factor (Table 3-7). The surfacing factor reduces the erosion rate in a manner similar to the vegetation cover factor. The traffic/precipitation factor can increase or decrease the base erosion rate, with the degree of increase determined by the intensity of traffic.

***Table 3-6. The correction factor for road surfacing as presented in the WM, Table B-7.***

| Road Surface | Correction Factor |
|---|---|
| Paved | 0.03 |
| Dust-oil | 0.15 |
| Gravel, > 6" deep | 0.2 |
| Gravel, 2-6" deep | 0.5 |
| Native soil/rock | 1.0 |

The final correction factor deals with the proportion of road area that delivers drainage water and sediment to stream channels. This correction is best developed from field survey data; this was beyond the scope of this assessment. Consequently, it was necessary to develop an assumption regarding proportion of delivery from roads to streams. The WM suggests that roads draining directly to any channel deliver 100% of the eroded sediment, with the fill slope considered separately. For roads within 200 ft of streams, but not draining directly to a stream, the WM suggests that 10% of the material is delivered to stream channels. Finally, for delivery of sediment from roads to slopes > 200 ft from streams, the WM suggests that there is not sediment delivery. Because

appropriate field data were unavailable to determine what the delivery ratio is for roads, it was assumed that 100% of sediment eroded from the entire road prism within 200 ft of streams was delivered to streams. These data were generated from the CDF GIS data base containing layers for road location and class and stream location and class.

***Table 3-7. Traffic/precipitation correction factor as presented in the SM, Table B-8.***

| | Annual Precipitation | | |
|---|---|---|---|
| **Traffic Use/Road Category** | **<1200 mm (47 in.)** | **1200 - 3000 mm (47 - 118 in)** | **> 3000 mm (118 in.)** |
| Heavy Traffic/ Active Mainline | 20 | 50 | 120 |
| Moderate Traffic/ Active Secondary | 2 | 4 | 10 |
| Light Traffic/ Not Active | 1 | 1 | 1 |
| No Traffic/ Abandoned | 0.02 | 0.05 | 0.1 |

In addition to roads used by heavy trucks and light vehicles, native soil surfaces in the Garcia River have been extensively disturbed by skid trails constructed by caterpillar bulldozers and tractors for the purpose of yarding cut logs to roads where they are loaded onto heavy trucks for transport to mills. The 1965 photography used in the mass wasting inventory revealed high densities of skid trails. Measurements of skid trail length were made in two relatively small areas, in Fleming Creek (a tributary of the South Fork Garcia), and in an unnamed tributary of the North Fork Garcia. In the former case, approximately 6.7 miles of skid trail (and an undetermined but small portion of road) were measured in an area of about 0.25 $mi^2$, yielding an estimated skid trail density of about 27 $mi/mi^2$. In the latter case, about 14.9 miles of skid trail (and an undetermined but small portion of road) were measured in an area of about 0.97 $mi^2$, yielding a density of about 15 $mi/mi^2$. The average of these two values, 21 $mi/mi^2$, is used to represent the average skid trail density in the watershed.

Based on 1965 photography and data from the CDF GIS on THPs filed in the past 10 years, it was assumed that skid trails were built at an average density of 21 $mi/mi^2$ over 100 % of all subwatersheds except Hathaway Creek and Pardaloe Creek. In these two subwatersheds, there appeared to be substantially less area logged in 1965. THPs over the past 10 years were filed for only 17% of Hathaway Creek subwatershed (much of which is not forest vegetation) and for only 12% of Pardaloe Creek. For these two subwatersheds, it was assumed that skid trails were "constructed" on only 15% of the drainage area (i.e. skid trail density of 21 $mi/mi^2$ was applied to only 15% of watershed area to estimate total length of skid trails). These assumptions are crude and undoubtedly in error in many areas, however, an estimate of the magnitude of the historic skid trail erosion is critical to the assessment of erosion and sedimentation in the Garcia River watershed.

Erosion from skid trails was estimated using the road methodology described above, but with smaller dimensions in the road prism (5 ft for both cut and fill slopes, and 12 ft for

the tread). These dimensions, combined with the estimated average skid trail density, yield estimated area of skid trails equivalent to about 9% of watershed surface area. Based on systematic observations of skid trails in Mendocino County by CDF personnel, typical surface area in skid trails ranges from 12 to 20% of watershed area in commercial timber lands (Cafferata, 1997). This suggests that skid trail erosion may be underestimated with respect to assumed surface area occupied by skid trails.

In addition, because of the re-use of skid trails in successive harvests (there have been approximately 3 harvest cycles on much of the watershed), and because of the large area of skid trails, the base erosion rate for the 0-2 year age class of road surface (Table 3-4) was incorporated in the estimate to avoid potentially significant underestimation of historic skid trail erosion rates. The factors selected for calculating road erosion for each road and skid trail category are given in Table 3-8.

Background erosion rates were estimated according to the WM as a function of the average creep rate (natural erosion processes excluding larger-scale mass wasting) of soil material into channels. The average creep rate was assumed to be 2 mm/yr (about 0.007 ft), the average streambank height across which the creep rate applies was assumed to be 1 m (about 3.3 ft), and the stream length was estimated based on drainage density in subwatersheds where relatively complete data on the channel network were available in the CDF GIS (typical drainage density was 7 mi/mi$^2$). The product of creep rate, bank height, stream length and 2 (once for each streambank) is the estimated background erosion rate.

***Table 3-8. Summary of base erosion rate and correction factors applied to calculate estimated annual erosion from roads and skid trails. Skid trail delivery ratio (25%) is equivalent to the delivery ratio that results from delivering 100% of sediment eroded from roads within 200 ft of stream channels.***

| Road Class | Base Erosion Rate (T/ac road prism/yr) | Cover Factor for Cut and Fill Slopes | Surface Material Factor for Road Tread | Traffic/Prec-ipitation Factor | Proportion of Sediment Delivery to Channels |
|---|---|---|---|---|---|
| Paved | 60 | 0.37 | 0.03 | not applicable | 100% for prism < 200 ft from channels |
| Rocked | 60 | 0.37 | 0.5 | 4 | see above |
| Seasonal | 60 | 0.37 | 1 | 1 | see above |
| Temporary | 60 | 0.37 | 1 | 0.05 | see above |
| Skid Trail (0-2 yr old) | 110 | 1 | 1 | 1 | 25% |
| Skid Trail (> 2 yr old) | 60 | 0.37 | 1 | 0.05 | 25% |

**v. Results**

The estimated annual erosion rate from roads and skid trails resulting from the calculations described above are presented in Table 3-9. Estimates for skid trails and background are derived from estimates of skid trail and stream density per unit area, which were assumed to be the same for all subwatersheds with the exception of skid trail density in Pardaloe and Hathaway Creek subwatersheds (see above). Consequently, these values are multiples of the subwatershed area, and the rates per unit watershed area are the same. The estimates for roads were based on CDF GIS data for roads, and these vary among the subwatersheds as a function of road type and proximity to stream channels mapped in the CDF GIS.

As can be seen from Table 3-9, estimated delivery of sediment from new skid trails (i.e. within 2 years of initial construction or re-use) is on the order of 10 times that from old skid trails. This results from the higher base erosion rate and lower cover density on the new skid trail prism compared to the older skid trail prism (Table 3-8). Old skid trails and existing roads were estimated to deliver roughly comparable quantities of sediment to streams. This results from the assumed density of skid trails, which is at least 5 times that of roads (and probably more according to some knowledgeable observers), which compensates for the much lower estimated erosion rate of old skid trails compared to active roads. Estimated background sediment delivery rates are a fraction of either the estimated road delivery rate or the skid trail delivery rate.

***Table 3-9. Estimated annual sediment delivery to streams (tons) from roads, skid trails, and creep processes for subwatersheds of the Garcia River. Although estimates are given with several digits, the estimates should be considered to have at most two significant digits (i.e., the values should be rounded to hundreds and thousands of tons).***

| Sub-watershed | Area (sq.mi.) | Roads | Skid Trails (0-2 yr. old) | Skid Trails (> 2 yr. old) | Background (Creep) |
|---|---|---|---|---|---|
| Larmour Cr. (2) | 10.2 | 913 | 15760 | 2080 | 652 |
| 3 | 7.7 | 1287 | 11860 | 1566 | 491 |
| 4 | 6.2 | 2165 | 9558 | 1262 | 396 |
| Pardaloe Cr. (5) | 16.4 | 1961 | 3780 | 499 | 1043 |
| 6 | 5.4 | 2740 | 8240 | 1088 | 341 |
| Inman Cr. (7) | 8.6 | 3970 | 13189 | 1741 | 546 |
| 8 | 4.1 | 1676 | 6317 | 834 | 261 |
| Signal Cr. (9) | 6.2 | 3178 | 9514 | 1256 | 394 |
| South Fk. Garcia (10) | 8.7 | 393 | 13462 | 1777 | 557 |
| Hathaway Cr. (11) | 12.3 | 1888 | 2832 | 374 | 782 |
| North Fk. Garcia (12) | 16.2 | 7653 | 24961 | 3295 | 1033 |
| Rolling Brook (13) | 12.5 | 1428 | 19249 | 2541 | 797 |
| TOTAL | 114 | 29252 | 138723 | 18311 | 7293 |

### vi. Interpretations and Implications

The results of the surface erosion assessment are considered along with the results of the mass wasting assessment and information on sediment yield in the Garcia River watershed in the following section.

## *C. Synthesis of mass wasting and surface erosion assessments*

### i. Introduction

This section combines the results of the two assessment modules for purposes of interpretation and discussion of implications. This section has two parts. The first develops an hypothetical budget for delivery of sediment to the channel network within the Garcia River basin over a period of approximately the past 40 year, including an accounting of coarse sediment (> 2 mm diameter) and fine sediment (< 2 mm diameter). This part is intended to assist in the development of monitoring plans and interpreting erosion and sedimentation conditions in the watershed as a whole. The second part is a discussion of confidence in the assessment. This part includes a comparison of sediment delivery rates estimated in this assessment with observed sediment yield in the Garcia River and elsewhere in the Coast Range. The second part also includes a discussion of recognized sources of potential or likely error in the quantification of sediment delivery rates.

### ii. Sediment Delivery Budget

Estimates of sediment delivery from mass wasting were developed for the intervals between aerial photographs used for the mass wasting inventory. This procedure yielded sediment volumes and mass delivered over the time interval. In contrast, estimates for sediment delivery from road and skid trail erosion were developed as annual rates in terms of mass per unit watershed area per year. Background erosion rates were developed in a similar fashion. In order to combine these estimates, it was necessary to extrapolate the annual erosion rates calculated in the surface erosion assessment over the time intervals defined by the mass wasting inventory.

Extrapolation of surface erosion rates necessitated several assumptions. First, with respect to roads (as distinct from skid trails), it was assumed that the current road network is representative of the historic road network of the past 40 years. This is justified on the supposition that most of the existing road network was likely constructed during the initial entry of the watershed for logging using post-war techniques during the 1950's. Consequently, sediment delivery from erosion of roads was simply estimated as the current rate extended over the 40 year budget period. Background rates from creep processes were treated in the same way.

For skid trails, it was necessary to apply two rates, one for new or recently used skid trails and one for skid trails in the period beginning two years after the most recent use (Table 3-8). This was accomplished by sub-dividing the 40 year period into lengths corresponding to the mass wasting inventory intervals, and applying the "new" skid trail rate for 2 years within the interval, and the "old" skid trail rate for the remaining period. This procedure assumes that the skid trail network as represented by samples from 1965 photographs does not change over time (or in response to regulatory changes), and that only one cycle of timber harvest (and skid trail use) occurred in each interval.

The estimated total sediment delivery for each erosion process in each subwatershed is displayed graphically in Figure 3-3. In general, Figure 3-3 shows that estimated road and/or skid trail erosion accounts for significantly more sediment delivery than mass wasting processes. This result is not typical of watersheds where large-scale mass wasting processes are active; conclusions regarding Figure 3-3 should not be drawn without careful consideration of potential error in sediment delivery estimates presented in the section on confidence in assessment products.

Figure 3-3 presents estimates of total sediment delivery, not the corresponding erosion rates. Consequently, it is difficult to judge the implied sensitivity of different subwatersheds to erosion. Figure 3-4 presents the sediment delivery rates that correspond to data depicted in Figure 3-3. Note that the rates of skid trail erosion (except in Hathaway and Pardaloe Creeks as described above), are identical in all subwatersheds, as are background rates. Only the mass wasting and road rate estimates vary between subwatersheds.

The time trend in sediment delivery rates that can be inferred from the estimated sediment delivery rates is shown in Figure 3-5. Here, all source processes are combined and the composite delivery rate is shown in the sediment delivery budget time intervals. This graph shows a generally declining rate of sediment delivery. Interpretation of this graph (and all results) should be conditional on the confidence discussion to follow.

The sediment delivery estimates shown above were also used to estimate the delivery rates of fine (< 2 mm diameter) sediment and coarse (> 2 mm diameter) sediment. This was accomplished in part by developing a composite soil profile for the dominant soil association in the Garcia River watershed as described in the Sonoma County Soil Survey (USDA, 1972). The particle size distribution in the Hugo/Josephine/Laughlin soil association was aggregated to develop a weighted mean particle size distribution. This procedure yielded a weighted average of about 30% coarse sediment and 70% fine sediment in the composite soil profile.

The Washington Methodology for road erosion assumes that only fine sediment is delivered from roads, so the distribution of coarse and fine sediment has no effect on the road estimate. All sediment delivery from erosion of the road prism is assumed to be composed entirely of particles <2 mm diameter. For mass wasting and background sources, the estimated delivery is 30% coarse and 70% fine. For skid trails, the Methodology was modified: it was assumed that 10% of estimated sediment delivery was in the coarse fraction and the remaining 90% was in the fine fraction. This assumption is intended to account for potential delivery of coarse sediment from skid trails in or adjacent to streams and steep skid trail in which gullies may have formed. These types of skid trail erosion are less likely to occur under existing forest practice regulations compared to practices in the 1950's and 1960's.

Figure 3-6 shows the estimated total fine sediment delivery while Figure 3-7 shows estimated total delivery of coarse sediment. In the case of fine sediment, the corresponding estimate for watershed average fine sediment delivery to streams is about 660 t/mi$^2$/yr. (Note to the reader: based on new information, these estimates were revised as described in the following section of the assessment "Suggestions for Further Work..." These original figures and estimates are retained to document the progression of the analysis and the impact of new data.) For coarse sediment, the estimated watershed average rate is about 90 t/mi$^2$/yr.

Figure 3-3. Estimated Mass of Sediment Delivery from Surface Erosion, by Subwatershed over Time

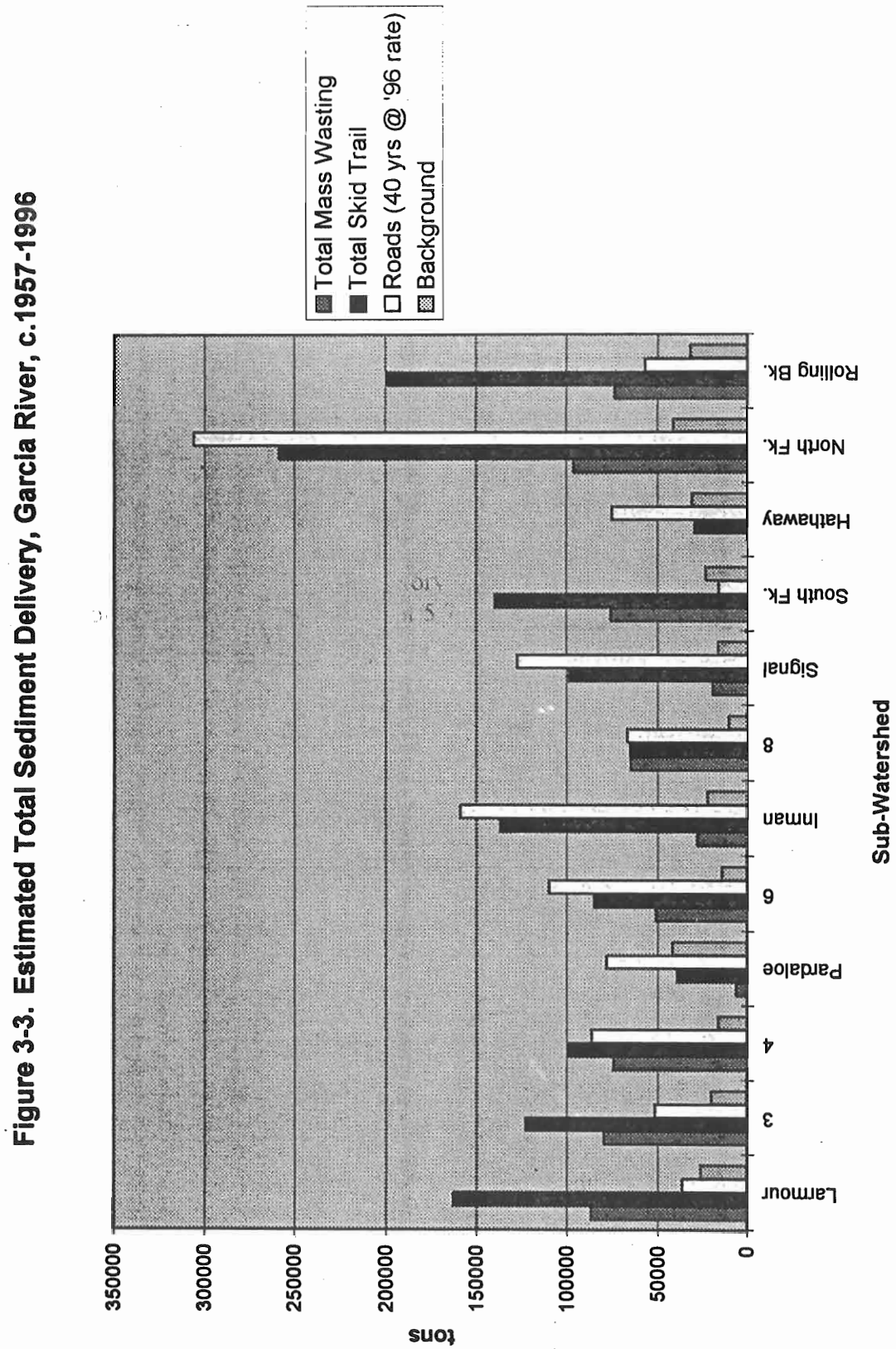


Figure 3-4. Estimated Rate of Sediment Delivery by Source Process, by Subwatershed.

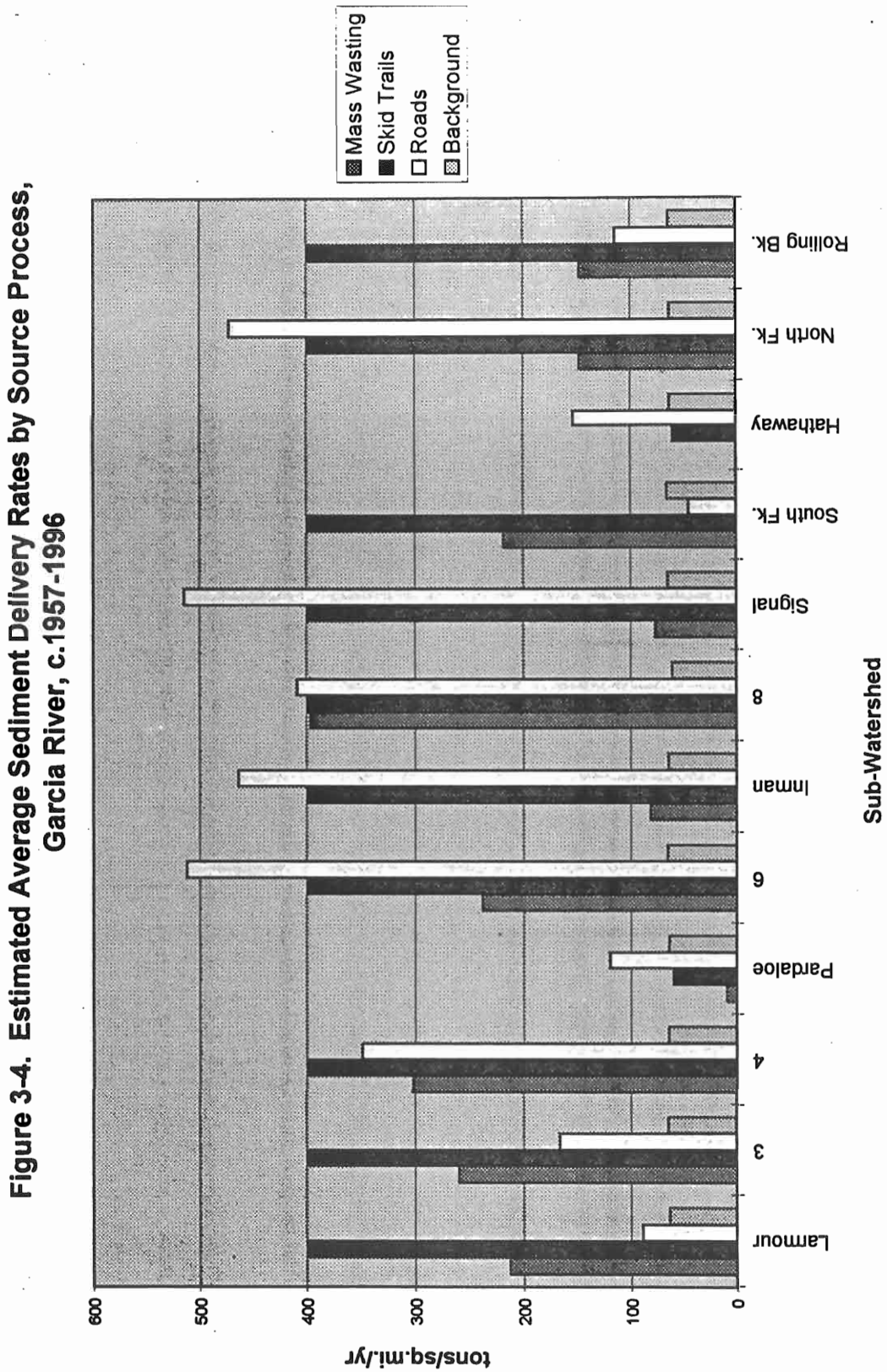
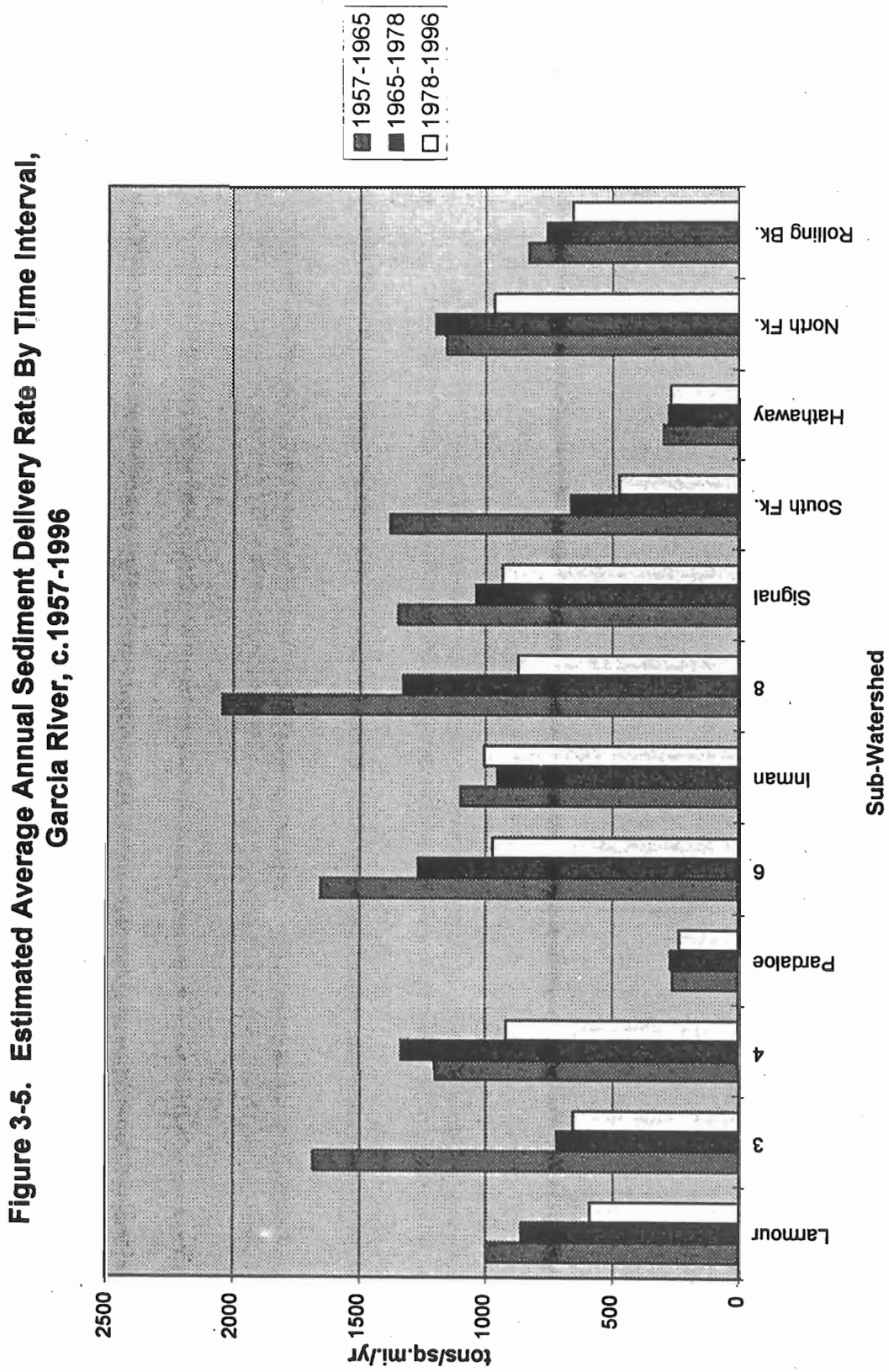


Figure 3-5. Estimated Average Annual Sediment Delivery by Time Interval, by Subwatershed.



### iii. Confidence in Assessment Results and Comparison With Other Studies

One means of checking the accuracy of the estimated sediment delivery rates is to compare these estimates to estimates of sediment yield developed or cited in other studies. The Garcia River Gravel Management Plan (Philip Williams & Associates, Ltd., 1996) developed and cited several estimates of sediment yield for the Garcia River.

USGS sediment discharge measurements and stream gauging data were used to estimate bedload and suspended load yield at Conner Hole, located on the Garcia River downstream of the confluence of the North Fork Garcia. Bedload and suspended load sediment are comparable to coarse and fine sediment, respectively. At this location, the estimated bedload transport rate in terms of mass per unit watershed area, was 160 t/mi$^2$/yr. The estimated coarse sediment delivery rate calculated in this study at the same location (which is approximated by excluding the Hathaway Cr. subwatershed) is about 100 t/mi$^2$/yr. The estimated suspended load based on the USGS data set and the Williams analysis (1996) is about 1800 t/mi$^2$/yr. The estimated fine sediment delivery rate from this assessment is about 740 t/mi$^2$/yr. Although the estimated average delivery rates are roughly half the estimated average sediment yield, the comparison suggests that the estimates in this assessment are not excessive, and are of roughly the same magnitude.

***Table 3-10. Comparison of estimated sediment delivery rates for this study with other estimates of sediment transport or yield (adapted from Philip Williams & Associates, Ltd. 1996, unless otherwise noted). Rates are in units of t/mi$^2$/yr.***

| Source/Method | Bedload | Total Load (Suspended load + Bedload) |
|---|---|---|
| This study-Estimated sediment delivery | 100 | 840 |
| Williams & Assoc./USGS-Extrapolation of sediment transport and stream discharge records (Garcia Gravel Management Plan best estimate) | 160 | 2,000 |
| Meyer-Peter, Mueller bedload transport equation | 115 | n.a. |
| Englund and Hansen total load equation | n.a. | 450 |
| Brownlie total load equation | n.a. | 105 |
| Lehre for Mad River | 309 | n.a. |
| Fugro West, Inc. for Redwood Creek | 532 | n.a. |
| PWA for the Gualala River | 87 | n.a. |
| Fugro West, Inc.; average sedimentation rate for California Coast Range reservoirs | n.a. | 442 |
| Napolitano (1996) for Caspar Creek, a managed redwood forest watershed | n.a. | 200 - 750 |
| Rice et. al. (1979) South Fork Caspar Cr., managed second growth redwood forest watershed | n.a. | 1,420 |

Further perspective on the accuracy of the estimates in this study are gained from Table 3-10. The bedload estimate of delivery rate is near the low end of the range of values presented, and is bracketed by local estimates for the Garcia River and the Gualala River. The estimated average total load delivery rate falls in the middle of the reported

range. These comparisons further suggest that the sediment delivery estimates produced in this assessment are reasonable.

However, considering the best estimate developed in the Garcia River Gravel Management Plan, and assuming that the sediment delivery rate and the sediment yield should be equal over a few decades, the estimated sediment delivery rates in this study account for only about 40 percent of the yield. In other words, this study may underestimate sediment delivery by as much as 100% or more. Some portion of this underestimate may be accounted for by erosion of alluvial terraces in the lower Garcia River, thus removing sediment from storage. This type of sediment delivery is unaccounted for in this assessment.

Although the foregoing suggests that the estimated sediment delivery rates are reasonable, there are many assumptions that were necessary to develop the estimates. Field visits, discussions with forest managers, and other studies suggest several areas where improved assumptions (or additional data) would likely improve the level of confidence in the estimates.

The mass wasting inventory map for the North Fork Garcia subwatershed was compared to a similar map prepared for Coastal Forest Lands Ltd. (1997). The CFL map was based on similar photo-interpretation criteria, and utilized a single set of 1:12,000 scale color photographs taken in 1995. The CFL inventory found a landslide density of about 27/mi$^2$ in the North Fork Garcia, compared to about 5.7/mi$^2$ for this study. A substantial portion of this discrepancy can be accounted for by the different resolution of mass wasting sites in this study compared to the CFL inventory. Nevertheless, the CFL inventory suggests that this study underestimates mass wasting, particularly smaller features with areas of < 100 to 200 yd$^2$. This could compensate for some of the apparently missing sediment. In addition, smaller-scale streamside mass wasting not detectable on aerial photos is not accounted for in either study.

Another potential underestimate of sediment delivery may be from gullies that are generally too small to be detected on aerial photos, but cumulatively may represent a significant quantity of sediment. Delivery of sediment from roads is underestimated in several subwatersheds where the stream channel data in the CDF GIS is of lower quality (areas where THPs have not been recently prepared), hence some road segments that may meet delivery criteria are not accurately represented.

Potential errors in estimates of skid trail and road erosion include (at least) excessive assumed delivery from road fill slopes and inaccurate road and skid trail density and area. Other assumptions detailed above and inherent in the techniques used are also potential sources of error. The overall level of confidence in these sediment delivery estimates is low to modest. The lack of resources for a significant field component to this assessment is perhaps the greatest source of uncertainty undermining the assessment.

Figure 3-6. Estimated Fine Sediment Delivery, 1957-1996.

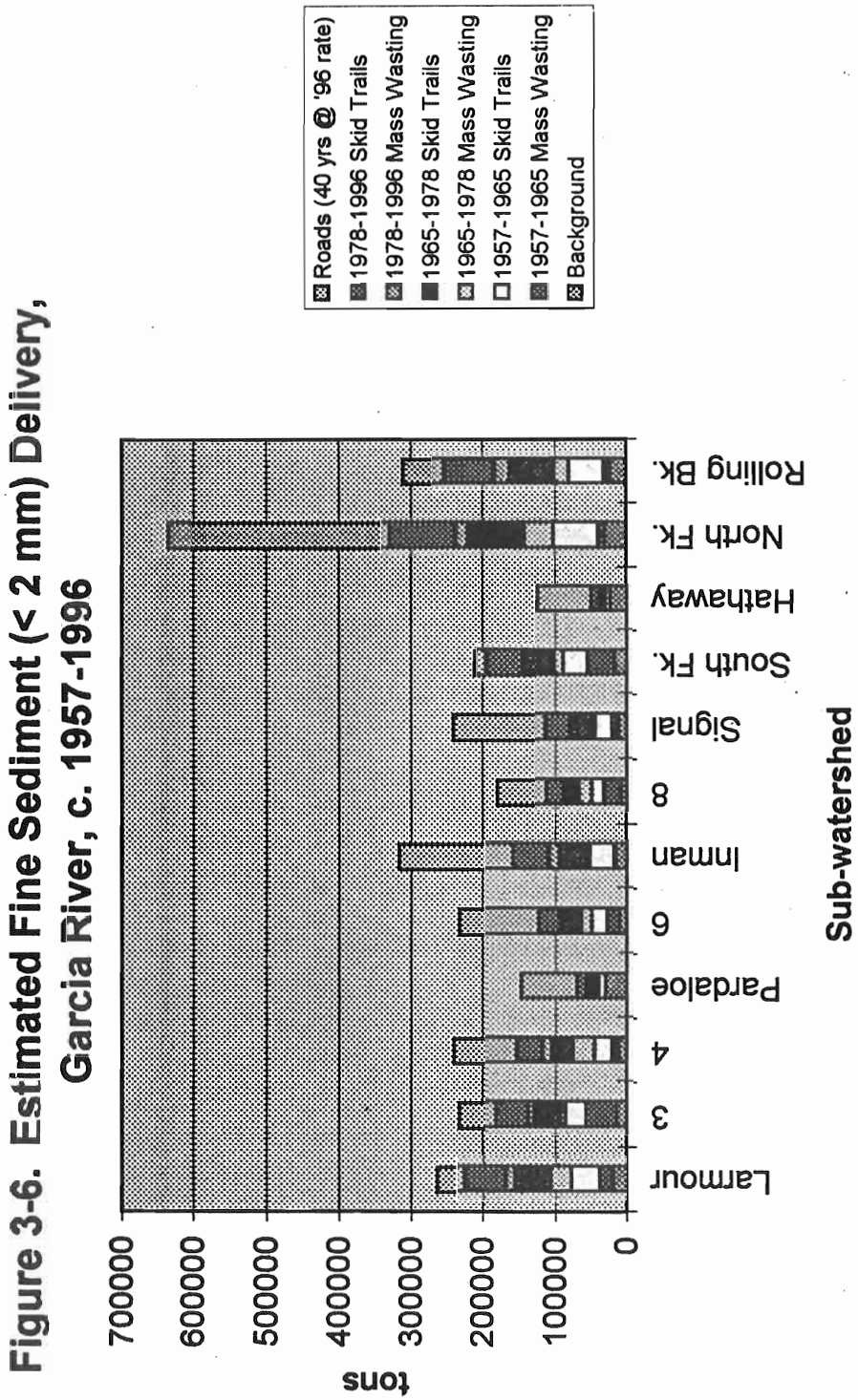
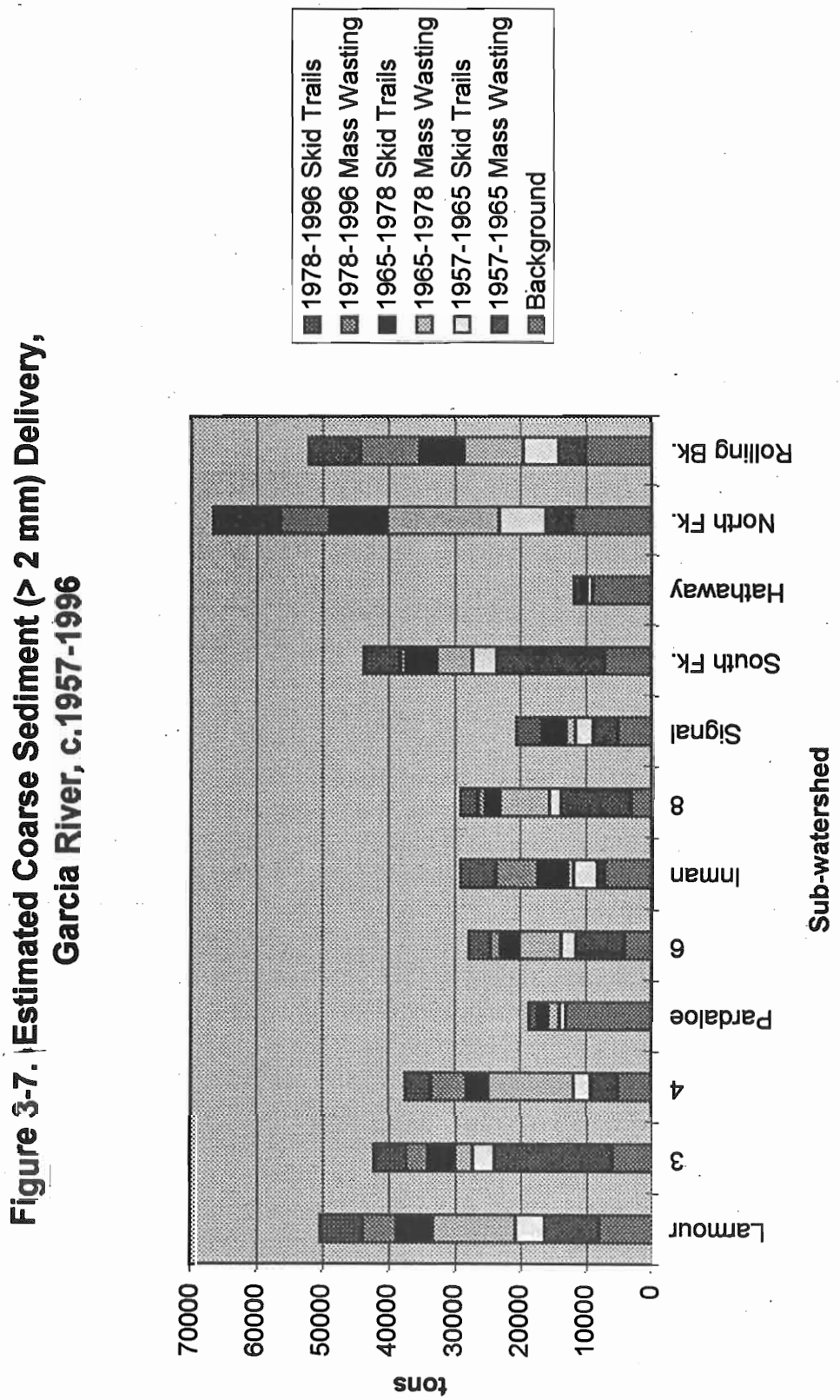


Figure 3-7. Estimated Coarse Sediment Delivery, 1957-1996.



Suggestions for further work to refine assumptions and improve sediment yield estimates

### iv. Introduction

This section reviews several of the assumptions necessary to the completion of the Level 1 assessment. The purpose of this review is to emphasize the tentative nature and quantitative limitations of this type of assessment (i.e. Level 1), to suggest possible improvements to assumptions/techniques, to incorporate comments made by several reviewers of the Level 1 assessment, including the results of some Level 2 assessment work, and to assess how revised assumptions would affect estimated sediment yield.

### v. Review of Selected Assumptions

To estimate sediment delivery from mass wasting inventory data, the amount of material mobilized was determined from landslide area (either measured or estimated from photos) and an assumed depth of material, and it was determined whether particular landslides delivered to a stream (yes or no). For those that did deliver, it was assumed that 25% to 75% of the mobilized material was delivered to a stream, depending on the mass wasting process (Table 3-1). The values selected are reasonable, somewhat conservative, and based on prior experience. Nevertheless, these are assumptions that could potentially be revised based on field investigations or other relevant data.

Several assumptions regarding the extent and character of roads and skid trails were necessary to complete the Level 1 assessment of surface erosion. Those assumptions that are most questionable, and that could conceivably be revised or improved, are discussed below. All of the assumptions and model parameters of the DNR method are described in the preceding section on the surface erosion assessment.

The level of historic road erosion was estimated based on the assumption that the existing road network, as portrayed by the CDF GIS data, is representative of the historic forest road network that was built beginning in the 1950's. This assumption was made for lack of a feasible alternative that could be implemented for the assessment. This assumption overlooks a few likely facts.

First, sediment delivery to streams caused by road construction is not accounted for. There was probably a large amount of sidecast spoils and road crossing material that was introduced to stream channels when roads were constructed.

Second, the CDF data do not include inactive or abandoned forest roads from the period prior to 1986. This problem is probably not significant in subwatersheds where a high density of THPs have been prepared in the past ten years because old road grades are typically reoccupied, but probably is significant in areas where timber harvest activity has been sparse in the past 10 years. Consequently, historic road erosion for subwatersheds such as Rolling Brook and South Fork Garcia, where commercial timber harvest historically occurred, is likely underestimated in the Level 1 assessment.

Table 3-11 summarizes the CDF data by subwatershed. Subwatersheds with low percentages of their area in recent THPs are most likely to underestimate the historic extent of the road network. In the cases of Hathaway Cr.(11) and Pardaloe Cr. (5), the low relative extent of coniferous forest vegetation and the known land use history suggest that these areas were not as intensively harvested. In these two sub-basins it was assumed that the current condition is reasonably representative of historic conditions with respect to forest roads.

***Table 3-11. Summary of selected data abstracted from the CDF GIS data base. The data base is built on information from THPs collected since 1986. Recent THPs have provided accurate maps for headwater stream channels not mapped on USGS topographic maps, hence the large differences between drainage density for areas with low and high percentage of THP. It is expected that drainage density should be fairly uniform. Drainage density correlates well with percent of area in THP. Extrapolating the correlation suggests that actual drainage density is about 7 mi/mi$^2$. Road density follows a similar pattern, but varies over a smaller range.***

| Sub-watershed | % Area in THP Since 1986 | Drainage Density (mi/mi$^2$) | Road Density (mi/mi$^2$) |
|---|---|---|---|
| Larmour Cr. (2) | 13 | 1.5 | 2.6 |
| 3 | 35 | 2.2 | 4.4 |
| 4 | 52 | 4.5 | 4.4 |
| Pardaloe Cr. (5) | 12 | 2.4 | 3.4 |
| 6 | 62 | 5.2 | 4.2 |
| Inman Cr. (7) | 76 | 5.7 | 4.2 |
| 8 | 76 | 5.3 | 4.2 |
| Signal Cr. (9) | 70 | 5.5 | 5.2 |
| South Fk. Garcia (10) | 15 | 1.5 | 3.5 |
| Hathaway Cr. (11) | 17 | 1.4 | 2.9 |
| North Fk. Garcia (12) | 82 | 5.6 | 4.8 |
| Rolling Brook (13) | 20 | 1.3 | 4.4 |

Road erosion rates were used to estimate sediment delivery rates to streams based on the assumption that roads within 200 ft of streams deliver 100 percent of eroded sediment and roads greater than 200 ft deliver no sediment. This assumption was developed from guidance in the DNR methodology that stated that, in general, for roads greater than 200 ft from streams, all eroded sediment would be deposited on hillslopes prior to reaching the stream. Delivery from road ditches was not addressed by this guidance. Hence, the Level 1 assessment may overestimate delivery of sediment across hillslopes to streams, but may well underestimate delivery from inboard road drainage ditches. The delivery issue is best resolved on the basis of site-specific field survey data for road drainage. This solution was beyond the scope of this Level 1 assessment.

Historic skid trail erosion was assessed by modifying the DNR methodology to treat skid trails as a type of road. This included using a high rate of erosion for a two year period following construction or re-use of skid trails, with much lower rates in subsequent years owing to lack of use. It was also assumed that skid trails were used only once in each of

the three sediment production intervals. In some areas in the past ten years, forest entries for harvest have been more frequent.

Delivery of sediment eroded from skid trails to streams was estimated using reasoning similar to that for estimating delivery from roads. Basin-wide, about 25 percent of road length was within 200 ft of streams. It was assumed that the proportion of skid trail length within 200 ft of streams was that same as that for roads, and that the effective delivery rate from skid trails was 25 percent of the erosion rate.

Regarding skid trail erosion, it was further assumed that ten percent of the sediment produced from skid trails would be coarse (> 2 mm), whereas the DNR method assumes surface erosion from roads produces only fine sediment (approximately < 2 mm). This component of coarse sediment attempts to reflect historic erosion of small channel fills and the development of gullies in some skid trails. Although these erosion processes are likely to have contributed significantly to the sediment load of the Garcia River, the selection of ten percent as a component of coarse sediment is little more than a guess. The maximum value would be thirty percent—the estimated proportion of coarse sediment in the typical soil column.

The estimated quantity of skid trails, however, is probably the most sensitive factor in the estimate of erosion from skid trails. All estimates of historic skid trail erosion are based on skid trail density measurements from two areas in aerial photography from 1965. After the implementation of forest practice rules in 1974, skid trail density was probably reduced. Nevertheless, it was assumed that skid trail density was constant over time. This suggests that the estimated rate of erosion from skid trails may be too large. On the other hand, investigations of skid trail densities in other areas of coastal Mendocino County suggest that the skid trail density in terms of surface area are typically about 33% over 200% greater than that assumed in this assessment (Cafferata, 1997), suggesting that the estimated erosion rates may be too small. Observations on a few recent skid trails in the North Fork Garcia revealed virtually no sediment delivery to channels, but these observations were neither systematic nor extensive. It is clear that skid trail erosion was a major source of sediment in the Garcia River; it is also clear that estimating historic erosion rates from skid trails requires either several major assumptions or a detailed investigation based on existing data and additional field research.

### vi. Suggestions for Further Work

In general, a Level 1 assessment under the DNR methodology does not allow for sufficient field survey work to refine assumptions that would make the assessment product more accurate. The scope of this assessment limited field work to 3 field reconnaissance trips to become familiar with ground conditions. If time had been available to conduct field survey work, several tasks would have been useful.

With respect to mass wasting, field verification of a high proportion of mapped deep-seated landslides would be a high priority owing to their low occurrence but high sediment production (4% of slides, 36% of sediment). Field verification of a sample population of

shallow rapid landslides and debris torrents would be aimed at comparing estimates of sediment delivery made from aerial photo interpretation with estimates made from field measurements. These data would be used to adjust the assumed delivery rate of sediment from landslides. In addition, field surveys would provide perspective on the proportion of landslides that exist on the ground but were not mapped from aerial photos.

Erosion caused by development of gullies and by smaller streamside shallow landslides cannot be estimated from aerial photographs because they are typically too small to see or are obscured by forest canopy. Estimates of sediment delivery from these processes should also be obtained from field surveys. These erosion processes are not well-accounted for in the Level 1 assessment. Gullies related to skid trails are conceptually accounted for in skid trail erosion estimates. Gullies caused by road runoff are not included, but a few were observed during field reconnaissance. Gullies are thought to be significant historic sources of sediment (Monschke, 1997).

Shallow streamside landslides occur naturally, but may also tend to increase in stream channels that become aggraded or are subject to unusually intense floods. These mass wasting sites appeared to be relatively common in some of the areas visited in the field. In this assessment, sediment delivery from this type of mass wasting is implicitly included in the background creep rate (Table 3-9). Sample data from a range of stream sizes could be used to estimate streamside landslide sediment delivery rates, or could be used to revise the creep rate.

Further work could also refine assumptions used in the road erosion assessment. Historic photography could also be used to more accurately estimate the distribution and density of skid trails in the Garcia River over the past 40 years. As noted previously, a field survey component would significantly improve the reliability of road erosion estimates. First, road segments could be surveyed to refine assumptions regarding road width, surfacing, cover on cut and fill slopes, drainage and delivery to streams. Existing (and possibly abandoned) skid trails could be surveyed for the same purpose.

### vii. Effects and Interactions of Climate and Management on Sediment Yield

The sediment yields estimated are gross averages. They have been developed for three different decade-scale time periods, but these do not necessarily reflect the interaction between land use and climatic fluctuations. In the Coast Ranges of California, significant increases in erosion rates occur during periodic wet winters when runoff rates are very high. Naturally-elevated erosion rates are often compounded when intensive management occurred, particularly in the era preceding regulation of forest harvest practices.

In the Garcia River watershed, there were at least two episodes of unusually intense winters prior to adoption of modern forest practice regulations. The first was in the mid-1950's when much of the Garcia was being logged for the first time. The second was in the early 1970's. It is likely that a high proportion of erosion and sedimentation occurred during these relatively short periods, and that sediment delivery and transport rates may have been on the order of 10 times greater during these periods. Consequently, the rates

of sediment delivery presented in Figures 2, 6, 7 and 8 smooth a record that, if it could be displayed by annual time step, would have a few extreme peaks and valleys.

An example of how climatic fluctuation and management practices affect annual sediment yield in northern California was suggested by a Cafferata in his review of the assessment (Cafferata, 1997). Table 3-12 shows sediment yields measured at the Caspar Creek experimental watershed in Mendocino County. These data suggest that in some areas, natural processes under wet conditions produce significantly more sediment than management practices under more typical winter conditions, but that the combination of poor management practices and wet winters generate the highest sediment yields by far.

***Table 3-12. Sediment yield data for Caspar Creek, Jackson Demonstration State Forest. Data for the "no recent harvest" condition after Napolitano (1996). The "modern practices" value is attributed to R. Rice, (pers. comm.), by P. Cafferata (pers. comm.), and is considered to be a preliminary approximation. The "historic practices" value is after Rice et. al. (1979). Units are t/mi²/yr.***

| Management | Typical Winter (approx. <10 yr return period) | Wet Winter (approx. >10 yr return period) |
|---|---|---|
| No Recent Timber Harvest | 180 | 680 |
| Timber Harvest, Modern Practices (late 1980's) | ~ additional 100 | ~ additional 100 |
| Timber Harvest, Historic Practices (early 1970's) | n.a. | 1420 |

### viii. Potential Influence of Franciscan Melange Formation on Sediment Yield

A major area of the Franciscan Complex melange occurs in the Garcia River basin, a northwest-southeast trending swath about two miles wide in Inman Creek and Blue Waterhole Creek (subwatersheds 3 and 4), covering roughly ten percent of the watershed. This formation tends to be vegetated by grasslands, and is typically dissected by significant gullies and prone to landsliding along stream channels. A sediment budget prepared for the Navarro River watershed (Trihey & Associates, Inc., 1997) reported sediment production rates for different geology-vegetation associations.

For melange-grassland, sediment production was estimated at 4,000 t/mi$^2$/yr, with about 90 percent coming from streamside landslides and gullies along third through sixth order streams. For first and second order streams, sediment production from bank erosion and shallow landslides combined was reported to be about 400 t/mi$^2$/yr. The magnitude of these natural erosion rates is high compared to other estimated source rates for the Garcia River (e.g. Figure 3-4).

These estimates could be loosely applied to the Garcia by adjusting the background rates for the affected subwatersheds (3, 4 and 7) based on the proportion of melange in the subwatershed and the distribution of stream in relation to the melange to reflect the nature of the rates for the Navarro River. Assuming that about half of each drainage is composed

of the melange, and using the sediment production rate for first and second order channels only, the background rate could be increased to at least 230 t/mi$^2$/yr. Depending on the interpretation of the Navarro River rates and how they might be applied with regard to stream order, the background rate for these subwatersheds might be estimated at rates as high as 2,000 t/mi$^2$/yr.

**ix. Level 2 Watershed Analysis Data and Implications for Level 1 Results**

During the summer of 1997, Louisiana-Pacific Corporation (L-P) performed field work for Level 2 watershed analysis of portions of the Garcia River watershed under their ownership, primarily in the South Fork Garcia and Rolling Brook subwatersheds. Preliminary results of the mass wasting and surface erosion components were made available as part of L-P's comments on the Level 1 assessment. Elements of the L-P analysis that could be applied to the Level 1 assessment are discussed below.

Estimated sediment delivery rates have been recalculated to show how Level 2 field data could be used to revise Level 1 assumptions. Whether the revised estimates should be considered valid depends on whether field data from the Rolling Brook and South Fork Garcia subwatersheds are representative of the remainder of the Garcia River watershed.

L-P's mass wasting module included extensive field measurements of shallow rapid landslide and debris torrent sites. They estimated delivery rates of mobilized sediment to stream channels for shallow rapid landslides to be 76 percent. For debris torrents, L-P estimated 85 to 100 percent delivery. With respect to this Level 1 analysis, substitution of a delivery rate derived from local field data from shallow rapid landslides would be significant because about 85 percent of the inventoried landslides were of this type. Revising the delivery rate to 75 percent from 50 percent would increase the shallow rapid component by 50 percent. The assumed debris torrent rate is somewhat less than the L-P field estimate, but is in relatively good agreement. The effect of modifying the assumption of delivery rate from shallow rapid landslides is shown in Table 3-13. Overall mass wasting rates are increased about one-fourth.

L-P's mass wasting analysis field survey also collected data on streamside landslides that were not visible or two small to identify on aerial photographs. This component of mass wasting was not included in the Level 1 analysis. L-P's estimate for sediment delivery from small streamside landslides ranged from about 185 to 250 t/mi$^2$/yr, averaging about 210 t/mi$^2$/yr. These rates are generally consistent with rates reported by Trihey & Associates, Inc. (1997) for the Navarro River, although they do not specifically distinguish between shallow landslides that are visible on aerial photographs from those that are not visible.

The rates reported by L-P are roughly equivalent to about 30 yards of sediment per mile of stream length, a quantity that is physically reasonable, or even conservative, based on field observations in the Garcia River and in other mountain streams. The effect of incorporating L-P's streamside landslide rate is shown in Table 3-13. The total mass wasting rate is more than doubled with inclusion of small-scale streamside mass wasting. These two adjustments to the mass wasting sediment delivery rates would have the effect

of increasing estimated total sediment yield from the Garcia River by about half, to 1,200 t/mi$^2$/yr. In the context of Table 3-10, these adjustments bring sediment delivery closer to the sediment yield estimated for the Garcia by Philip Williams & Associates (1996).

L-P also developed a Level 2 analysis of surface and road erosion. L-P developed a map of the road network developed beginning in 1952, and thus included many roads that were not in the CDF GIS data base. They also measured erosion from culvert wash outs, gullies, and small fill failures that delivered sediment to streams. L-P adapted the DNR methodology to estimate surface erosion from roads. They modified some assumptions to more accurately reflect the condition and usage of L-P roads. Since most of the log hauling on roads occurs during the dry season, they weighted the traffic/precipitation factor (Table 3-7) 85 percent toward annual precipitation < 47 in. and 15 percent toward the 47 to 118 in. category. In addition, they modified the road surface factor (Table 3-6) for native surfaces from 1.0 to 0.75 (halfway between "native" and "gravel, 2-6 in"), to account for the high proportion of rock incorporated in the bed of cut and fill roads that frequently excavate bedrock. These modifications would reduce estimated erosion rates.

Level 2 work by L-P in the South Fork Garcia and Rolling Brook estimated average sediment delivery from roads over the past 45 years to be 387 t/mi$^2$/yr and 238 t/mi$^2$/yr, respectively. The Level 2 estimates are consistent with the average rate (255 t/mi$^2$/yr) and the maximum subwatershed rate (514 t/mi$^2$/yr) for the Garcia estimated from Level 1 data. These estimates represent significant increases from the Level 1 estimates for these subwatersheds which were 45 t/mi$^2$/yr and 114 t/mi$^2$/yr for the South Fork Garcia and Rolling Brook, respectively. The relatively low rates predicted by Level 1 assessment are not due to very low road density compared to other subwatersheds (Table 3-11). L-P's work involved field measurements of proportions of roads that deliver sediment to streams and included local erosion such as gullies that are not accounted for by the DNR method. This suggests that the Level 1 road erosion estimates may be conservative, and might be more likely to increase rather than decrease should more detailed field investigations be performed.

L-P's Level 2 analysis also considered skid trail erosion. They adjusted the skid trail density over time to reflect lower rates of harvest in recent decades. (The Level 1 analysis assumed that the 1965 skid trail density was constant at its maximum level.) They also adjusted delivery rates from skid trails based on field data for the average length of contributing road adjacent to stream crossings (300 ft) and the number of skid trail crossings.

Despite significant methodological differences, L-P calculated skid trail erosion rates comparable to those calculated for the Level 1 assessment, about 350 t/mi$^2$/yr for the 1952 to 1966 period. These rates declined in subsequent time intervals to about 150 t/mi$^2$/yr. The average over their 45 year time period was about 220 t/mi$^2$/yr compared to 400 t/mi$^2$/yr from the Level 1 analysis. These data suggest that the Level 1 skid trail erosion rates may be overestimated by about half. However, the density and frequency of use of

skid trails is likely to vary for areas under different ownership, and that is likely to affect estimated erosion rates.

***Table 3-13. Mass wasting rates for Garcia River subwatersheds based on selected Level 2 mass wasting analysis data; these estimates supersede those presented in prior sections. Shallow rapid delivery rate for photo-inventoried landslides is increased from 50% to 75%. Small-scale streamside mass wasting was estimated based on an average field-derived rate of 210 t/mi²/yr. The Level 1 analysis did not include an estimate for streamside mass wasting. If accepted, these revisions increase the total estimated erosion rate for the Garcia River from about 840 t/mi²/yr to about 1,200 t/mi²/yr, representing an increase of about 50%.***

| Sub-watershed | Area ($mi^2$) | Original Total Mass Wasting (t) | Revised Total Mass Wasting (t) | Revised Rate; Increased Shallow Rapid Delivery ($t/mi^2/yr$) | Estimated Streamside Shallow Rapid (t) | Total Including Estimated Streamside Shallow Rapid (t) | Revised Rate: Shallow Rapid Delivery and Streamside Shallow Rapid ($t/mi^2/yr$) |
|---|---|---|---|---|---|---|---|
| 2 | 10.2 | 86,000 | 103,000 | 252 | 85,700 | 188,700 | 463 |
| 3 | 7.7 | 81,000 | 96,000 | 312 | 64,700 | 160,700 | 522 |
| 4 | 6.2 | 74,000 | 82,000 | 331 | 52,100 | 134,100 | 541 |
| 5 | 16.4 | 5,500 | 8,000 | 12 | 137,800 | 145,800 | 222 |
| 6 | 5.4 | 51,000 | 69,000 | 319 | 45,400 | 114,400 | 530 |
| 7 | 8.6 | 27,000 | 34,000 | 99 | 72,200 | 106,200 | 309 |
| 8 | 4.1 | 65,000 | 79,000 | 482 | 34,400 | 113,400 | 691 |
| 9 | 6.2 | 19,000 | 23,000 | 93 | 52,100 | 75,100 | 303 |
| 10 | 8.7 | 76,000 | 87,000 | 250 | 73,100 | 160,100 | 460 |
| 11 | 12.3 | 0 | 0 | 0 | 103,300 | 103,300 | 210 |
| 12 | 16.2 | 102,000 | 141,000 | 218 | 136,100 | 277,100 | 428 |
| 13 | 12.5 | 78,000 | 98,000 | 196 | 105,000 | 203,000 | 406 |
| Total | 114.5 | 664,500 | 820,000 | 179 | 961,900 | 1,781,900 | 389 |

### x. Conclusion

Several potential improvements to the Level 1 analysis were suggested. Level 2 analysis by L-P on their ownership in the Garcia included some of these improvements. These improvements could serve as a basis for modifying the results of the Level 1 assessment. Modification of the mass wasting component of sediment production and delivery consistent with L-P's Level 2 analysis would roughly double the estimated rate of sediment delivery by mass wasting processes (Table 3-13). Most of that increase comes from adding small-scale streamside mass wasting to the sediment budget. Modification of the road and skid trail erosion components were also suggested by L-P's Level 2 work. However, the site specific qualities of roads and skid trails, and uncertainty regarding the historical distribution of skid trails make these modifications more difficult to incorporate with respect to Level 1 results. Application of any Level 2 data to revise Level 1 results requires the assumption that conditions in the South Fork Garcia and Rolling Brook subwatersheds are representative of other Garcia River subwatersheds.

### xi. Relevance to Proposed Monitoring of Channel Conditions

These estimates of sediment delivery to stream channels by various processes should be considered preliminary and in need of verification based on field observations. This should include field measurements of a sample of landslide sites. In addition, the assumptions regarding road and skid trail geometry and sediment delivery to streams should be examined in a systematic field investigation and revised as necessary. These activities are consistent with proposed monitoring presented in subsequent chapters of this report, which are structured to provide the opportunity to collect additional field data on hillslope sediment sources (e.g. identification of sediment transport corridors).

It is likely that monitoring efforts targeting instream conditions related to erosion and sedimentation processes will yield ambiguous or inconclusive results regarding the efficacy of forest practices regulations and erosion control efforts if a more refined estimate of sediment production is not prepared for drainage areas upstream of proposed monitoring sites. Interpretation of monitoring data for stream conditions, particularly related to erosion and sedimentation, is extremely challenging even with the best sediment budget data.

With regard to monitoring hillslope management activities for efficacy of forest practice regulations and their effect on instream sedimentation, efforts would best be focused on the finer fraction of sediment that is transported relatively rapidly through the channel network. Coarse sediment that is transported as bedload has a long residence time in channels (typically decades to centuries), and its dynamics and conditions are likely to be influenced as much or more by management practices prior to the adoption of forest practices regulations in 1974. In contrast, fine sediment that is transported in suspension or in intermittent suspension (silt, sand and fine gravel), is routed through channels on a time scale of years to decades. Monitoring this fine fraction of sediment is most likely to provide insights regarding contemporary management practices in a time frame of years to decades.

## 4. *Synthesis of Information*

### *A. Matrix of impact certainty and resource sensitivity.*

One large, inclusive matrix has been developed of present resource condition, by tributary and mainstem segment (Appendix B). Data have been taken from a variety of sources, principally the evaluations by O'Connor (1997), Manglesdorf (1997) and Hagans (1997). Additional data were supplied by SYP documents (L-P, 1997; CFL, 1997), topographic and thematic mapping (USGS, 1991 and 1977; CDF, 1997), the previous watershed assessment prepared for the MCRCD (Monschke and Caldon, 1992), and input from people knowledgeable about the watershed. Qualitative and quantitative evaluations were transposed or interpreted from these reports and maps. Data were entered for as specific areas as possible.

Resource condition was interpreted from the evaluations of present condition relative to specific beneficial uses. We looked for specific interpretations of sedimentation, canopy, stream complexity, dissolved oxygen, temperature and fisheries. In some cases, the information was clear and unambiguous. In other cases, various interpretations were old, sketchy, unclear as to location, or given only in relative terms to other sites, in and out of the Garcia basin. In some instances, such as the canopy cover on Signal, Inman and Whitlow Creeks, data simply conflict.

Sensitivity to impact was evaluated by first establishing the presence of the resource to be protected, then determining if that resource was responding negatively to land management. For instance, where fish were specifically 'not present', an interpretation of 'no sensitivity to fisheries' was given, meaning no sensitivity within that tributary. If estimated erosion rates were high (>300 tons/sq.mi/yr) but did not result in a 'high' reported level of instream sedimentation, a value of 'no sensitivity to land use impacts' would have been given. Including a range of source material, no watershed within the Garcia basin was considered unaffected by sediment impacts.

Other beneficial uses, beyond fisheries, that have sensitivity to fine sediment, temperature, dissolved oxygen, channel complexity, and shade are domestic water, industrial and agricultural water and recreation. In the case of the Garcia, these other beneficial uses are limited in extent and, in general, track with fishery quality. Evaluating the watershed for fishery quality is therefore, in most cases, an evaluation for other beneficial uses. The most widely reported impact is fine sediment; other habitat impacts reported are lack of stream complexity and lack of riparian shade.

Sediment, lack of complexity and open canopies affect fisheries and streams in a profound manner. Sediment can adversely affect domestic water via inlet structure limitations and incorporation of a pollutant which must be filtered out before use; sediment also reduces recreational opportunities as it reduces pools important for fisheries. Complexity reflects

the stability of a channel, or the mobility of sediment and specific functional elements. A loss of complexity affects the utility of inlet structures and the location and depth of pools. Shade restricts the growth of algae and reflects dissolved oxygen levels in the stream. A loss of shade and concomitant growth of instream vegetation affects the color and taste of water, its aesthetic quality and its pool utility for recreation.

The matrix of tributaries and subwatersheds by resource condition and sensitivity is attached as Appendix B. Future data can be categorized within the matrix as the monitoring program is implemented and new data are gathered by basin stakeholders and agencies.

One approach to synthesis has been to look at estimated erosion generation from watersheds, both as a total and by its component parts. These data are derived from O'Connor's analysis given in Chapter 3 and shown in Figure 4-1. Using the Level 2 analysis conducted by L-P changes the sediment delivery ratio of streamside landsliding upward, from 50% to 75%, representing an increase in total landsliding of about 50%. Adjusted or unadjusted, the values demonstrate the importance of understanding processes in the small, steep planning watershed (PW) areas of Graphite Ck. South (PW 8) and Hot Springs Creek (PW 6). Graphite Ck. South, in particular, is an area with more landslide activity than any other basin in the watershed, and deserves appropriate protocol evaluations.

Another approach to synthesis is to develop a model of predicted erosion and evaluate present impacts to it. This synthesis found a significant correlation between landsliding (O'Connor, 1997) and topography, as shown in Figure 4-2. More than half the randomness of landslide volumes can be accounted for by the relative relief of watersheds (area/relief), with a significance of greater than 99%. This data is important because it points out subwatersheds in which high sedimentation is predicted, and where high sedimentation is anomalous (Appendix B). When compared with field data (Manglesdorf, 1997; Monschke and Caldon, 1992) areas with low relief and high sedimentation indicate priority sites for understanding sediment delivery processes. Watersheds which stand out are Pardaloe Ck., Inman Ck., the North Fork subwatersheds and Hathaway Ck.

The synthesis element in this report should not be considered definitive, but rather a first cut. As researchers get more information in, as models are proven, and as data improves, synthesis will become more fully attainable. The first step in that process should be the implementation of protocols which demonstrate the nature of causal mechanisms within the Garcia River watershed.

Figure 4-1. Total Estimated Erosion Rates by Planning Watershed (Unadjusted)

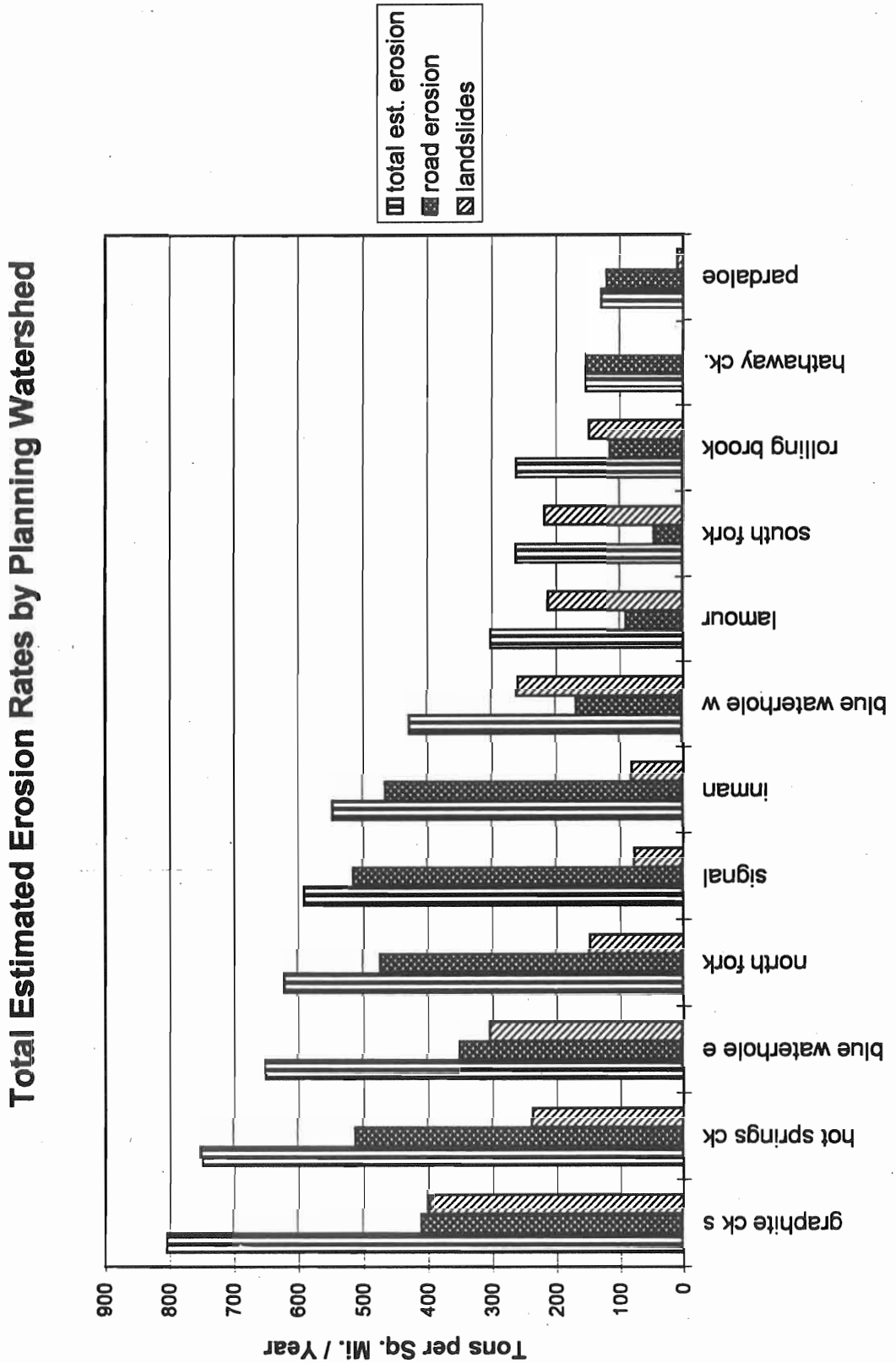
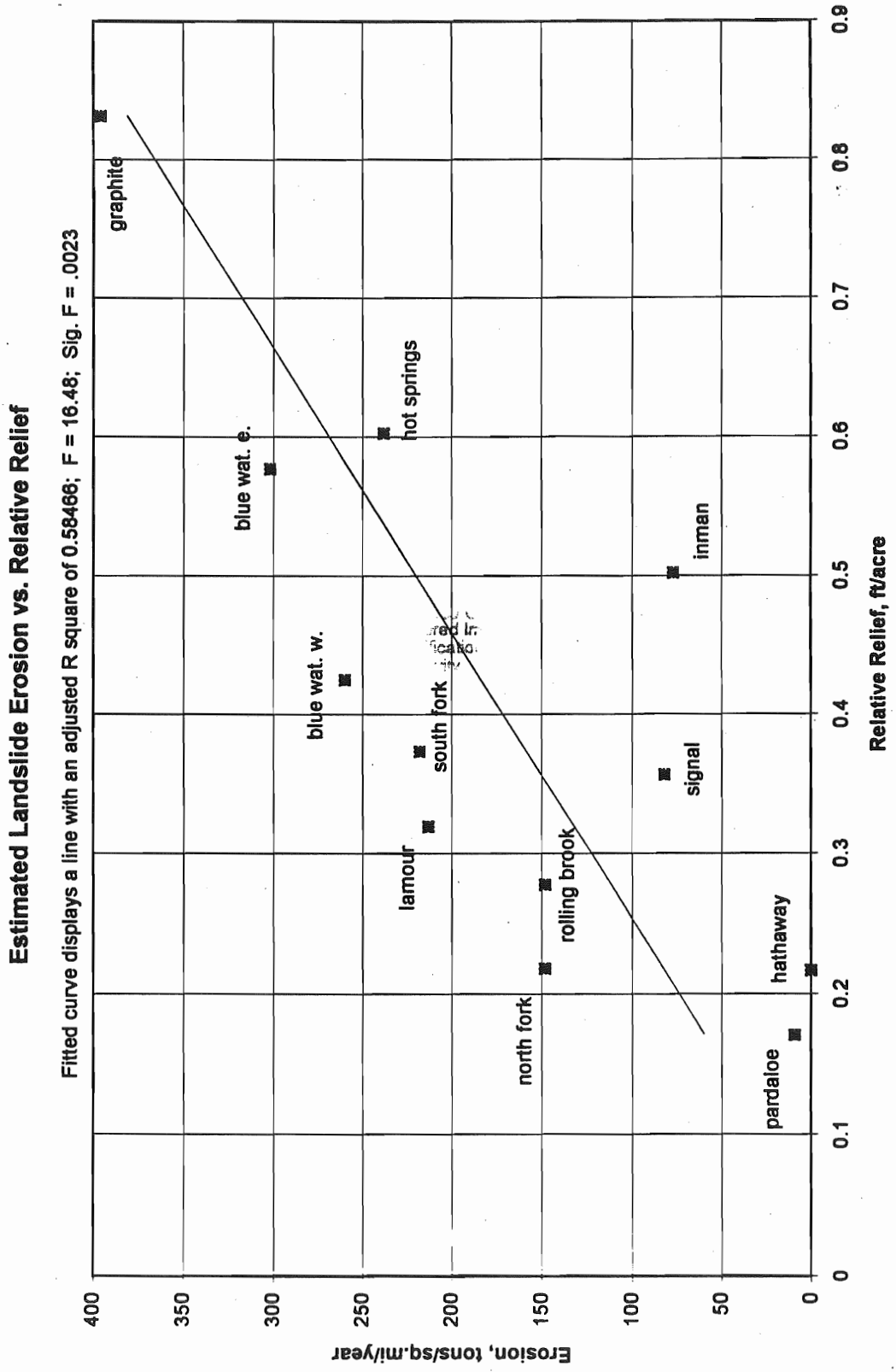


Figure 4-2. Estimated Landslide Erosion vs. Relative Relief



### *B. Causal mechanism statements*

Causal mechanisms are important for understanding the direct relationship between *actions*, in this case from timber harvesting, and *impacts*, in this case, restricting salmonid fisheries. The Washington State watershed analysis protocols (WFPB, 1995) describe causal mechanisms as the outcome of the resource assessment process, as shown in Figure 4-3a. The resource inventory is combined with resource analysis modules in a synthesis, described in process by a routing model, and culminating an analysis of *how* watershed actions occur, *what* impacts those actions generate, *what course* they take to the resource of consideration, and *how and when* they limit that beneficial use. The resource inventory allows adaptive management--to observe, act and observe again to best manage resources from documented experience.

This report is based on a Level 1 air photo analysis of the Garcia watershed and previous studies. These references do not allow the demonstration of causal mechanisms, but, instead, document likely sediment sources and instream resource conditions. We know, too, that the watershed has received significant timber harvest impacts over time, and we know the location and the nature of those impacts. We can presume that the watershed is presently recovering from these impacts. However, without documentation, we can only hypothesize that streams and the habitat they provide are recovering from the harvests of the 1950's to 1970's. We know that present conditions in these streams have embedded gravels, stored sediment, and poor shading, low complexity and reduced fish populations. Without causal data of *why* the old logging practices make present habitat poor, or how old logging practices continue to suppress fish populations, we cannot test the hypothesis that old practices are, indeed, at fault; we need quantitative, causally-oriented data to distinguish old problems from new ones.

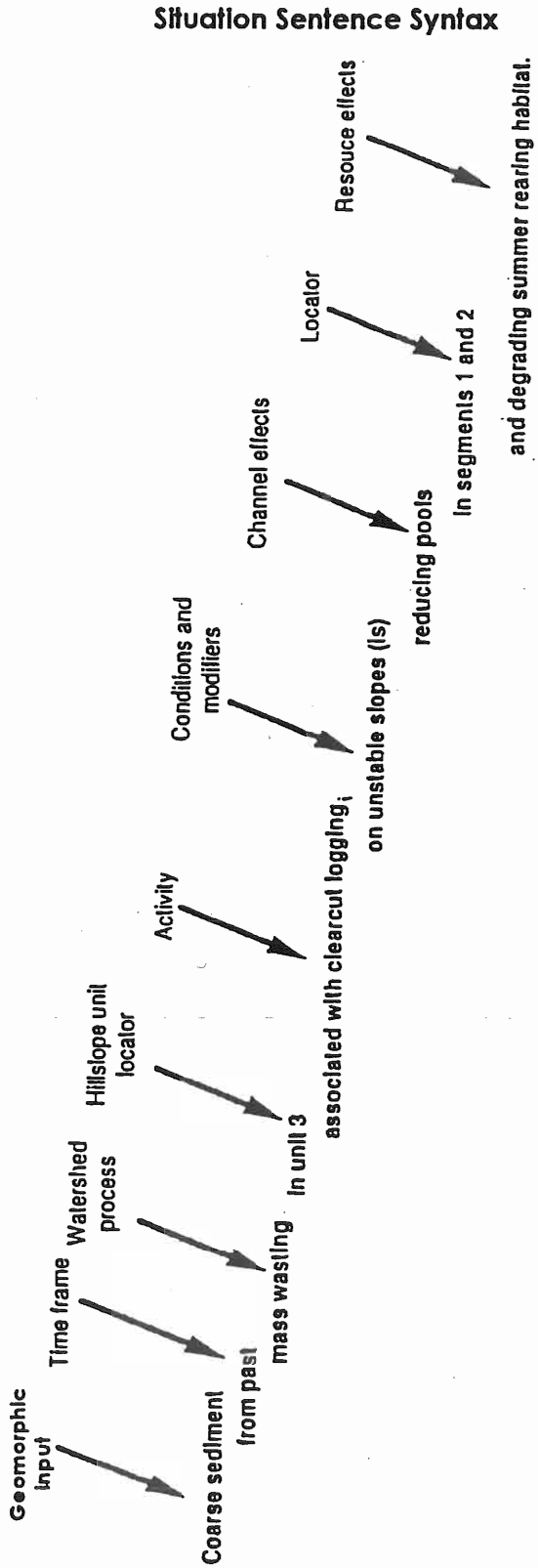
A causal mechanism statement tracks impacts from the landscape to the beneficial uses affected. The clear statement of cause and effect allows both mitigation of impact and relaxed monitoring of innocent activities. A model statement from the WM is shown in Figure 4-3b.

The causal information that is needed from watershed studies in the Garcia should answer the following questions:

- Are streams presently limited in fish production by sediment, temperature or habitat?
- What mechanisms contribute fine sediment to the stream system?
- What mechanisms contribute heat to the stream system?
- What mechanisms reduce habitat quality of the stream system?
- Does the habitat quality limit fish productivity?

A causal analysis of the Garcia watershed would track specific units of water with elevated levels of fines or heat from their sources to the stream. Monitoring, however, is limited in scope, and cannot operate in all sites or at all times. Because we cannot directly quantify

Figure 4-3b. Washington Methodology Causal Mechanism Statement (WFPB 1995).



### i. Sediment

Analytical approaches to the assessment of the Garcia assume that present sedimentation rates in the Garcia are significantly higher than they would be in a control watershed. The methodology for road-related erosion using the Washington State methodology, described in Chapter 3, has this concept at its core. The impact of this sediment may be to reduce the effectiveness of gravels for salmonid egg placement, incubation and emergence. Relative to unaltered baseline conditions, sediment-affected streams may have aggraded their beds, having an effectively lower water table in low flow conditions and higher peak flows in flood conditions. Pools may be reduced in size and frequency, by both filling of pools and covering of pool-forming elements, respectively. Establishing causality between sedimentation and reduced salmonid production requires either establishing the validity of these links or acknowledging their assumption.

The relationship between sedimentation and its impact on fisheries is examined widely in established literature, such as Furniss, et al. (1991). The authors cite sediment as affecting streamflow, channel depth, fish passage, reduced spawning area, reduced egg-to-embryo success, reduced total habitat, and increasing further sedimentation through positive feedback mechanisms. Another source, Bjornn et al. (1977), describes the physical and social effects on salmonids in test channels, and states:

> The immediate effects of adding sediment to the channels were a reduction in available habitat (fewer pools and fewer interstices in boulder piles and cobble) and an increase in the turbidity of the water. The turbidity decreased within minutes after the addition of sediment. The reduction in cover for fish (mainly in the pools) and habitat for insects (in the riffles) affected both organisms.
>
> * * *
>
> Fish exhibited hierarchical behavior in the channels with two-thirds or fully imbedded pools, but territorial behavior in the channels without fine sediment. As we increased the imbeddedness levels in the channels, the amount of cover decreased in both pools and riffles. The smaller age 0 steelhead utilized the riffles and pools in the control channels and in the test channels with one-third imbeddedness. As we increased the imbeddedness of the riffles, the age 0 steelhead using the riffles moved into the pools. As cover became scarce in the pools, hierarchical behavior predominated. The main holding areas for fish were at the upstream and downstream ends of pools.

Sediment monitoring should, therefore, be oriented towards problem areas, solutions for implementation and establishing connections between hillslope processes and instream impacts. A useful protocol for the evaluation of this site-specific evaluation of sedimentation is the 'Sediment Transport Corridor' protocol, which identifies sediment entry points along a specific stream segment, and traces the path to its source. This method is also called a 'forensic' approach. Instream protocols can make general statements regarding the disposition of that sediment, in terms of thalweg depth, pool filling and inter-particle deposition. It is probably not within the scope of the Mendocino County RCD to demonstrate causality between the lowering of stream habitat indicators and a concomitant lowering of salmonid productivity, but regular measurements of fishery

productivity will confirm or deny the relative long-term importance of habitat variables in the Garcia watershed.

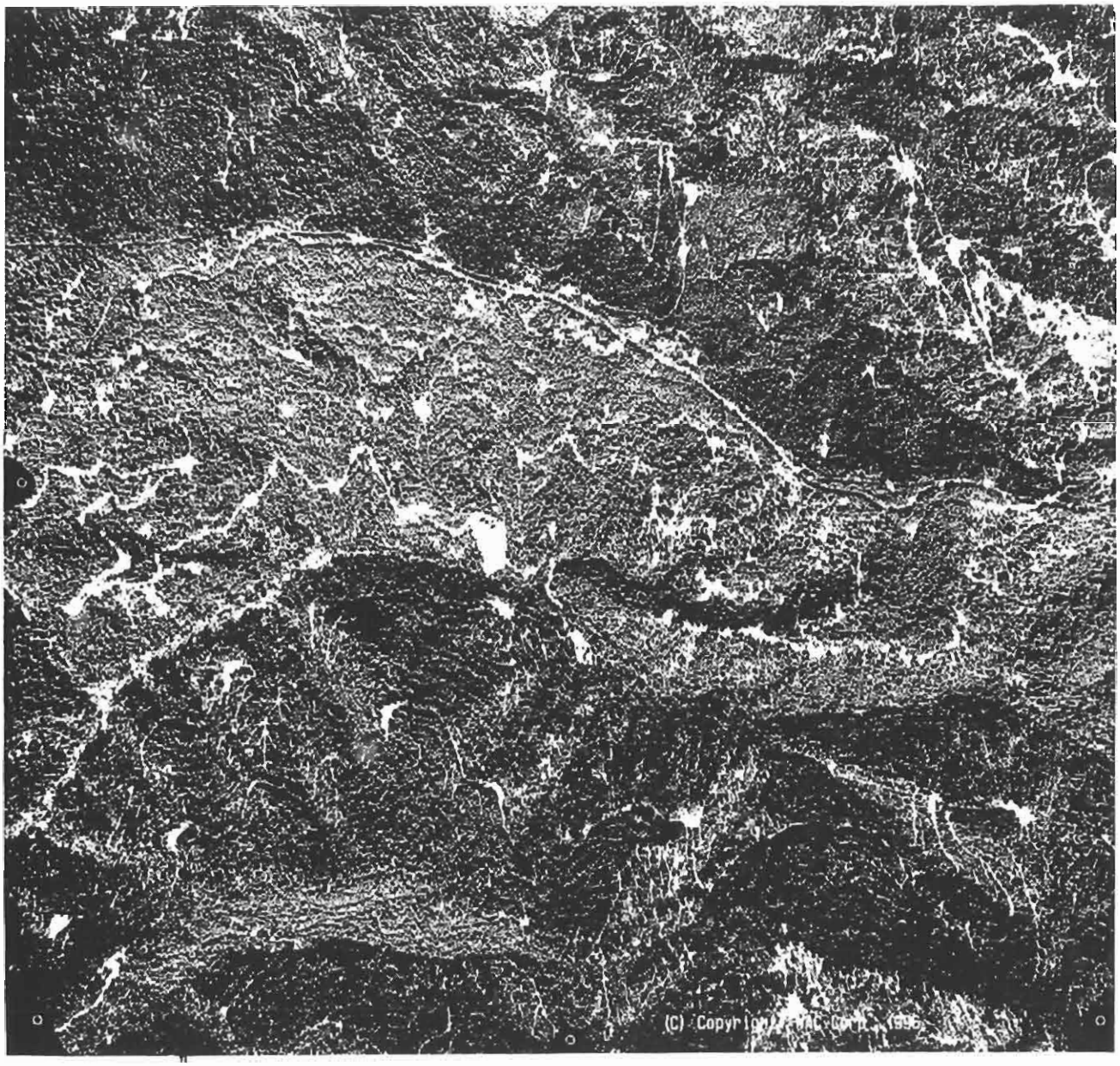
In the Level 1 watershed analysis (Chapter 3), the only causal mechanism paths identified in photos and on the ground is the delivery of unsorted sediment to the stream system through landsliding. Erosion of fine sediment paths from roads are not documented, they are presumed. Other causal mechanisms routing sediment presumed in this analysis are soil creep and delivery into channels, erosion of fine sediment from harvested areas.

Examination of the aerial photography of the watershed shows the following features as potential causal sediment contributors to the stream system:

1. roads, particularly those used as part of timber harvest activity;
    a. roads too close to streams to allow forest floor percolation to capture sediment from diverted water
    b. roads adjacent to streams, allowing loss of fill material through bank erosion processes
    c. roads crossing streams
    d. old roads up draws
2. power line right of ways;
3. tractor logging areas, principally through skid road networks;
4. cable logging areas principally through landings and cable roads extending downslope;
5. streamside bank erosion;
6. deep-seated, grassland landslides with associated gully systems; and
7. debris flows, often in association with road or skid trail networks.

These features have been identified as potential contributors of sediment to the stream system because, without on-the-ground confirmation of delivery, the impact of any transport mechanism within any specific watershed is postulated. Field notes, however, show definite contributory roles of road inboard ditches, crossings of small draws and the existing private road system, bank erosion, steep slopes with unvegetated fills, steep roadcuts and unstable geologic material at roads. Photo details of Olsen Gulch and Signal Creek are presented in Photos 4-1 and 4-2, showing extensive timber harvesting road networks. These photos identify tractor harvesting, landings, roads, cable roads and road crossings as likely problem areas, which need systematic field checking.

Photo 4-1 Olsen Gulch, North Fork Planning Watershed; 1996




Kilometers
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Feet
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Miles
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Photo 4-2 Signal Creek, Signal Creek Planning Watershed; 1996

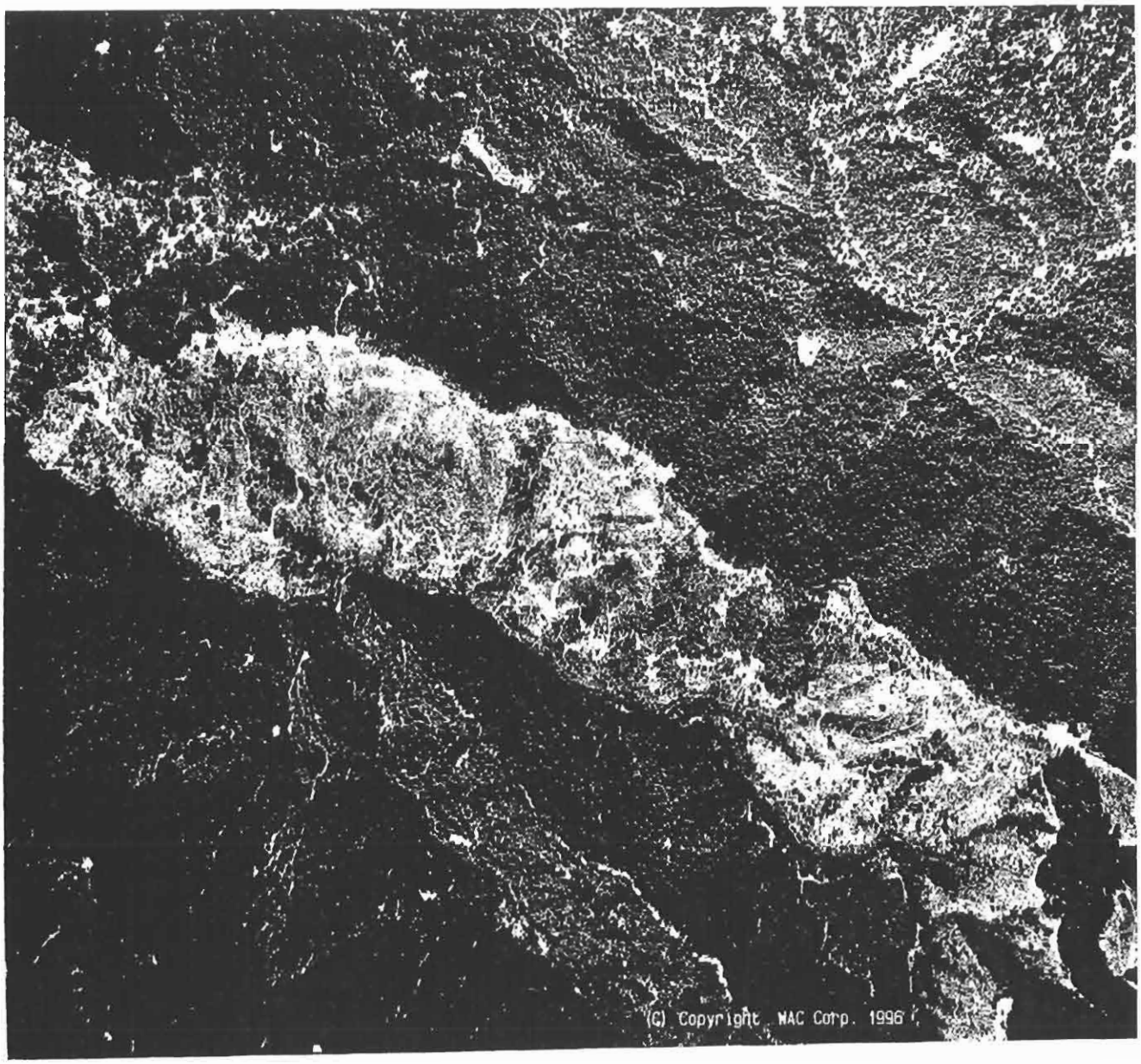


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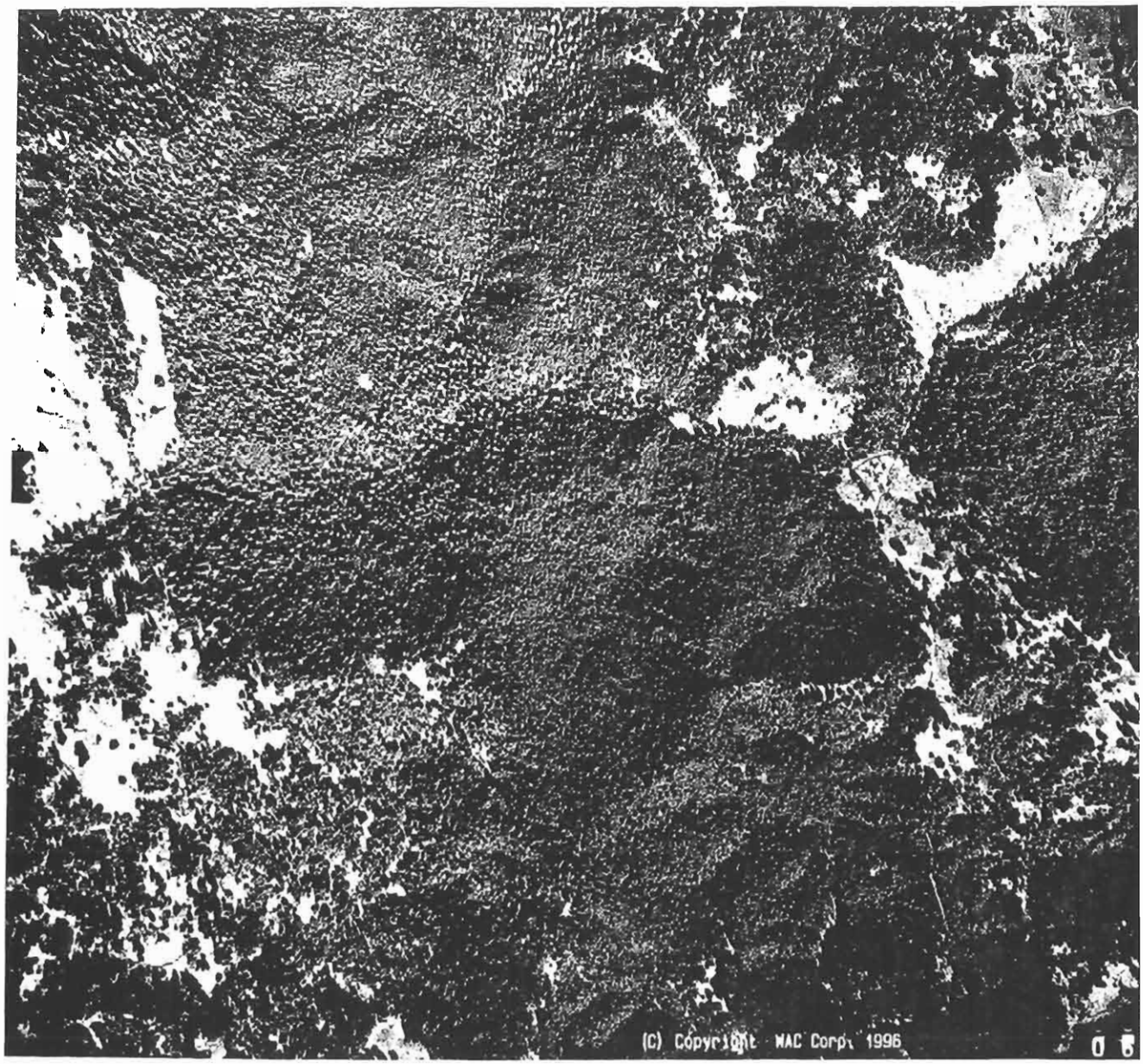
Photo 4-3 Mill Creek, Pardaloe Planning Watershed; 1996

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Final determination of *how* and *from which areas* fine sediment enters the Garcia remains a needed outcome of this IMP and analysis effort. A specific field investigation looking for the direct input of sediment to sample areas of the stream system--forensic methods, in particular the sediment transport corridor methodology and watershed-wide turbidity and source area investigations--will allow a reasonable estimate of source areas, relative volumes, time spans, and specific fixes for an array of sediment sources. Ideally, this would be a Level 2 investigation, and should be considered by the RCD as a watershed-wide project.

Causal understanding of fisheries impacts from sedimentation will also require monitoring the disposition of sediment in the Garcia watershed following its entry into the stream system. Protocols should assess the *relative quantity* of sediment in pools and gravels, their *effect,* and their *rate of change.* This allows addressing the severity and persistence of impacts on fisheries created by sedimentation.

### ii. Canopy Cover

While canopy cover is specifically identified as a resource to be protected within the Forest Practice Rules (CDF 1974-1997), timber harvesting and related roads have reduced canopy cover in the Garcia watershed. The apparent reasons for low canopy values in the watershed are continuing engagement of roads and landings too close to the stream to allow for maintenance of significant canopy, roads which cross streams and reduce canopy on both sides of the watercourse, timber harvesting in previously cut, low basal area forests, and natural or historic openings in streamside forests. The areas of Photos 4-1 and 4-2, Olsen Gulch and Signal Creek, can be compared with near-natural levels of forest, such as in the Maillard State Redwood Reserve on Mill Creek, shown in Photo 4-3. The difference is more pronounced when assessed on site, where one can see it is not only the direct shade from the canopy which has been altered, but also the host of forest influences created by the canopy, such as wind speed, air temperature and humidity which have been changed.

Causal tracing of the loss of canopy is direct: cutting trees removes forest canopy. Tracing the impacts of that canopy loss is much more speculative. In places, canopy loss increases direct insolation. Canopy loss also reduces source areas for allocthanous deposition into streams, both of leaf litter and insect drop. Canopy reduction reduces deposition of woody debris into the stream system, of fine, coarse to very coarse materials. In indigenous forests, redwoods were capable of placing extremely long lasting, very large diameter boles into stream systems, complete with extremely large root wads. With harvesting, the addition of these very significant materials has been greatly curtailed, to the point of near cessation.

Causal tracing of increased insolation would evaluate the physical parameters of stream temperature, growth of algae and levels of dissolved oxygen. Biological measures would

evaluate location and frequency of organisms with habitat affected by sunlight or other physical changes to the stream ecosystem.

At this time in the Garcia there are both established canopy and temperature monitoring sites, and a record of one-time canopy and temperature measurements, as shown in Appendix C. There are also stated goals within the Forest Practice Rules, SYPs, NTMPs and THPs for canopy retention and recruitment trees. Data have not been collected with the intention of demonstrating causality between physical parameters nor the connection to biological impacts. Future data must take this step, evaluating direct insolation, temperature changes (or not) related to that insolation, and the role of trees and canopy in creating habitat and providing nutrients to the stream.

### iii. Stream Complexity and Habitat Elements

As biological systems become increasingly complex, our knowledge of them retreats accordingly. There are some demonstrated relationships between stream complexity and salmonids, however. Salmonids prosper with pools and riffles; instream cover among rocks, logs or other submerged objects; shade; overhanging banks; diverse bottom structure; depth; bubble curtains; and turbulent flow down the channel (e.g. backwaters, eddies and cross-currents). The concept of complexity is evaluated as 'Stream Habitat Elements' within the California Department of Fish and Game protocols (Flosi and Reynolds, 1991). Complexity is also appreciated by fisherfolk, who cast for deep pools, converging waters, the break of water in front of rocks, the flat of water behind rocks, bubble curtains, towards logs and towards the shady area adjacent to banks.

Demonstrating the loss of complexity as causally linked to timber harvesting and related activities may take a few forms, starting with the quantification of the existing stream condition. Stretches of streams can be documented for frequency and size of pools, riffles and runs. Woody debris can be monitored for size and frequency. Thalweg profiles can demonstrate the effect of sediment covering, uncovering or filling habitat elements. Photographic stations can record changes in bank, bed and boulder placement and relative imbeddedness of substrates. Recruitment trees can be monitored for presence and induction into the stream system.

All of these evaluations require repeated visits to document *long-term* changes in the stream. Complexity takes years to develop and change. All of these evaluations also require specific ties to upslope activities to demonstrate causal linkages to timber harvest activities. Sediment transport corridors can document aggradation and imbeddedness sources. Sketch maps can document woody debris sources as well as the cutting associated with the loss of potential woody debris and recruitment trees.

Linkages of these elements to salmonid populations in the Garcia can be addressed by evaluating where fish use the stream during their life cycles. As habitat elements create diverse environments, so do those environments create opportunities for fish at varying portions of their lives. Fish surveys, using different techniques to evaluate the Garcia's

mainstem and tributaries for different populations, can yield important information on spawning location, summer habitat, feeding sites and territoriality. Together with site data, fish data can show how the salmonid populations are causally affected by land management actions, over the long-term time frame of habitat elements.

### iv. Dissolved Oxygen

Both the Monschke and the Manglesdorf reports documented low oxygen levels in the stream as a likely occurrence, particularly at the bottom of mainstem holes below Rolling Brook. If true, these levels would be reducing some of the best habitat in the system; the deeper holes are considered important as refugia as the coldest, darkest parts of the system.

It is not clear how timber harvesting could have a causal affect on receiving waters that would result in lower oxygen. One possible scenario is that increased insolation could increase both temperatures and algal growth, resulting in higher night time oxygen demand, when the algae respire, higher biological oxygen demand (BOD) when the algae die and decompose, and lower capacity of the water to hold oxygen, due directly to higher temperatures.

Investigation of this causal chain will require first, monitoring oxygen in mainstem pools, and, if it is low, determining its cause. While it may not be possible to establish causal links between mainstem conditions and timber harvesting impacts, the importance of oxygen levels in the mainstem Garcia demands monitoring and assessment of these conditions.

# 5. *Instream Monitoring Plan*

## *A. Objectives for the Garcia River Watershed IMP.*

The Garcia Watershed Instream Monitoring Plan (IMP) will represent a cooperative data collection effort between individual landowners and agencies in the watershed, will complement the existing, continuing data set, and is described in 5.D. and in Appendix C. The primary objective of this plan is to test the capability and effectiveness of the California Forest Practice Rules to protect determined beneficial uses, in this case, the salmonid fishery of the Garcia River. A secondary objective is to create a long-term monitoring data set whereby the Garcia River can be compared to other neighboring rivers in the development of a regional standard. The third, and perhaps most important objective is to understand the Garcia River watershed and reduce its overall sediment load through adaptive management.

### i. Context

The context of monitoring is the most important consideration for implementation. The IMP will be implemented by a combination of landowners (in this case, forest owners), agencies and the RCD. All of these participants must recognize that their pieces of data unite to form a framework for adaptive management. Thus, all the protocols must be:

- relevant to both primary and secondary timber harvest impacts;
- shared among agencies for the creation of a functional database;
- conducted with agreed-upon protocols, so they can create that database;
- heuristic, so that protocols can fine-tune, and monitoring elements can change with greater knowledge of the system;
- ecosystem-oriented, so that they describe existing conditions relative to healthy, functioning redwood/Douglas-fir/grassland/anadromous fish ecosystem; and
- stewardship-oriented, so that results are of a meaningful scale and value for the protection of acknowledged resources, specifically anadromous fish and water supplies.

### ii. Objectives

Protocols must address this context of cooperation and long-term utility while evaluating the existing and potential salmonid productivity of the Garcia stream system. In other words, we must begin by testing those parameters we believe to be important. As stated above, those parameters are evaluated through indices which respond to particular characteristics of the stream system, and those characteristics are hypothesized to be important to fish in the Garcia. An outline of parameters, indices, characteristics and fishery values is shown in Table 5-1.

Table 5-1. Parameters, Indices, Characteristics and Fishery Values for Guiding Assessment of the Garcia River Stream System.

| class of parameter | index | measured characteristic | fishery values |
|---|---|---|---|
| water quality | turbidity | suspended sediment, sediment sources | incubation, juvenile rearing |
| | dissolved oxygen | oxygen saturation | incubation, summer refugia |
| | temperature | heat, potential oxygenation | incubation, summer refugia, juvenile rearing |
| gravel quality | percent fines <2 mm | substrate composition | spawning, incubation, emergence |
| | permeability of gravels | interstital flow | spawning, incubation, emergence |
| channel assessment | cross sections | bed mobility, sediment transport | juvenile rearing |
| | V* | pool depth | summer refugia |
| | LWD survey | stream complexity | juvenile rearing, summer refugia, overwintering habitat |
| | longitudinal profiles | bed mobility, bed complexity, pool depth, sediment transport | juvenile rearing, summer refugia, overwintering habitat |
| riparian function | canopy measures | shade, allochthanous input | juvenile rearing, summer refugia |
| causal mechanisms | sediment transport corridors | sediment sources, delivery mechanisms | spawning, incubation, emergence, juvenile rearing, summer refugia, overwintering habitat |
| | turbidity | suspended sediment, sediment sources | incubation, juvenile rearing |
| fish productivity | spawning surveys | escapement, spawning opportunity | potential productivity |
| | summer fish counts | utilization of pools and riffles | productivity of juvenile age classes |

Parameters for monitoring have been distinguished as *water quality, gravel quality, channel assessment, riparian function, causal mechanisms,* and *fish productivity.* These categories correspond to sets of metrics, or indices, for determining stream quality because they directly relate to fishery qualities. Some forms of pollution cross the borders of these parameters easily, such as sediment, the routing and consequences of which may be measured in many ways. In order to understand the 'life history' of sediment or other pollutants within the system, however, a set of metrics should be applied, combined and interpreted.

### iii. Sampling Framework

The application of any metric requires a sampling framework in which it is implemented. While there are plenty of good data on the Garcia, many measurements were taken as once-only; many were gathered at adventitious spots; some were biased by access considerations; some may have been biased by aiming at a specific result. Similarly, many protocols bring with them a pre-determined sampling frame that does not correspond to other metrics. A spawning survey, for instance, samples the whole stream width over a continuous length moving upstream from a fixed point. An airphoto canopy survey evaluates stream corridors with a grid. A recording thermometer is generally part of a relatively sparse network, placed purposefully in a stream segment with adequate depth (so it is covered) and relatively slow flow (so it does not pull away). These measurements may correspond, but they are not directly comparable.

In the following parameter descriptions, it is important for the reader to understand that *all* metrics must be applied within a regular framework. They can not be limited to single samples; they must include multiple or spatially continuous samples on streams which are monitored; they must be located for repeatability with permanent benchmarks; they must be located relative to each other so that multiple benchmarks address each site; and all samplers should be using *similar sampling frames*, so that data are comparable.

Repeating multiple protocols on a single reach of stream implies the establishment of a "**study reach**," a length of stream where researchers place and measure a systematically (or 'mechanically') defined cluster of sample **plots**, or "reference sites" (Harrelson et al., 1994). Harrelson, Rawlins and Potyondy describe locating and measuring plots one meander (two bends) in length. FSW recommends placing clusters of four plots in one study reach, scaled so they capture approximately 15% of a study reach's total length. We have attached FSW's plot location guidelines for locating plots in study reaches (FSW 1997a). This approach will achieve a stratified systematic sample.

Study reaches on selected streams should be identified, as per the Washington or TFW methodologies, within strata that have relatively homogenous slope, geology, and long-term land use. Slopes of streams for long-term full protocol monitoring should, ideally, be less than 2.5%, an upper limit for coho, but can be up to 5 %, a limit for most steelhead, if no less steep areas are present (Trush 1997). The GISs of CDF, L-P and CFL are a good

source for stratification and plot location, and will be useful cooperative information in site selection.

Plots should be one meander (two turns) long. The stream reaches should not be dominated by braided channels. Selected sites must be capable of having three to four plots, representing 15% of the stream reach. A meander length of 40 meters, therefore, would require 265 meters between plots, and a total length of 1220 meters (e.g. 40+ 265+ 40+ 265+ 40+ 265+ 40+ 265). Sites should be chosen to start the measurement which are more than 100 m upstream from confluences or blockages; calculations for inter-plot distance should be rounded down, to maintain a 15% minimum sample; the crews will have to use judgement to site the plots when they arrive at the pre-determined study area; and plots should not be sited with the stream in a culvert. Culverts and blockages should be monitored separately from the plot-oriented component of this IMP.

Within the plots, field crews should make **site maps** of plots, one meander (two turns) in length, as described in Harrelson (1994). Valley bottom morphology should be recorded, and the map should cover the alluvial segment of the stream. **Monuments** need to be installed, as well as **a system of flagging** that does not conflict with others used in the region. These procedures are also described in Harrelson, and are attached.

Once a stream reach of appropriate size and slope on a selected stream is located for a set of plots, it is important to implement the sampling frame on the study reach, both in plots and continuously along the stream reach. Suggested sampling intensities for all recommended protocols are shown in Table 5-2. Measurements which are appropriate for one or two points only (not including replication for quality control) are temperature and dissolved oxygen. Remonitoring of historic transects, keyed to a single point, is appropriate for cross-sections. Continuous samples, with data collection at multiple adventitious points, should be done for sediment transport corridors and fish surveys. A continuous sample centered on one plot is appropriate for a longitudinal survey. Data measured at pre-selected points in the larger plots are best for canopy coverage and shade. Measurement of pools and riffles, for V*, McNeil and permeability metrics are taken up to a target level, three gravel samples in riffles, and two pools per plot, when possible. Large woody debris is measured inside plot areas, only. Recruitment trees need a look up the slope, within the length but outside of the width of plot areas.

Table 5-2. Sampling Frames for Selected Protocols

| ***Protocol*** | ***Sampling Frame*** site specific | plot | stream reach *(3-4 plots)* |
|---|---|---|---|
| sketch map | | 1 | *3 to 4* |
| large woody debris (LWD) | | 1 | *3 to 4* |
| recruitment trees | | 1 | *3 to 4* |
| V* of pools | | 1 to 2 | *4 to 8* |
| substrate composition | | 3 | *9 to 12* |
| permeability of gravels | | 3 | *9 to 12* |
| canopy measure | | 3 | *9 to 12* |
| longitudinal profiles | | | 1 per reach |
| sediment transport corridors (STCs) | | | whole length |
| spawning surveys | x | | whole length |
| fish counts | x | | whole length |
| temperature | x | | 1 per reach |
| aerial turbidity survey | x | | as observed |
| turbidity | x | | |
| flow | x | | |
| dissolved oxygen | x | | |
| cross- sections | x | | |
| barrier evaluation | x | | |

### iv. Implementation

An objective for the IMP is that it can be implemented by the RCD. The budget for this IMP includes money for hiring an in-house or consulting coordinator for this program. That person must be able to:

- implement field studies, particularly instream protocols;
- train crews and cooperators in methodologies;
- schedule complex tasks over a wide geographic area, often in adverse weather conditions with a broad range of people;

- create a functional database for data accumulation , sharing and analysis.
- work well with cooperators to assure data quality; and
- help with protocol and equipment needs of cooperators.

The success of the Garcia IMP will hinge on effective implementation of protocols, both in the field and in the office. It is intended to be trend monitoring for conditions in the Garcia watershed, and is thus primarily a data analysis effort, with data collection as its foundation.

This IMP outlines protocols and a framework in which to implement them. It is not, in itself, a turnkey process. Only with a good on-the-ground leader, responsible for oversight of the varied elements of the study, including data entry and analysis, will the IMP effort be successful. FSW recommends that the RCD hire a masters' level project coordinator, experienced with instream and hillslope monitoring, at one-third time to be responsible for in-house coordination, cooperative monitoring participation, data entry and management, budgeting and reporting to the RCD and the MSG.

The coordinator's effort in implementation will make this a worthwhile program. Without a good coordinator, this set of protocols can not be effectively implemented, nor can the RCD or MSG derive value from the data.

## *B. Protocols*

### i. Water Quality

The water quality metrics which appear most relevant to the productivity of salmonids in the Garcia are turbidity, dissolved oxygen and temperature.

**Turbidity** is a proxy for suspended sediment, and would be most useful if collected simultaneously throughout the basin, to determine, in a forensic sense, which watersheds are the most rapidly contributing sediment to the mainstem. It is a relatively blunt instrument; watersheds cannot be truly corrected for precipitation, human or natural inputs that create turbidity. But because turbidity is clearly related to salmonid survival (through suspended sediment and its effect on smolts and fry), because it is bounded by legal requirements under the Basin Plan (NCRWQCB 1988), and because it is a useful forensic tool, turbidity should be monitored.

Generation sites of significant, timber-harvest related turbidity may be few, far between, and extreme. Dodge's (1976) review of 65 sample THPs found only two plots, or 3% of study areas with 'extreme' erosion rates; Lewis and Rice (1990) state that most studies find that "most of the erosion occurring on timber harvesting areas was from large mass wasting events found on a small fraction of the disturbed sites." Looking across the whole watershed for turbidity and its sources will serve to:

- aim monitoring tools at important sites, to determine causality of the few, extreme events that may dominate local sediment budgets;
- direct restoration efforts; and
- direct further studies for CDF's Long-Term Monitoring Project.

A classic monitoring strategy would be to implement mechanical turbidity and flow samplers at watershed-wide locations. This would cost $3000 to $5000 per station, plus data downloading and instrument checks. The Garcia's 12 planning watersheds contain more than 25 named tributaries of greater than one square mile, as well as the 40 miles of mainstem. Because turbidity is created by the cumulative output of the watershed above, while a set of stations would be useful monitors, they would not identify of causal effects.

An alternate approach, which FSW recommends, is looking for turbidity and its sources during the winters season, either from a hired plane, helicopter or by contracted aerial photography. This allows a broad view of the entire basin during the period when erosion is occurring, and is likely to find important erosion sites in the watershed. Monschke (1998) found a helicopter to be a useful tool for identifying streams with high turbidity in CFL's ownership, covering 60,000 acres in about 3 hours. A complete color airphoto set taken in winter of the whole basin would cost about $6000 (WAC, 1998). Limitations of airphotos may be canopy-restricted visibility, or the low sun angle creating shadows on important sites--these drawbacks should be evaluated following the first years' flight. Interpretation of the airphotos should look for slides, failing crossings, gullies and other significant sediment sources in the watercourses, as well as overall turbidity and its generation points.

Site specific data, in the form of grab samples during major storms at key, wet weather access locations are presently being taken public, private and volunteer agencies. This cooperative data should continue to be useful for instream data to accompany other information, and as an important, referenced record of the Garcia's condition. The IMP coordinator should check with these cooperators to assure that they are following acceptable, comparable protocols.

FSW recommends that the RCD cooperate with stakeholders who are presently taking grab samples at gaged sites, to make simultaneous flow and turbidity data available. In addition, the RCD should gather airphoto information for turbidity on a clear day immediately following a winter storm, well into the wet season. Cooperators with air equipment or interested in getting photographs of the basin in winter could be save significant costs for the RCD in the future. Small plane or helicopter flights would add significant information to the process, though they could not serve as a substitute for photogrammetry.

**Dissolved oxygen** (DO) measurements are not normally considered important for cold water systems, though concerns about DO levels have been voiced regarding the lower mainstem Garcia. Because these are important summer refugia, and because there are a set of causal reasons to be concerned about DO levels, we recommend formalizing DO

surveys. Key measurement points are in the mainstem, deep in pools, and in warmer, sunnier and algae-affected tributaries. This is a summertime, low-flow survey. If, after several years of inconsequential data results, this metric appears irrelevant, it should be abandoned.

A protocol for sample collection needs to be established that is relevant to field sampling in the Garcia. As with turbidity, DO evaluation is within the NCRWQCB basin plan, and protocols must meet their requirements, which reflect national standards (APHA 1997; NCRWQCB 1988). Board staff Peter Otis has developed 'tailgate protocols' for DO sampling in the Laguna de Santa Rosa which may be applicable, and should be considered for the Garcia (Otis, P. 1997). FSW recommends the RCD pursue discussions with the NCRWQCB to agree upon protocols, using, if possible, the inexpensive Hach or LaMotte kits and a simple grab sampler (a one-liter bottle at the end of a pvc handle).

If an area tests positive for low DO, it would be reasonable to find the cause of that depression. Evaluation of that cause would be to evaluate temperature, flow and biological oxygen demand around that site and upstream. The methodology and search for causality should include consultation with the NCRWQCB; low oxygen strongly limits beneficial uses.

**Temperature** has been identified as a potential limiting factor in the Garcia stream system. Many of the streams in the watershed, as well as the mainstem, have documented high temperatures over 64, 70 or 80 degrees, so temperature is both an active concern and a metric for which there is a data history. Temperatures in Rolling Brook tributary greater than 64F are considered a "screening criteria to identify potential problem areas for salmonids" (L-P 1997). Temperature should be monitored with one protocol, similar sample sites, and a shared data pool. A useful protocol is being put forward by the FFFC (Taylor 1997), which includes testing, installation and programming of Hobo recording thermometers.

FSW recommends that the RCD implement temperature monitoring with placement according to the FFFC protocol, and no ice water calibration. We also recommend using pairs of recording thermometers, to get average values and secure data in case of instrument failure.

In review of this IMP, the people who are monitoring the river for temperature now considered the ice water bath calibration technique of the FFFC less prudent than calibration at room temperature. A representative from Onset Computing, the manufacturer of Hobos, states that the instruments are "factory calibrated," and the ice-water bath process is to determine if the device will fail at its low range; it is a stress test, not a calibration (Onset Computing, 1998). Further confounding the calibration of thermometers, Vicky Ozaki of Redwood National Park has found that Hobo XTs tend to vary about one degree Centigrade from each other at room temperature, greater than their listed specifications; and that different types of thermometers record with different biases to the warm or cool side (Ozaki, 1998).

FSW recommends using a network of two thermometers per stream reach, with an error of less than one degree, Centigrade. The Hobo XT's error at expected stream temperatures is approximately 0.2 degrees, though it may, in fact, be less. Two thermometers will account for variations in stream temperature along the course of the stream reach, at deep riffles near the centers of plots one and four, and give redundancy in the event one thermometer fails. Two thermometers will also point out any instrument giving erratic readings. The greatest danger with Hobos is that they stray beyond acceptable tolerances of temperature or time variation, and FSW suggests the coordinator stay up to date with the FFFC and the Forest Science Project of HSU, which are evaluating this problem.

### ii. Gravel Quality

Gravel quality is critical for the production of redds, the protection and oxygenation of incubating eggs and smolts, the emergence of fry, and the habitat for invertebrate fauna. Healthy gravels are critical for the production of salmonids in the Garcia, both in the mainstem and in tributaries.

Two gravel assessment strategies should be considered by the RCD, bulk samples and permeability samples. Because of the significant difference in effort in conducting the samples, the two methodologies should be tested side by side, to see if they strongly correlate. If this is true, the permeability sample should be continued, because it is much cheaper, faster and easier to accomplish. Other approaches to evaluating gravels may be useful tools in the Garcia, but at this time we do not have similar levels of confidence in their utility or repeatability. In particular, Dietrich et al. (1989) discuss the utility of $q_*$, a value reflective of the differentiation between surface and subsurface gravels, reflecting sediment input. While this value may be useful, it is not clear how to translate the flume work into a field protocol, nor how to correct for the high degree of spatial variability in stream sediment deposits. In addition, in order to develop $D_n$ values for any set of fine sediments, it is necessary to complete a bulk sieve analysis first. Thus, we recommend the McNeil because of its relatively long track record and established protocols. We believe, too, that the permeability approach measures the important qualities of gravel in spawning streams.

**Substrate composition** should be taken with a McNeil sampler, and evaluated by the gravimetric method. It can be presented as a cumulative frequency distribution (CFD). The CFD should be designed, through choice of sieve sizes, to report:

- Fines < 6.5 mm
- Fines < 2.0 mm
- Fines < 0.85 mm
- $D_{16}$, $D_{25}$, $D_{50}$, $D_{75}$, $D_{84}$

These metrics take into account the considerations of the North Coast Regional Water Quality Control Board (Manglesdorf and Lundborg, 1997), the MSG (Lee, 1996), and the recommendations of this IMP. Readers should note that these extra pieces of data do not increase the cost of data collection, but are variations on reading and reporting the data that is collected.

**Fines < 2mm** appears to be a very important metric for evaluating the quality of gravels. Bjornn and Reiser (1991) document a set of studies which show significant drop-offs in percentage of fry emerging from redds with greater than 10-20% fines of 2-6.4mm. The critical values for the Garcia will change by species of salmonid (Kondolf & Wolman 1993), but documentation of sizes will allow understanding of relative gravel quality. The 'standard' methodology for this assessment is a McNeil sampler, which collects a bulk sample from the top 6-12 inches of spawning riffles. Platts et al. (1983) recommend a minimum 12" core depth. While Taylor (1996) puts forth Valentine's 1995 unpublished protocol as an appendix to the FFFC protocol package as a well documented, agreed upon protocol for the North Coast, Klein (1997) stresses the importance of choosing the correct screen sizes, and using the weight, not the volume of particles. Klein has developed a 'how-to' protocol for conducting gravimetric data analysis assessing the impact of the Caltrans work in Prairie Creek watershed, attached as an appendix. We also attach the TFW McNeil protocol, including site selection and sampling within the stream.

**Permeability of spawning gravels** is a corollary to percent fines. It is important to incubating fish because "During incubation, sufficient water must circulate through the redd as deep as the egg pocket to supply the embryos with oxygen and carry away waste products" (Bjornn & Reiser 1991). The waste products are organic material. If that material remains, it may consume oxygen in decomposition, and "if the oxygen is consumed faster than the reduced intragravel water flow can replace it, the embryos or alevin will asphyxiate" (Bjornn & Reiser 1991). While the permeability of the redds is different from unaltered gravels (Kondolf et al. 1993), unaltered gravels are an important index to the condition of the gravel and its suitability for redds. Barnard and McBain's 1994 protocol for measurement of interstitial flow is presently in use by L-P and CFL, and appears to be an appropriate choice for the Garcia. As stated above, if it tracks McNeil results with strong significance, it should be considered a more cost effective and direct-reading replacement for the more time consuming bulk sample approach.

### iii. Channel Assessment

This section provides protocols that are specifically designed to address channel size, shape, complexity and persistence. In choosing methods, we should note that, while 'habitat typing' has been used extensively to describe channel conditions for fisheries in the region, it may be, as an evaluation tool, relatively insensitive to human influences in watersheds in the Garcia and is not a repeatable monitoring tool to assess change over time (Poole et al., 1997). Alternatively, data keyed into fixed points leaves little room for doubt as to changes in depth, shape or profile of the stream. Coupled with photo points, airphotos and maps (see also Riparian Function), the channel assessment strategies of

cross sections and longitudinal profiles answer many of the questions asked regarding river systems in general and the Garcia, in particular.

Channel assessments for pool filling and woody debris, both past and future, are more oriented towards fish habitat and habitat-forming elements. It is these elements which provide the stream with the niches used by fish, cover for hiding and for protection from the sun, low velocity areas for avoiding winter flows and a heterogeneous bank and substrate for a diverse, productive environment. Several protocol suites for evaluating the functional elements of stream channels have been put forward, in particular the TFW Ambient Monitoring Program Manual (Shuett-Hames 1994) and the Washington Forest Practices Board Standard Methodology for Conducting Watershed Analysis (1995) and the CDF Instream Monitoring Protocols (Lee, 1997). These protocol approaches variously include elements of sampling design, an array of specific protocols, such as V*, McNeil, large woody debris, debris jams, recruitment trees and habitat units. All approaches include a general approach to whole watershed analysis. All are designed in segments so that implementing agencies can use the protocols in logical sets.

This section bundles cross-sections, longitudinal profiles, V* and woody debris surveys together as 'channel assessment.' These are metrics which are useful to monitor the condition of streams--their physical shape and quantity of large wood interaction--relative to specific benchmarks. Channel assessment protocols are the heart of trend monitoring because, relative to other parameters, the elements they measure change slowly, over years and decades.

**Cross Sections** are a long-standing metric in the Garcia. Jackson's 1997 report on the Garcia evaluated the historical record of the Garcia with the addition of new data from 1996 and concluded that the river is not aggrading its mainstem. A 1996 report by Philip Williams and Associates also relied heavily on cross-sections in developing a gravel management strategy. In some ways, the best reason to continue monitoring with cross-sections is because the present data record is relatively complete. In addition, future monitoring will provide confirmation or denial of conclusions drawn to date from the data--whether the river is downcutting or aggrading on the mainstem, and whether gravel extraction is allowing maintenance of a 'steady-state' condition on the river. Protocols are well established throughout engineering literature, with differences based on equipment, choice of benchmarks, and spatial distribution of data collection intervals. We are hesitant, however, to give one protocol. Simple methods are described in Dunne and Leopold (1978) and Rosgen (1996a), which are appropriate for tributary streams and continuation of existing data records. Field methods are already established for the mainstem Garcia, such as at the Highway 1 bridge, Connor Hole and the Hooper Property, and have been documented by Caltrans and the Mendocino County Water Agency. Essentially, all cross-sections will be comparable if they start and end with the same benchmarks, use a tripod-mounted level, stretch a tape level across the span, and measure at intervals that reflect the change in topography.

**Longitudinal profiles** are a long-standing tool for stream assessment (Leopold et al. 1964; Morisawa 1968) to determine geologic boundaries, reactions to flow and particle size, and to track the deposition or erosion of sediment. They may also, on small streams, be used to evaluate pools and complexity (Trush, 1997a). Dunne and Leopold (1978) give a good description of the procedure, noting that profiles "should be no less than 30 times the river [bankfull channel] width." Trush (1997a) recommends no less than two meanders (four bends). The key is to locate the assessment area in a reach not affected by nickpoints above or below, and well above confluences with larger streams. The length of these plots is necessarily greater than other types of in-channel surveys, so they should be considered as part of a larger survey array. If, for instance, a stream reach were being evaluated at three plots for woody debris, pools and gravels, covering ten percent of the stream length, one longitudinal profile may be adequate when initiated downstream from the center of the middle plot, where it would cover an overlapping ten percent of the reach.

Trush (1997b) notes that an important criteria in the speed of longitudinal profiles is the choice of level; he recommends the Topcon dome head levels AT G-7 and AT F-2 for small and large streams, respectively, along with the Harrelson (1994) protocol. At this time, we have attached the Dunne and Leopold (1978) protocol, and a more complete description from the San Francisco Estuary Institute (Rigney et al. 1997).

**V***, as described in Lisle and Hilton's (1992) is an approach to measuring the fine sediment volume deposited in pools. Testing Indices of Cold Water Fish Habitat , a study conducted for the North Coast Regional Water Quality Control Board in cooperation with CDF, (Knopp 1993), included sites within the Garcia watershed, and V*, along with riffle-armor stability index and median particle size, were found to be significant indicators of historical management activity. In our opinion, V* values are particularly important because they track the location of sediment outside of the thalweg but inside important fish habitat. Adequate training needs to be given to field crews to promote standardized measurement of mobile fine sediment in the pool, as distinguished from older sediments which may make up the bed.

**Large woody debris (LWD)** in the stream channel is a reflection of the health of streams relative to native ecological conditions. In the original landscape, large wood was lost only in very intense fires, and those did not consume very large redwood boles, particularly in streams. Salmonids have evolved with those conditions, and large wood to provide geomorphic stability, thermal consistency, and a variety of niches for themselves and other members of the stream ecosystem, on whom they depend. Direct measurement of woody debris is a useful, intuitively clear method to indicate complexity of small streams, and can be repeated easily. The most complete protocol for evaluating present LWD is in the TFW protocols (Shuett-Hames 1994).

### iv. Riparian Function

While the shape and the water quality of a stream and its channel are important, measurement of vegetation in and near the stream are important in producing present and future habitat. This section presents the use canopy indices of solar exposure and canopy closure. Collection of these data implies stratifying the stream system, developing a systematic survey within those strata, finding field sites, drawing site maps, taking site photos, and establishing permanent monuments. The approach should consider either long, continuous data sites or multiple data sites within identified stream segments for many of the riparian function metrics. This report will assume a shelled, multiple measurements within an identified reach approach, and support from topographic maps and airphotos.

**Canopy measures** determine either the total amount of overhanging vegetation at a point, generally above one meter, or the total amount of sun incidence at a given point. It is important to note that these are different measures and, while they may correlate at points of their distribution, do not measure the same functional elements. Shade may be provided by hillslopes on east-west trending streams. Canopy on north sides of stream may not contribute any appreciable shade, while providing abundant allocthanous material for instream invertebrate food. The two accompanying protocols are for canopy at waist level (one meter+-), using a densiometer (Flosi and Reynolds 1991) and solar input using a Solar Pathfinder with a 'horizontal surface' grid (Solar Pathfinder 1995). Canopy monitoring for shade should be conducted during the hottest months with the lowest flows, probably June through October. While the solar pathfinder is designed with a tripod for use on dry, flat surfaces, we recommend purchasing the instrument without the tripod, attaching it to a board or box, and holding it above the center of the stream channel.

While the densiometer measures overstory cover and the Pathfinder measures shade, neither of these instruments can be used at only one point. It is critical to take multiple measurements along a stream system in a systematic plot array. These values can then be correlated with airphoto interpretation. Our experience reviewing the Garcia data suggests that airphotos consistently overestimate cover. This may be due to a lack of sampling strategy on the airphotos or due to the 'look' presented to the interpreter by many layers of vegetation. With ground truthing and a scale for evaluating interpretation results, it may be possible to extend canopy surveys far beyond plots with airphotos.

FSW recommends doing both the Solar Pathfinder and densiometer measurements, at the beginning, middle and end of each plot. These three measurements will be repeated four times in the stream reach, giving 12 data points for both Pathfinder and densiometer per selected stream.

**Recruitment Trees** are future woody debris and an important canopy component. The most complete protocol for recruitment trees is in the Washington State methodology (WFPB 1995). We recommend implementation of this protocol adjacent to plots within selected stream reaches. As with canopy, basic recruitment trees information comes from

aerial photography. FSW recommends following the WFPB's on-the-ground protocol for plot areas within stream reaches, and its air photo methodology for the entire stream reach. This allows field measurement to correct a set of interpreted data, and a Garcia-specific, photo-flight specific key to develop for good interpretation results on other watershed sites.

### v. Causal Mechanisms

As discussed above, we have scant information connecting the propagation of timber harvest impacts into and around the Garcia watershed's stream channels. A specific goal of monitoring must be to evaluate the hillslope-channel connections. FSW has had good success simply following sediment trails which enter streams and their tributaries to their sources. Other forensic approaches also follow sediment trails, either through photography--specifically aerial photography following storms--or turbidity measures. In all cases, it is important to see the effects of storms, either during them or in the following year, before evidence is obscured. In planning for evaluating *future* impacts via causal mechanisms, we need to identify watersheds prior to harvesting, and continue observations ten to fifteen years following harvest. The long time frame is for the assessment of landslides which may be caused by harvest, and evaluate the predictive capability of unstable-area avoidance models, such as used by Louisiana-Pacific (L-P 1997).

**Sediment transport corridors (STCs)** are any areas, apart from the natural drainage system, which produce sediment and move it into stream systems. Debris flows, the faces of deep-seated landslides, gullies, failing roads, failing crossings, eroding streambanks, inboard ditches and flow from waterbars which do not adequately deposit sediment are all STCs. FSW developed a measurement approach in 1994 and 1995, which requires evaluating both sides of the entire stream reach. This is done when walking upstream between instream monitoring plots. The measurement of each site goes fairly quickly and each STC is noted for location and relative ease of access for restoration. When an STC is encountered, field crew measure the surface area of the eroding site, record the probable cause of the erosion and suggest a possible solution. Area is measured as an index of volume, but does not require the researcher to reconstruct the original or modified landscape which failed. In practice, STCs indicate high priority areas for restoration, and have been used for targeting restoration efforts on Greenwood Creek in Mendocino County and UC Berkeley Blodgett Forest, in the Sierra. Our present protocol (FSW 1997) is attached.

**Turbidity**, as discussed under *Water Quality*, is a useful forensic tool when applied to watersheds during and immediately after storms. As rainfall progresses, the watershed tends to produce significantly more sediment, as stable areas 'unravel'. Using turbidity to track causal mechanisms will require 'finding the sediment' as it enters the mainstem Garcia. This could be done via day-specific airphotos by flying the watershed and taking 'uncontrolled' photos from a small plane, or contracting for aerial photography on a specific day. Neither of these methods are inexpensive, but they both can give important, unexpected answers to the question "Where are the sediment sources to the Garcia?" This

can direct future research and restoration efforts, and should not be downplayed as important causal mechanism research tools.

### vi. Fish Productivity

Fish habitat is an instream beneficial use of water. Because this is an instream monitoring plan, it must consider fish productivity as a test, albeit indirect, of habitat. The above sections concerning water quality and habitat elements have all been related to salmonid fisheries, and the causal mechanism section noted that, until proven directly related to fisheries, any element monitored is done so for reasons based on hypotheses. Unless we measure the fishery, we cannot know if other metrics, restoration programs or best management practices are truly working.

Unfortunately, while increasing fish numbers will suggest that BMPs are working, decreasing fish numbers will not necessarily mean that BMPs are failing. Too many other factors, from ocean conditions to genetic considerations, may dominate results. Despite this lack of direct correlation, this report recommends fishery research, particularly **spawning surveys** and **summer fish counts.** These have been done in the Garcia for many years. The IMP should continue this practice, with particular inclusion of stream reaches on which stream reaches have sets of reference sites.

Trush (1998) recommends spawning surveys in the few days following peak flows, during the recession of flow. Coho spawn about two days after the peak. Steelhead spawn significantly later than coho, and would require a separate set of surveys. Because coho are the threatened species in the Garcia, we recommend coho spawning surveys.

Summer fish counts are important indicators of spawning success, and need trained, calibrated individuals looking into pools with a mask and snorkel. These people should be calibrated with electrofishing surveys, so that they are aware of any distinct undercounting bias. Summer surveys can also be used to get relative populations of coho and steelhead juveniles. FSW recommends summer surveys to accompany stream reach surveys, as a way of partially testing the habitat hypotheses that underlie this research effort.

Fisheries protocols are a good point for cooperators to get involved with the IMP. Winter protocols need to be done in a relatively short amount of time, training is straightforward, there are many experienced individuals involved with the watershed, and it requires little instrumentation or benchmarking. Ideally, all streams with habitat monitoring should receive fishery surveys.

### *C. Description and Map of Selected Monitoring Sites*

The selection of monitoring sites for the Garcia River Instream Monitoring Program involved evaluating each sub-basin individually while keeping in mind a larger picture for data collection throughout the Garcia River watershed. While many studies have been conducted at varying intensities and locations, there are large gaps in the amount of quantitative data available for the basin as a whole. Monitoring sites were chosen in both basins with recent timber harvest and in basins that will be harvested in the foreseeable future. One site on Mill Creek was chosen as an index reach.

The whole watershed will continue to be evaluated on an overall basis by winter overflights, to find specific sediment-generating areas.

Selection of monitoring sites throughout the Garcia River Watershed was based on:

- Mass Wasting and Surface Erosion Modules (Chapter 3), the synthesis of the Watershed Assessment modules (Chapter 4), the Limiting Factors Analysis (Mangelsdorf, 1997) and the sediment production and delivery analysis (Hagans, 1997);
- Data previously collected throughout the Garcia River basin, looking for both the gaps in the data, and places where future monitoring can build on past monitoring efforts. Appendix C : Inventory History in the Garcia River is a record of past data collection efforts compiled from available literature including the Limiting Factors Analysis (Mangelsdorf, 1997), the Garcia River Watershed Enhancement Plan (Monschke 1992), Watershed and Aquatic Wildlife Assessment (CFL, 1997), Analysis of the Garcia River Cross-Sections (Jackson, 1996), the Garcia River Gravel Management Plan (P. Williams & Assoc., 1996) and the Sustained Yield Plan for Coastal Mnemonic (L-P, 1997);
- Current monitoring in progress and opportunities to create a cooperative monitoring strategy. The underlying objective of this plan is to coordinate with existing industry, environmental groups and public agencies, to build on data collection efforts that are already underway throughout the basin and to fill in gaps where data is needed; and
- The history of individual streams within sub-basins with present, potential or historical favorable fish habitat and/or presence of fish.

The final products in this section are;

- Map 5-1: Monitoring locations.
- Map 5-2: Map of land ownership within the Garcia River basin;
- Table 5-2: Selected sites, parties recommended for monitoring and parameters to be measured at each site.

### i. Planning Unit 113.70010: Pardaloe Creek, Mill Creek and Redwood Creek

The headwaters of the Garcia, Pardaloe planning watershed is largely owned by eight ranching families. The Maillard Ranch conducts timber operations on Redwood Creek, and is the source of the Maillard Redwoods State Reserve on Mill Creek. This is a watershed which has a significantly different land use pattern than downstream, industrially-owned watersheds, and also has records of good anadromous fisheries following the blasting of falls in Larmour PW in 1964. By the late '60's, however, Pardaloe Creek's old-growth had been removed with significant disruption, and the stream was considered, for more than 80% of its course, 'damaged' (Monschke and Caldon, 1992).

**Pardaloe Creek**

Potential Limiting Factors:

- Elevated summer temperatures related to insufficient shade/riparian cover and reduced channel depth/low summer flows.
- Minimal pool depth, related to aggradation and limited stream complexity.
- Minimal over wintering habitat, related to sedimentation and limited stream complexity.

Since the 1964 removal by Fish and Game of a waterfall on the mainstem of the Garcia River , Pardaloe Creek has had a history of some of the highest densities of steelhead redds anywhere in the Garcia Basin (Mangelsdorf, 1997). According to the Watershed Enhancement Plan (Monschke and Caldon, 1992), "given its high potential for fish, Pardaloe Creek is an ideal stream to continue monitoring for recovery from past land use impacts". Due to the need to stay within the available monitoring plan budget and the focus on timber harvest activities, FSW is not recommending that a full set of monitoring protocols be employed on Pardaloe Creek at this time. However, it is noted that if more funds become available, establishing a monitoring program or conducting a fish survey on Pardaloe Creek would be a first priority. Because of its inland position up in the headwaters of the watershed, Pardaloe Creek has some of the highest temperatures in the entire Garcia basin (Mendocino County Water Agency, 1997). Temperature data should continue to be collected by the Mendocino County Water Agency in Lower Pardaloe above Mill Creek and in Upper Pardaloe at the bridge on Fish Rock Road.

**Mill Creek**

Potential Limiting Factors:

- No limiting factors identified.

At the April 17, 1997 Limiting Factors meeting of the Garcia Watershed Advisory Group, the agency group discussed the possibility of de-listing the Mill Creek sub-basin from the 303(d) Impaired Waters list. Fish and Game stream surveys, Salmon Trollers Association data and local observations imply that Mill Creek and Redwood Creek have good habitat cover, complexity and riparian conditions which indicates a functioning system

(Mangelsdorf, 1997). It was suggested that instream monitoring be conducted on Mill Creek to confirm the conditions in the basin and to consider it as a potential reference stream for the Garcia Watershed. Data collection may be coordinated between agencies and ranch landowners in the sub-basin. FSW recommends that monitoring protocols be employed in Mill Creek to assess parameters of temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, STCs, LWD, recruitment trees and fishery surveys. Temperature data should continue to be collected by the Mendocino County Water Agency in lower Mill Creek above Pardaloe and in upper Mill Creek at the Maillard Preserve on Fish Rock Road.

### ii. Planning Unit 113.70011: Grant's Camp Creek, Larmour Creek and the Garcia River

Data collected throughout this entire sub-basin is both scant and outdated. Fish and Game stream surveys date back to 1967 on Grant's Camp Creek and no real data is recorded for Larmour Creek. Although this sub-basin represents a gap in data for the entire Garcia River basin, it is not a high priority for this monitoring program because of the relatively low percentage of lands in timber operations. The land use within the basin is divided between Coastal Forestlands and two non-industrial owners who operate cattle ranches with periodic non-industrial timber management plans.

**Grant's Camp Creek**

Potential Limiting Factors:

- No limiting factors identified.

Grant's Camp Creek, due to its low gradient and historical presence of good salmonid habitat, has the potential to provide either suitable salmonid spawning grounds or overwintering habitat, although clearly more data is needed to confirm this (Mangelsdorf, 1997). It is recommended that an evaluative study be conducted on Grant's Camp Creek to measure temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees, STCs and fishery. After a first year study, the project coordinator can evaluate the value of this stream as anadromous fish habitat and decide whether long-term monitoring is an affordable priority.

**Larmour Creek**

Potential Limiting Factors:

- No limiting factors identified.

Larmour Creek, because of its steeper gradient (7-8% on up) likely provides little anadromous fish habitat. The upper reaches of the stream however should be monitored for sediment delivery (STCs) and temperature to determine the contribution of these two factors to the mainstem Garcia River.

**Garcia River**

The Mendocino Water Agency has been monitoring temperatures on the mainstem of the Garcia River, at a site approximately 3.6 miles downstream from the confluence of Pardaloe Creek with the mainstem Garcia. Hollow Tree Road comes very close to the mainstem at this location. FSW recommends that the Water Agency continue to monitor for temperature in this location.

### iii. Planning Unit 113.70012: Stansbury Creek, Whitlow Creek and the Garcia River

This sub-basin is high on the priority list for establishing an instream monitoring plan. Both Whitlow Creek and Stansbury Creek have a long history of timber harvesting, with extensive operations underway in the Whitlow drainage previous to 1952. The land use within the basin today is divided between Coastal Forestlands (CFL) and two non-industrial owners who operate cattle ranches with periodic harvests under non-industrial timber management plans. In the last ten years, THPs have been filed for approximately 50% of the sub-basin. In spite of the long-term timber extraction within the sub-basin, virtually no data has been collected on stream condition or presence of fish. This sub-basin represents a gap in understanding the processes at work in the Garcia Basin and offers an opportunity to directly test the Forest Practice Rules capability of protecting beneficial uses, in this case fish habitat. Monitoring could become a shared responsibility between the landowners and resource agencies.

**Whitlow Creek**

Potential Limiting Factors:

- Number and depth of pools, particularly due to fine sediment from roads and limited instream complexity.
- Pool cover due to limited instream complexity.

If constraints require choosing only one tributary in this sub-basin, FSW recommends monitoring in Whitlow Creek over Stansbury, for the following reasons: 1) it has a more favorable gradient for fish (3-4%), 2) THP review comments in 1996 note that "the stream was heavily impacted by recent sediment," 3) CFL is installing a sediment catchment basin upslope, to prevent sediment from reaching the creek and 4) the Division of Mines and Geology have recommended that all permanent culverts be pulled so as to reduce the amount of road-related fine sediment that ends up in the stream (Mangelsdorf, 1997). A long-term instream monitoring plan should be established by the RCD on Whitlow Creek for parameters of temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy measures, LWD, recruitment trees, STCs and fisheries.

CFL could act as cooperators with the fishery evaluation of Whitlow Creek.

**Stansbury Creek**

The Limiting Factors Analysis describes Stansbury Creek as a fairly steep stream with 6-8% gradient in lower reaches, steepening even more in the upper reaches. Comments

from the GWAG committee suggested that the stream might support good summer rearing habitat, given the adequate canopy cover and bedrock channel (Mangelsdorf 1997). Because of the relatively little data available for Stansbury Creek and the active logging in this sub-basin, FSW recommends the RCD begin an instream monitoring program employing protocols for temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy measures, LWD, recruitment trees, STCs and fisheries.

**Garcia River**

Since 1995, FrOG has been collecting water temperature on the mainstem of the Garcia River, just upstream from Blue Waterhole Creek. They will continue this data collection as part of the cooperative monitoring process.

### iv. Planning Unit 113.70013: Blue Waterhole Creek

**Blue Waterhole Creek**

Potential Limiting Factors:

- Water temperature for summer rearing, due to poor shade canopy.
- Pool depth, due to fine sediment.

The Blue Waterhole subwatershed has a long history of disturbance and is currently noted for its scattered active slide areas, debris slide slopes and disrupted ground (Mangelsdorf, 1997). A 1967 stream survey by Fish and Game estimated steelhead density of 100 fish per 100 feet, while more recently, revegetation crews observed many steelhead, including large, adult fish (Mangelsdorf, 1997). For these reasons and because of the high density of timber harvest plans filed in this area in the last ten years, this is an excellent sub-basin to monitor.

The basin is owned by both Coastal Forestlands and a family ranch. There have been a number of studies completed on Blue Waterhole Creek, including the NCRWQCB and CDF study, Testing Indices of Cold Water Fish Habitat (Knopp, 1993), MCRCD cross sections established in 1995 to evaluate the restoration work of New Growth Forestry projects, FrOG temperature data and a 1967 Fish and Game stream survey.

FSW recommends that cooperative monitoring be a priority for Blue Waterhole Creek. Cross-sections already established by the MCRCD should be periodically revisited and temperature data collected at four stations by FrOG, should continue to be collected. An instream monitoring program should be also be conducted by the RCD with fixed plots to evaluate temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees, and STCs. Blue Waterhole Creek is also a good selection for a fish count and spawning survey on an annual or biennial basis.

### v. Planning Unit 113.70014: Inman Creek

**Inman Creek**

Potential Limiting Factors:

- Water temperatures for summer rearing, due to poor canopy cover.
- Number and depth of pools, due to sedimentation and lack of woody debris.
- Instream cover due to lack of woody debris.

Inman Creek, with a gentle gradient in the lower reaches (0-3%), good potential coho habitat and high densities of observed steelhead, is an excellent stream to monitor over time. Approximately 80% of the sub-basin has been included in timber harvest plans during the last ten years, making it a good choice of streams to monitor the effects of timber harvest activities on downstream water quality.

The basin is owned primarily by Coastal Forestlands with smaller parcels owned by both Louisiana-Pacific and a private rancher. Inman Creek is currently being monitored by Coastal Forestlands at three locations, as part of their Watershed and Aquatic Wildlife Assessment plan (CFL 1997). FSW recommends that CFL continue to collect data under their existing channel assessment and riparian habitat monitoring plan at already established sites. Additionally, we recommend that the RCD employ the full set of instream protocols recommended by this plan for parameters of temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees, STCs and fisheries. Temperature should be monitored at the confluence of Inman Creek with the mainstem of the Garcia.

Possibilities for cooperative monitoring between CFL and the RCD should be explored on this creek, both for temperature and fisheries.

### vi. Planning Unit 113.70020: Signal Creek

**Signal Creek**

Potential Limiting Factors:

- Pool depth and size, due to a lack of woody debris.
- Excessive flow velocities.

Fish counts and spawning surveys on Signal Creek conducted by Fish and Game (1987) and the Salmon Trollers Association (1995-1997) indicate that both live fish (steelhead and a few coho) and spawning redds are found regularly in Signal Creek. Substrate composition, as estimated by Fish and Game habitat typing is favorable for spawning and limiting factors to fishery success are related more to lack of canopy (18% F&G, 1995), woody debris and pools (Mangelsdorf, 1997). Approximately 80% of the sub-basin has been included in timber harvest plans during the last ten years, making this sub-basin an excellent choice of locations to monitor the effects of recent timber harvest activities on downstream anadromous fish habitat. Application of the WM showed Signal Creek PW to have the highest road-related estimated erosion (Chapter 3).

The Signal Creek sub-basin is owned primarily by Coastal Forestlands. Three locations on Signal Creek are currently being monitored by CFL as part of their Watershed and Aquatic Wildlife Assessment plan (CFL 1997). FSW recommends that CFL continue to collect data under their existing channel assessment and riparian habitat monitoring plan at already established sites. Additionally, it is recommended that the RCD establish a set of monitoring protocols on Signal Creek to establish fixed plots and employ the full set of instream protocols recommended by this plan for parameters of temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees, STCs and fisheries. Temperature should be monitored at the mouth of Signal Creek.

Possibilities for cooperative monitoring between CFL and the RCD should be explored on this creek for both temperature and fisheries.

### vii. Planning Unit 113.70021: Caspar Creek, Graphite Creek and the Garcia River

Ownership of this sub-basin is divided between Louisiana-Pacific (31%) and Coastal Forestlands (69%). L- P rates both of these subwatersheds with a High erosion hazard rating (L-P, 1997), and approximately 60% of the entire sub-basin has been included in timber harvest plans by CFL during the last ten years (CDF, 1997). Very little data has been collected on either Graphite Creek or Caspar Creek. CFL has established a permanent sample site in this sub-basin on the mainstem of the Garcia River. This subwatershed ranked second highest in erosion rates, according to the WM (Chapter 3).

**Graphite Creek and Caspar Creek**

Potential Limiting Factors:

- Channel depth at the mouth, limiting upstream migration particularly during summer when juveniles might be seeking escape from elevated mainstem temperatures.

Although fish surveys conducted by both L-P and the Salmon Trollers Assoc. found no live fish in either Graphite Creek nor Caspar Creek drainage, it was noted at the April 17, 1997 Limiting Factors meeting, that Graphite Creek could be a good coho spawning stream. The presence of a seasonal sediment barrier at the mouth of both Graphite Creek and Caspar Creek is thought to prevent upstream migration of fish escaping high summer temperatures in the mainstem Garcia. FSW recommends that the RCD evaluate seasonal blocking of summer upstream migration and options for possible removal or mitigation of these barriers should be studied. FSW is also recommending that an instream monitoring study reach be established on Graphite Creek employing protocols for temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees and STCs. A cooperative fish survey would serve to evaluate spawning and fish utilization, if it occurs.

**Garcia River**

Potential Limiting Factors:

- Elevated water temperatures for summer rearing, due to stream width.

The mainstem of the Garcia River within this planning unit is currently being monitored at one site by Coastal Forestlands as part of their Watershed and Aquatic Wildlife Assessment plan (CFL 1997). FSW recommends that CFL continues monitoring at this established monitoring site, according to their stream channel/riparian function and aquatic habitat protocols.

### viii. Planning Unit 113.70022: Beebe Creek and the Garcia River

Land ownership within this sub-basin is shared by Louisiana-Pacific (9.3%), the US Air Force (ridgetop) and Coastal Forestlands (majority). Some instream data is available for Beebe Creek from short (100 ft.) stream surveys and a population distribution study (Fish and Game, 1989). Because of its relative steepness (12%) and a potential bedrock barrier found just above the Garcia Haul Road (Mangelsdorf, 1997), Beebe Creek is not designated as high priority for instream monitoring. This barrier should be investigated before a monitoring program can be recommended.

Because this watershed consistently scored highest in erosion rates, with sources equally split between mass wasting and surface erosion (Chapter 3), this stream should be considered a good site for conjunctive hillslope monitoring. The stream, therefore, should be monitored for sediment delivery (STCs) and temperature to determine the contribution of these two factors to the mainstem Garcia River. This could be accomplished by the RCD at the same time that the barrier is evaluated.

**Garcia River**

Potential Limiting Factors:

- Elevated water temperatures for summer rearing, due to stream width.

The mainstem Garcia River is currently being monitored by CFL at two sites in this sub-basin, as part of their Watershed and Aquatic Wildlife Assessment plan (1997). FrOG collected temperature data near the Hot Springs camp in 1994, with late summer temperatures exceeding the upper limit of the preferred coho range approximately 90% of the time (Mangelsdorf, 1997). FrOG has decided that due to the influence of the nearby hot springs, they will discontinue temperature monitoring at this site.

It has been recommended by Maahs (1997) that stretches of the mainstem in this subwatershed be surveyed for fish and spawning redds to evaluate whether steelhead and/or coho are using the mainstem of the Garcia for spawning and rearing.

FSW recommends that CFL continues monitoring at their established monitoring sites, according to their stream channel/riparian function and aquatic habitat protocols, while incorporating as much of this IMP as possible. This site would also be useful for a fish survey, either by the RCD, as part of a larger mainstem survey, or by CFL under the cooperative monitoring program.

### ix. Planning Unit 113.70023: South Fork, Fleming Creek and the Garcia River

Louisiana-Pacific owns approximately 92% of this sub-basin, with the remaining 8% holdings in three ranches atop the ridge separating the Garcia River watershed from the Gualala River watershed. Very little timber harvesting has occurred in this sub-basin over the past ten years (CDF 1997). This is an important sub-basin to begin monitoring in because data collected now before the next timber extraction phase will serve as a baseline

by which to assess future impacts of timber harvest and the capability of the Forest Practice Rules to protect fish habitat in the basin.

**South Fork Garcia**

Potential Limiting Factors:

- Pool depth, due to sedimentation and limited instream capacity.
- Cover, due to limited instream complexity.
- Low flow barrier to juveniles seeking refuge from elevated mainstem temperatures.

Many instream studies have been conducted on the South Fork Garcia, including Fish and Game surveys (1987-1989, and 1991-92), Salmon Trollers Association spawning surveys (1989-91 and 1996-97), and a Louisiana-Pacific stream survey (1995). FrOG monitored temperature at the mouth of the South Fork in 1995. Fish and Game stream survey data (1987-92) imply that the South Fork is in a state of recovery with 1992 numbers indicating low sediment levels (<2% sand), high spawning habitat (80%), and a high percent canopy cover (90%). In contrast, the sediment budget prepared by Hagans (1997) showed the South Fork to be inundated with sediment which is moving slowly downstream within the confines of the San Andreas fault zone. The Garcia River Watershed Advisory Committee noted that steelhead frequently pool on the mainstem Garcia at the mouth of the South Fork, unable to get in due to sediment barriers. It was also noted, however, that because of the stream's low gradient, the South Fork may be the best potential coho stream in the Garcia River basin (Mangelsdorf, 1997).

FSW recommends that a full set of instream monitoring protocols be employed by the RCD on the South Fork Garcia, to assess temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees and STCs. Temperature monitoring should be conducted by FrOG and/or the RCD. Fish and spawning surveys should be done by the RCD or a cooperator. Cross-sections and thalweg profiles could be used to help better understand the role of sediment and the rate at which it is moving through the system. The RCD should investigate the sediment barrier at the mouth of the South Fork. Ideally, the new owners of the L-P property will be willing and able to participate in cooperative monitoring with the RCD.

**Fleming Creek**

Potential Limiting Factors:

- Pool depth, due to sedimentation.
- Potential culvert barrier to migration.

Fish and Game conducted stream surveys on Fleming Creek in 1987-89 and 1991-92 including a McNeil sample at the mouth of Fleming Creek. According to data compilation from the Limiting Factors Analysis, Fleming Creek is composed of predominantly gravel and rubble, the canopy closure is good, summer water temperatures appear adequate but the proportion of pools to riffles seems to have declined over time (Mangelsdorf, 1997). Fish and Game fish surveys from 1987-89 and from 1991-92 noted steelhead densities of

0.55 fish/$m^2$ and coho seen in 1988 at a density of .5 fish/$m^2$. FSW recommends that the RCD establish a monitoring program on Fleming Creek, to collect data on temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees and STCs. A culvert noted as a potential barrier to fish passage should also be investigated (Mangelsdorf, 1997). The IMP recommends that cooperators be responsible for fish surveys in Fleming Creek.

**Garcia River**

**Potential Limiting Factors:**

- Pool depth, due to limited instream complexity

Available data for the mainstem of the Garcia River is limited to a 1967 Fish and Game survey and 1995 temperature data collected by FrOG just above the confluence with the South Fork. FSW recommends that FrOG continue to monitor temperature in this location.

### x. Planning Unit 113.70024: Mill Creek, Rolling Brook, Lee Creek, Hutton Gulch, and the Garcia River

Ownership of the Rolling Brook sub-basin is divided between Louisiana-Pacific (57.3%, Coastal Forestlands (small portion along Hutton Gulch) and small, individual landowners. Mill Creek, Rolling Brook Creek, Lee Creek and Hutton Gulch are all fairly steep tributaries flowing from the northeast into the mainstem Garcia. All of these streams could be candidates for monitoring, particularly for steelhead habitat and summer rearing and overwintering habitat for coho (Mangelsdorf, 1997). Studies conducted in this sub-basin have been on Rolling Brook Creek (L-P habitat survey, 1995 and FrOG temp data 1995-97), Hutton Gulch (F&G 1977 stream survey and FrOG temperature data, 1995) Lee Creek (FrOG temperature at mouth, F&G 1989 stream survey) and Mill Creek (FrOG temperature at mouth). Overall, there is a relative lack of quantitative instream data throughout the sub-basin, which represents a gap in data for the larger Garcia River watershed. The data collected now will also serve as a baseline for future evaluations of stream conditions when the Rolling Brook planning unit comes into a harvest rotation by L-P, or the land's new owner, in the future.

**Rolling Brook**

Potential Limiting Factors:

- Number and depth of pools, due to sedimentation.
- Quality of spawning gravels, due to sedimentation.

Rolling Brook is a good stream to monitor in this PW, because it has a higher measured density of fish than the other tributaries, a lower gradient channel, a history of dense steelhead in the lowest one mile stream reach and previous studies conducted by L-P. FSW recommends that the RCD establish a monitoring program on Rolling Brook to monitor for temperature, substrate composition, gravel permeability, longitudinal profiles,

V*, canopy, LWD, recruitment trees, STCs and fisheries. Fishery data can be the responsibility of the cooperator.

Collection of water temperature data should be continued by FrOG in Rolling Brook, on lower Mill Creek, in Lee Creek and in Hutton Gulch.

**Garcia River**

It has been noted that dissolved oxygen levels in the mainstem below Rolling Brook may be a limiting factor to juvenile rearing during the hot summer months. Both temperature, stage height and dissolved oxygen data are being collected by the Mendocino County Water Agency at two sites, above and below the Eureka Hill Bridge. This work should continue and a rating curve to relate stage height to flow should be developed. This site has also been selected by the Mendocino Watershed Services and Adopt-a-Watershed Program for a turbidity study to be conducted in conjunction with the Anderson Valley High School in the neighboring Navarro River drainage. Temperature data will also continue to be collected by FrOG in Louie's Hole, just upstream from Lee Creek and at the Eureka Hill bridge.

We also recommend a fishery survey in this section of the mainstem, to check for mainstem utilization. We have assigned this task to the RCD.

### xi. Planning Unit 113.70025: North Fork Garcia, John Olsen Gulch, Olsen Gulch and the Garcia River

Alder Creek is a tributary to the North Fork Garcia, and Olsen Gulch and John Olsen Creek flow directly into the mainstem Garcia downstream from the North Fork confluence. Almost the entire sub-basin is owned by CFL, and THPs have been filed for approximately 90% of the sub-basin over the past ten years (CDF, 1997). Georgia-Pacific also owns property in this sub-basin. Although all of the tributaries in this sub-basin warrant monitoring, the highest priority is to continue monitoring on the North Fork and in the mainstem of the Garcia River.

**North Fork Garcia**

Potential Limiting Factors:

- Lack of woody debris
- Spawning bed scour
- Subsurface flows.

The history of extensive timber harvest combined with reports of high sediment levels, lack of woody debris and high levels of hillslope erosion from failing roads, landings and skid trails (Mangelsdorf, 1997) make the North Fork Garcia a high priority for long-term monitoring and an excellent sub-basin to test the Forest Practice Rules capability of protecting instream beneficial uses.

FSW recommends that CFL continue to collect data under their existing channel assessment and riparian habitat monitoring plan at already established sites. Additionally, it is recommended that the RCD employ the full set of instream protocols recommended by this IMP for parameters of temperature, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees, and STCs. Possibilities for cooperative monitoring of fisheries, temperature, and instream characteristics should be explored on the North Fork.

**Garcia River**

The mainstem of the Garcia River flows through the North Fork sub-basin at a 1% gradient, in a fairly wide, open and unconfined channel. Summer water temperatures have been reported high for rearing of coho salmon, however both steelhead and coho spawning has been noted during the later months of the year (Mangelsdorf, 1997). Dissolved oxygen levels in the deeper pools may also be limiting fish habitat (GWAG, 1997). Cross-section analysis by Jackson (1997) documents that "overall channel width has remained constant at all of the cross-sections, with an overall trend of decline in both water surface elevation and thalweg elevation, relative to 1991"(Mangelsdorf, 1997).

In 1997, the Mendocino County Water Agency began monitoring for dissolved oxygen, turbidity, flow and conductivity at Connor Hole, and temperature at both Connor Hole and the Buckridge Bar. FrOG also measures for temperature at Connor Hole. FSW recommends that these data be collected annually as part of the cooperative monitoring program. Cross-sections should be repeated at more long-term periodic intervals to monitor the change in channel morphology and movement of sediment through the mainstem over time. It has also been recommended (Maahs, 1997) that stretches of the mainstem be surveyed for fish and spawning redds to evaluate whether steelhead and/or coho are using the mainstem of the Garcia for spawning and rearing. This is a good reach in which to do fish counts and spawning surveys.

### xii. Planning Unit 113.70026: Allen Gulch, Hathaway Creek, the Garcia River and the Estuary

The mainstem of the Garcia River and the Estuary have been studied intensively in the past due to the controversy surrounding extraction of aggregate materials in the lower 7 miles of river. This sub-basin has a number of small landowners and a multiple of land uses. FSW does not recommend that a full monitoring program be established in this sub-basin. Repeating cross sections at periodic intervals on the mainstem may be valuable to further understand the dynamics of this stretch of river. Temperature should continue to be monitored by the Mendocino County Water Agency on Hathaway Creek at Windy Hollow Road and at Minor Hole and Oz Hole by FrOG. Turbidity studies conducted by the Adopt-a-Watershed Program in conjunction with the Navarro High School should be continued at the Highway 1 bridge.

### *D. Cooperative Monitoring Plan for the Garcia River*

The underlying objective of the instream monitoring plan is to coordinate with existing monitoring already being done by industry, environmental groups and the agencies, to fill in the gaps in where data is needed and to build on data collection efforts that are already underway throughout the basin. This results in a cost-effective, comprehensive approach to watershed monitoring of stream and fishery conditions.

Cooperative data sharing with groups and agencies working in the watershed should be facilitated by allowing the RCD to become a data clearinghouse. These data are important to the public, to agencies and to landowners. They are relevant for timber harvest planning, coordinated resource management planning and enforcement of EPA and NCRWQCB goals. A coordinated effort, with the RCD managing protocols, certifying trainers and housing data will allow both information exchange and data analysis. The RCD should look to the Forest Science Project at HSU, an industry-academic cooperative project, for assistance in developing the clearinghouse and locating key personnel.

FSW recommends the RCD, the industry and private landowners cooperate for access to their lands, for training, for monitoring, for information and for the long-term. The long-term is key--this is a two year program, spread over 74,000 acres, monitoring a host of variables, many of which change slowly (Table 5-3). There are 12 streams on which we suggest the full suites of stream reach protocols, and another 16 streams on which we recommend that individual agencies or landowners continue their implementation of individual protocols. Sites are shown on Map 5-1; protocols with their respective streams and cooperators are listed on Table 5-2.

In some cases, people are presently collecting data in a manner similar to our recommendations. While similar, much of it is not directly comparable or interchangeable with the IMP protocols. As an overall watershed survey, the RCD must use uniform protocols in its inventory, implemented by people with the same level of training, and with uniform repetition to give the data similar statistical characteristics.

Some protocols in use are already easily comparable. Hobo XT data, for instance, will continue to be comparable, provided the instream data collection point is the same as in the IMP. Data collected by other equipment or techniques can be calibrated with the IMP protocols, to extend the record into the past and into present continuation of that alternate method.

FSW believes that fisheries monitoring is an element most easily shared by cooperators, representing an important aspect of both watershed condition evaluation and hypothesis testing. The RCD should work with the Salmon Trollers and other cooperators who have conducted these surveys in the past, for the continuation of those protocols into the future, and to train all cooperators on a strategies for spawner/redd surveys and summer

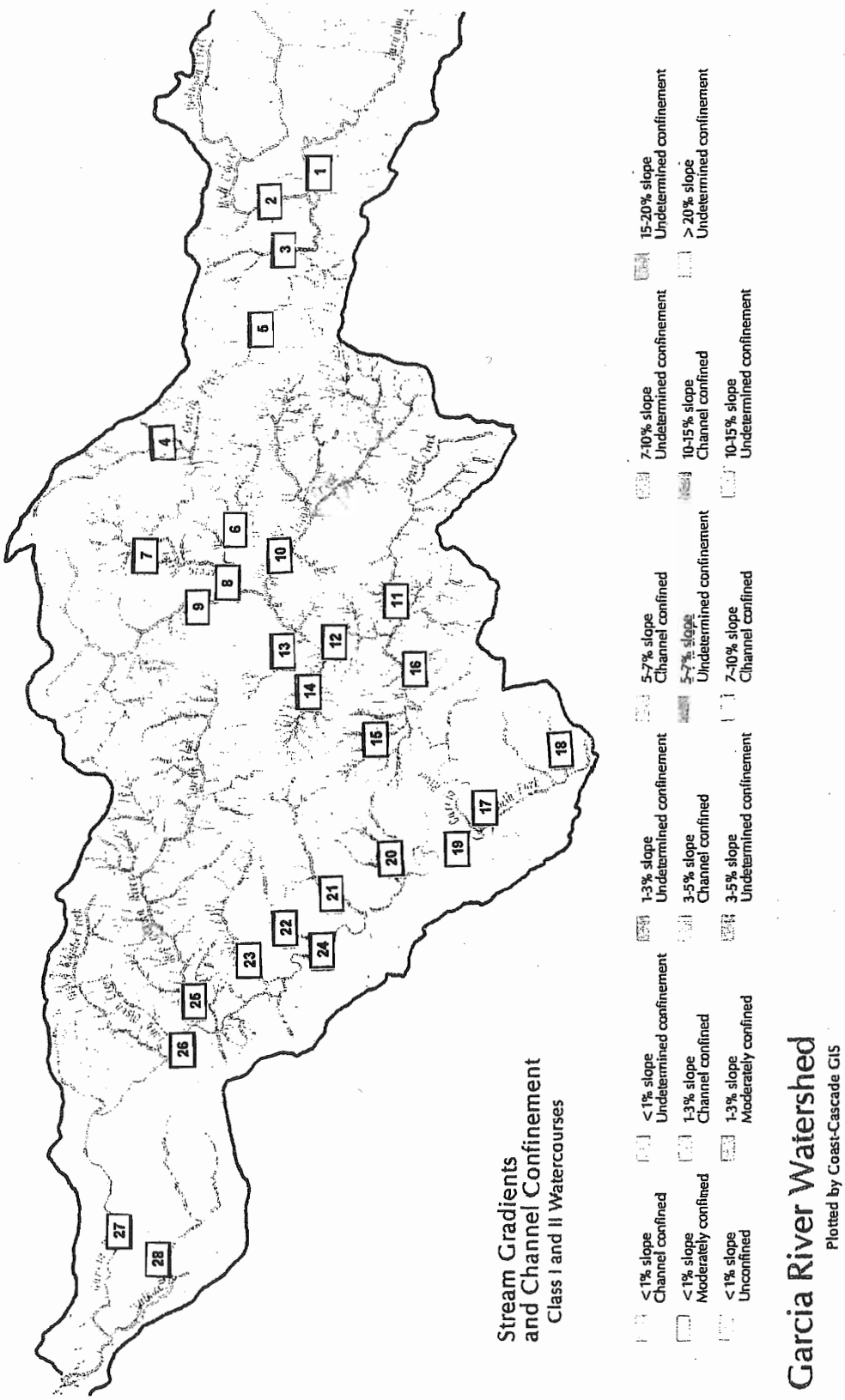
fish counts. In particular, the winter surveys need to happen quickly, so a host of cooperators would be most effective. Our budget accounts for eight intensive coho spawning surveys during the two year period. Cooperators can extend this capability significantly.

In addition, individual cooperators should use the implementation of stream reach monitoring as a training and benchmarking opportunity. While the crew inventories the designated plot, landowners should learn the techniques and flagging code, document the location of the stream reach and its plots on the ground and in their mapping system. Landowners can also anticipate remeasuring this plot in one or two years, installing new full or partial plots, and implementing individual protocols of the IMP on other portions of their holdings. In those cases where landowners already have a data collection history, it would be best if they implemented *both* the old and new methods of measurement for at least two years.

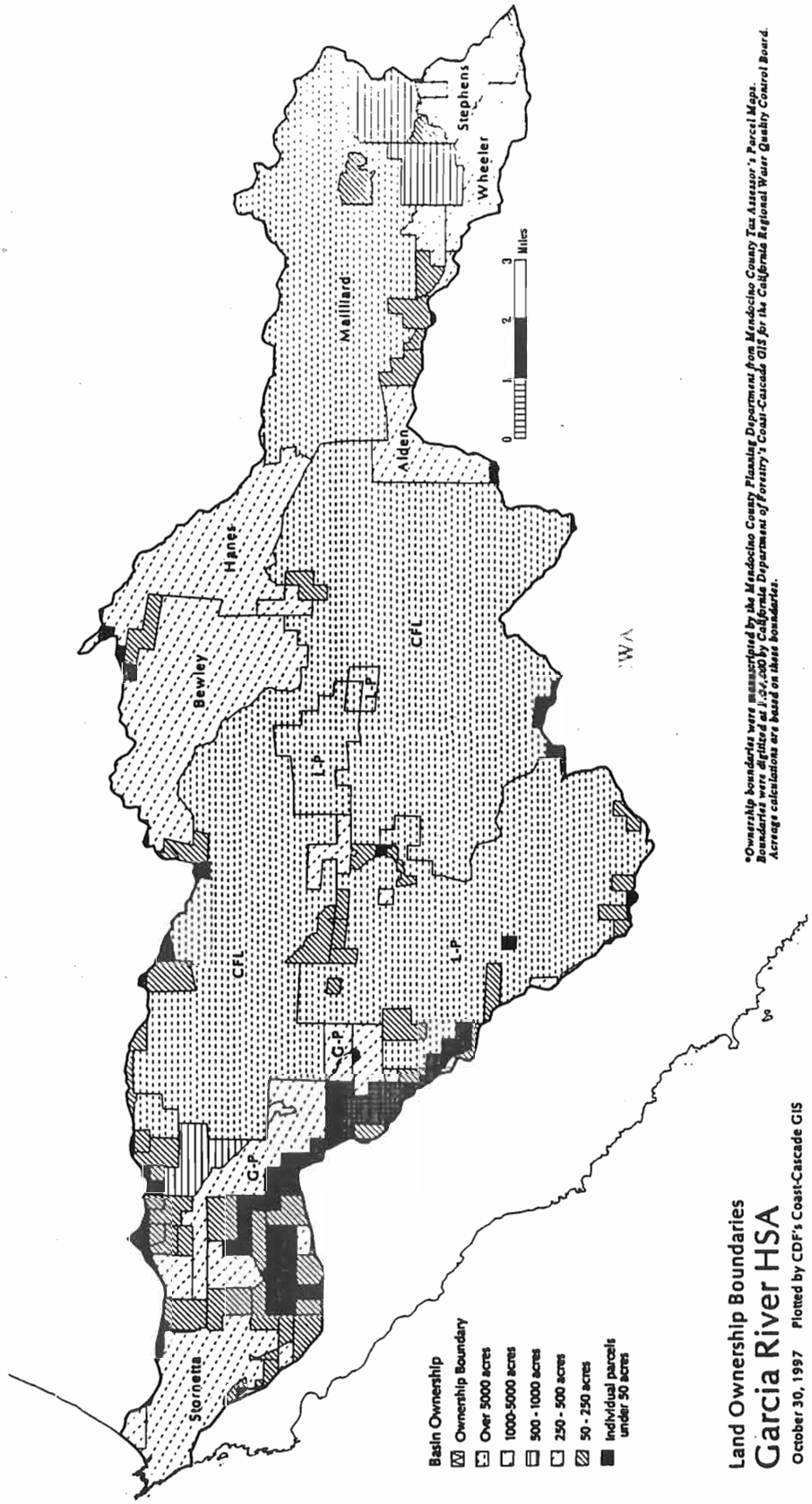
We do *not* recommend simply handing out the protocols and encouraging all landowners to conduct their own implementation. This is *not* a cookbook; Washington State certifies individuals as implementors of individual modules. In the Garcia, it is important to have a coordinator with experience and capable of training many people in the individual protocols, and acting, in effect, as the watershed IMP certifier.

Map 5-1 shows the recommended stream reach and individual protocol monitoring sites throughout the Garcia watershed. Each dot represents a beginning location from which stream reach selection would begin. Map 5-2 is a map of land ownership throughout the basin, followed by Table 5-2, which lists the selected sites for monitoring, parameters to be assessed at each site and recommendations for cooperators to implement this monitoring plan.

Map 5-1. Map of Selected Monitoring Sites for the Garcia River Watershed



Map 5-2. Map of Land Ownership in the Garcia River Watershed



## Table 5-2. Cooperative Monitoring Plan for the Garcia River Watershed

| Planning unit # Sub-basin | Selected monitoring sites | Monitoring Site Number | Sub-basin landowners | Cooperative monitoring | site map | temperature | substrate composition | permeability of gravels | longitudinal profiles | V* |
|---|---|---|---|---|---|---|---|---|---|---|
| 7010 Pardaloe and Mill Creeks | Pardaloe Creek | 1 | 8 ranchland owners | MCWA, RCD, CDFG | | MCWA (2 sites) | | | | |
| | Mill Creek | 2 | | MCWA, RCD | RCD | MCWA (2 sites) | RCD | RCD | RCD | RCD |
| 70011 Grant's Camp, Larmour Creek and the Garcia River | Grant's Camp Creek | 3 | CFL, private ranchers | Ranchers, CFL, RCD | RCD | RCD | RCD | RCD | RCD | RCD |
| | Larmour Creek | 4 | | RCD | | RCD | | | | |
| | mainstem Garcia | 5 | | | | MCWA | | | | |
| 70012 Stansbury Creek, Whitlow Creek and the Garcia River | Whitlow Creek | 6 | CFL, private ranchers | RCD | RCD | RCD | RCD | RCD | RCD | RCD |
| | Stansbury Creek | 7 | | RCD | RCD | RCD | RCD | RCD | RCD | RCD |
| | mainstem Garcia | 8 | | FrOG | | FrOG | | | | |
| 70013 Blue Waterhole | Blue Waterhole Creek | 9 | CFL, private rancher | CFL, FrOG & RCD | RCD | FrOG (4 sta.) | RCD | RCD | RCD | RCD |
| 70014 Inman Creek | Inman Creek | 10 | CFL | CFL, RCD | RCD | CFL, RCD | CFL, RCD | RCD | RCD | RCD |
| 70020 Signal Creek | Signal Creek | 11 | CFL | CFL, RCD | RCD | CFL, RCD | CFL, RCD | RCD | RCD | RCD |
| 70021 Caspar Creek, Graphite Creek and the Garcia River | mainstem Garcia | 12 | CFL and L-P | CFL | | CFL | CFL | | | |
| | Caspar Creek | 13 | | RCD | | | | | | |
| | Graphite Creek | 14 | | RCD | RCD | RCD | RCD | RCD | RCD | .RCD |

Table 5-2. Cooperative Monitoring Plan for the Garcia River Watershed (cont.)

| Selected monitoring sites | Monitoring Site Number | canopy measures | LWD | recruitment trees | STC's | aerial survey | cross sections | channel morphology | turbidity | flow | dissolved oygen | spawning surveys | fish counts | barrier evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pardaloe Creek | 1 | | | | | RCD | | | | | | RCD | RCD | |
| Mill Creek | 2 | RCD | RCD | RCD | RCD | RCD | | | | | | RCD | RCD | |
| Grant's Camp Creek | 3 | RCD | RCD | RCD | RCD | RCD | | | | | | RCD | RCD | |
| Larmour Creek | 4 | | | | RCD | RCD | | | | | | | | |
| mainstem Garcia | 5 | | | | | RCD | | | | | | | | |
| Whitlow Creek | 6 | RCD | RCD | RCD | RCD | RCD | | | | | | co-op | co-op | |
| Stansbury Creek | 7 | RCD | RCD | RCD | RCD | RCD | | | | | | RCD | RCD | |
| mainstem Garcia | 8 | | | | | RCD | | | | | | | | |
| Blue Waterhole Creek | 9 | RCD | RCD | RCD | RCD | RCD | RCD | | | | | RCD | RCD | |
| Inman Creek | 10 | CFL, RCD | CFL, RCD | RCD | RCD | RCD | | CFL | | | | co-op | co-op | |
| Signal Creek | 11 | CFL, RCD | CFL, RCD | RCD | RCD | RCD | | CFL | | | | co-op | co-op | |
| mainstem Garcia | 12 | CFL | CFL | | | RCD | | CFL | | | | | | |
| Caspar Creek | 13 | | | | | RCD | | | | | | | | RCD |
| Graphite Creek | 14 | RCD | RCD | RCD | RCD | RCD | | | | | | co-op | co-op | RCD |

Table 5-2. Cooperative Monitoring Plan for the Garcia River Watershed (cont.)

| Planning unit # Sub-basin | Selected monitoring sites | Monitoring Site Number | Sub-basin landowners | Cooperative monitoring | site map | temperature | substrate composition | permeability of gravels | longitudinal profiles | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|
| 70022 Beebe Creek and the Garcia River | Beebe Creek | 15 | CFL, L-P and US Air Force | RCD | | RCD | | | | |
| | mainstem Garcia | 16 | | CFL | | CFL | CFL | | | |
| 70023 South Fork, Fleming Creek and the Garcia River | South Fork | 17 | L-P, 3 ranchers | L-P, RCD | RCD | RCD | RCD | RCD | RCD | RCD |
| | Fleming Creek | 18 | | | RCD | RCD | RCD | RCD | RCD | RCD |
| | mainstem Garcia | 19 | | FrOG | | FrOG | | | | |
| 70024 Rolling Brook | Mill Creek | 20 | | FrOG | | FrOG | | | | |
| | Rolling Brook | 21 | L-P, CFL and private owners | RCD, FrOG | RCD | RCD, FrOG | RCD | RCD | RCD | RCD |
| | Lee Creek | 22 | | FrOG | | FrOG | | | | |
| | Hutton Gulch | 23 | | FrOG | | FrOG | | | | |
| | mainstem Garcia | 24 | | MCWA, MWS | | MCWA, FrOG | | | | |
| 70025 North Fork | North Fork | 25 | CFL, G-P, and private landowners | CFL, FrOG, RCD | RCD | RCD | CFL, RCD | RCD | RCD | RCD |
| | mainstem Garcia | 26 | | RCD, FrOG | | MCWA | | | | |
| 70026 Hathaway Creek | lower 7 miles of mainstem Garcia | 27 | private landowners | RCD, FrOG, MCWA, MWS | | MCWA, FrOG | | | | |
| | Hathaway Creek | 28 | | | | FrOG | | | | |

Table 5-2. Cooperative Monitoring Plan for the Garcia River Watershed (cont.)

| Selected monitoring sites | Monitoring Site Number | canopy measures | LWD | recruitment trees | STC's | aerial survey | cross sections | channel morphology | turbidity | flow | dissolved oygen | spawning surveys | fish counts | barrier evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beebe Creek | 15 | | | | RCD | RCD | | | | | | | | RCD |
| mainstem Garcia | 16 | CFL | CFL | | | RCD | | CFL | | | | RCD | RCD | |
| South Fork | 17 | RCD | RCD | RCD | RCD | RCD | | | | | | co-op | co-op | RCD |
| Fleming Creek | 18 | RCD | RCD | RCD | RCD | RCD | | | | | | co-op | co-op | RCD |
| mainstem Garcia | 19 | | | | | RCD | | | | | | | | |
| Mill Creek | 20 | | | | | RCD | | | | | | | | |
| Rolling Brook | 21 | RCD | RCD | RCD | RCD | RCD | | | | | | co-op | co-op | |
| Lee Creek | 22 | | | | | RCD | | | | | | | | |
| Hutton Gulch | 23 | | | | | RCD | | | | | | | | |
| mainstem Garcia | 24 | | | | | RCD | MCWA, FrOG | | MWS | MCWA | MCWA | RCD | RCD | |
| North Fork | 25 | CFL, RCD | CFL, RCD | RCD | RCD | RCD | | CFL | | | | co-op | co-op | RCD |
| mainstem Garcia | 26 | | | | | RCD | MCWA | | MCWA | MCWA | MCWA | RCD | RCD | |
| lower 7 miles of mainstem Garcia | 27 | | | | | RCD | FrOG | | MWS | | | | | |
| Hathaway Creek | 28 | | | | | RCD | | | | | | | | |

RCD - Mendocino County Resource Conservation District
MCWA - Mendocino County Water Agency
G-P - Georgia-Pacific
MWS - Mendocino Watershed Services
CFL - Coastal Forestlands, Ltd.
FrOG - Friends of the Garcia River
L-P - Louisiana-Pacific

*Table 5-2. Cooperative Monitoring Plan for the Garcia River*

### *E. Reference Catalogue*

The number of agencies which have engaged in the monitoring set of protocols included in this document ranges from extremely numerous to relatively few. Some methods are 'standard methods,' for which we reference the American Public Health Association Manual (1997). While this manual is the standard for *lab analysis*, it does not give field methods, or 'tailgate protocols.' These are generally developed by the implementing agency. We recommend working with the NCRWQCB for turbidity, dissolved oxygen protocols. They implement these protocols on a daily level, and have standards acceptable to the basin plan.

McNeil samples have been done by fisheries personnel for years. We recommend the gravimetric protocol, and reference Mr. Randy Klein of Arcata and Redwood National Park, as well as the TFW program. We believe that CFL has done samples within this protocol to date.

Permeability samples have been done by Mr. Scott McBain of Arcata, as well as the USDA Forest Service Six Rivers Forest. McBain and Trush are working with Simpson Timber Co. on increasing their use, and L-P is considering them for the Garcia, as well (Pious 1997).

Cross-sections have been used extensively in stream assessment and engineering applications. Jackson's (1997) report documents their use in the Garcia, as does Williams' (1996). They are also noted for many locations throughout California, including Dry Creek and the Russian River, and are a standard method in Dunne and Leopold (1978) and Rosgen (1996a). Both texts have multiple examples.

Longitudinal profiles are being used by the SF Estuary Institute for the development of 'Riparian Stations', and have been implemented on Coyote Creek, the Napa River and Wildcat Creek in the Bay Area. McBain and Trush use them within the Simpson holdings. Dunne and Leopold (1978) and Rosgen (1996a) put them forward as standard methodologies with examples.

V* has been used by Lisle and Hilton (1992) and Knopp (1993) in North Coast streams. In Trinity County, V* was used to assess the recovery of Grass Valley Creek. V* derivatives have been used within the WFPB protocols, and by FSW in the Sierras and Cascades, for UC's Blodgett Forest and Collins Pine Co. The Greenwood Watershed Association has also used a V* approach in coastal Mendocino County, under the tutelage of FSW.

The densiometer for measuring canopy is a standard forestry measure, around for more than 40 years. It has been used by timber companies throughout the US, and is included in the CDFG California Salmonid Habitat Restoration Manual (Flosi and Reynolds 1994).

The Solar Pathfinder approach was formalized for assessment of solar power potential, and has been used by architects throughout the US. It is used, as well, by the USDA Forest Service Six Rivers Forest, CDF, UC Berkeley Blodgett Forest, and as a standard tool for SFEI's Riparian Stations.

LWD measurements are standardized in the State of Washington under TFW and the WFPB. They are also used at UC's Blodgett Forest, and on Collins Pine Co. lands, for their SYP. Recruitment tree measurements are taken directly from the WFPB protocol, but it is not certain how commonly they are used. Blodgett Forest and CDF do conduct riparian recruitment tree assessments with similar tools, but their protocols are different, though similar. All use standard forestry assessment tools, and some form of plot-based measurements.

Sediment Transport Corridors have been evaluated systematically at Blodgett Forest, Greenwood Creek and Collins Pine Co. holdings. They have proven reliable for identifying restoration priorities and typical causal mechanisms. The causal mechanism approach of WFPB has been widely used in Washington state, and is similar in many respects.

Forensic methods for assessing sedimentation using overflights have been used in estuarine and lake sedimentation situations. Monschke (1998) has stated that helicopter overflights have been useful in this terrain. Rosgen (1996b) suggested that this is the easiest, most straightforward way to find watershed problems.

Fishery surveys have been done in this watershed for many years. We have found records of spawning surveys, redd counts, carcass counts, summer juvenile counts and electrofishing. The Salmon Trollers Association and the Department of Fish and Game are the best sources for training and protocol development for fishery surveys for this IMP.

### *F. Time Frame and Schedule of Monitoring Activities*

The protocols recommended have intrinsic timelines determined by what they measure. Some characteristics of watersheds change quickly, others slowly. The time scale shown relative to parameters and indices in Table 5-3 indicates the rate of change, and therefore the necessity of revisits and remeasures of the protocols presented in this section. Table 5-4 proposes a schedule for the RCD and cooperators for the next two years. Table 5-4 also states management needs for the RCD to implement this IMP, including hiring a coordinator, purchasing equipment, identifying sites, and interacting with cooperators.

The ultimate time frame for watershed monitoring relies on the amount of effort directed at this project by the MCRCD and its cooperators. While any given watershed can receive monitoring now, it may take years for a full suite of protocols to be instituted throughout the watershed.

It is FSW's experience that revisits to plots are best done sooner, rather than later, to take advantage of experienced personnel, to re-find points, to refresh flagging, to update maps (roads change quickly in timber harvest areas), and to not lose the plots. Some revisits are intrinsic in this sampling methodology; temperatures must be downloaded every two months, for instance. The tendency to let remeasures 'slide' until their location is lost or forgotten, though, will always be an active danger to this kind of long-term, watershed wide study in a changing landscape.

This is a two year study, however. In those two years, it would be a wasted effort to focus only on a very small number of streams while waiting for canopy and channel changes. Thus we recommend establishing twelve full plots, at a rate of six per year, with the hope of revisits by cooperators or a continuing RCD program over the next pair of years.

An alternative method would be to only install six plots and remeasure them the following year. FSW is concerned that indices may change very little in a year, and that extrapolation of these data into a trend would be misleading. These are long-term monitoring sites.

While morphology should be measured every other year or less often (but not less than twice a decade!), fishery values can vary strongly from year to year. We have budgeted for four sites per year to be walked three times during the winter season. The more this can be stretched, either by the RCD or cooperators, the better the overall quality of this study will be. The quality of the fishery is, ultimately, the true test of adaptive management.

We have not stated which streams should be monitored in which year. This will be highly dependent on access issues, cooperators' infusions of effort, and the implementation approach used by the coordinator.

Table 5- 3. Time Scale of Watershed Parameter Change: Remeasuring Schedule

| class of parameter | index | | time scale | | | | |
|---|---|---|---|---|---|---|---|
| | | point-in-time | seasonal | annual | multi-year | decades | centuries |
| water quality | turbidity | x | | | | | |
| | dissolved oxygen | x | x | | | | |
| | temperature | x | x | x | x | | |
| | | | | | | | |
| gravel quality | percent fines <1mm | | x | x | x | | |
| | permeability | | x | x | x | | |
| | | | | | | | |
| channel assessment | cross sections | | | x | x | x | x |
| | longitudinal profiles | | | | x | x | x |
| | LWD survey | | | x | x | x | x |
| | V* | | x | x | x | x | |
| | | | | | | | |
| riparian function | canopy measures | | | | x | x | x |
| | recruitment trees | | | | x | x | x |
| | | | | | | | |
| causal mechanisms | sediment transport corridors | | x | x | x | | |
| | turbidity | x | | | | | |
| | | | | | | | |
| fish productivity | summer fish surveys | | x | x | x | x | x |
| | spawner & redd counts | | x | x | x | x | x |

Table 5-4. Schedule of Monitoring Activities

| RCD Tasks | | 1998 | | | | 1999 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | winter | spring | summer | fall | winter | spring | summer | fall |
| Project Management | hire coordinator | X | X | | | | | | |
| | contact co-op's, share prot's, pool co-op data | X | X | | | | | | |
| | purchase equipment | | X | | | | | | |
| | select monitoring sites, gain access | | X | X | | X | X | | |
| | manage, analyze data | X | X | | | X | X | | |
| Stream Reach Sites | site map | | | 24 plots on six reaches | | | | 24 plots on six reaches | |
| | substrate composition | | | 3 points * 24 plots on six reaches | | | | 3 points * 24 plots on six reaches | |
| | permeability of gravels | | | 3 points * 24 plots on six reaches | | | | 3 points * 24 plots on six reaches | |
| | longitudinal profiles | | | 6 profiles on six reaches | | | | 6 profiles on six reaches | |
| | V* | | | 2 pools * 24 plots on six reaches | | | | 2 pools * 24 plots on six reaches | |
| | canopy measures | | | 3 points * 24 plots on six reaches | | | | 3 points * 24 plots on six reaches | |
| | LWD | | | 24 plots on six reaches | | | | 24 plots on six reaches | |
| | recruitment trees | | | 24 plots on six reaches | | | | 24 plots on six reaches | |
| | STC's | | | six entire reaches | | | | six entire reaches | |
| on plots, trib's and mainstem | spawning surveys | | | | | 8 reaches over 2 years + co-op's | | | |
| | fish counts | | | 6-10 reaches by co-op's or rcd | | | | 16 reaches by co-op's or rcd | |
| sites plus existing network | temperature | | 22 launches + co-op's | | | | 22 launches + co-op's | | |
| whole watershed | aerial survey | asap | | | | co-op opportunity | | | |
| specific pools | dissolved oygen | | | co-op or rcd | | | | co-op or rcd | |
| trib. sites | barrier evaluation | | | six, or with plots | | | | remainder | |

*Table 5-4. Schedule of Monitoring Activities*

### *G. Quality Assurance/Quality Control*

**Recommended project criteria** and necessary qualifications for people implementing these protocols are generally as stated in the TFW (Shuett-Hames et al. 1994) and WFPB (1995) documents. Crew trainers should be masters' level or its equivalent, with several years of field experience. Crew members should be tested on the protocols both in the office and in the field. If there is more than one crew, crews should redo each others' work on a regular basis to test for bias, and crew trainers should check on protocol implementation weekly. The tendency to drift is kept to a minimum if crew trainers are on site as team leaders; if crews are mixed regularly, to find irregularities; if crew members are not specialists, so the protocols do not drift under an individual's bias; and if field protocols are at hand, in the field to be checked at all times.

Cooperators should be considered as crew for their respective sector of the IMP. If they are conducting any kind of test or survey which occurs around the watershed and is part of the common database, they must train in a similar manner to other crews, and be checked regularly. Poor data collection can undermine the quality of the pooled data set.

**Recommendations for statistical considerations** related to data design, data processing and data analysis are to follow a multiple cluster plot design in a stratified systematic survey, as discussed in Chapter 5. Significant repetition of point samples, long continuous samples, large sets of points in pools, frequent measurement intervals along longitudinal profiles and cross-sections are all ways of ensuring statistical strength. Some samples, such as fishery data and McNeils defy statistics, because they are sampling highly variable situations with high-cost, intensive methods that prohibit multiple repetitions. Finding strongly correlated proxies for cumbersome methods, such as permeability for McNeils, encourages multiple sample points and significantly strengthens the statistic, even though it decreases apparent precision. This tradeoff for accuracy rather than precision is important, and is a paramount consideration.

The question of thermometer accuracy will be a problem with these data sets. We recommend launching the Hobo XTs after a check that they are working at room temperature, averaging two through a stream reach, and reading them with a +-one degree Centigrade error. This addresses questions of both accuracy of the device and zonation of streams. If Hobos are found to read significantly differently, either the stream or the instruments are showing more than expected variation.

### *H. Estimated costs of implementing the IMP.*

Table 5-5 gives our estimated costs for implementing an instream monitoring program in the Garcia watershed. Within a budget of $118,250, we believe the RCD can implement an effective start to adaptive management, with the help of cooperators. The cooperative monitoring provides continued cost support for many parameters already being measured, and new efforts a gathering fisheries data and supporting the RCD's IMP team in access, site location and site monitoring.

The budget is for a two year period. As this report is presented in late January of 1998, it may be too late to implement fish surveys this year. Trush (1998) has offered that it is probably too late for coho, but in time for steelhead, if we were to implement in late winter and spring of 1998. Money for two years of fishery surveys may be concentrated in the winter of 1999, or spread out to winter of 2000 if it is not used immediately. Cooperators are, of course, encouraged to continue and expand present activities to coincide with the IMP's stream monitoring recommendations.

This budget does not consider costs of maintaining the LTMP beyond the two year period. If the program is to continue, many portions can be extended by trained and calibrated representatives from the cooperators. Other points, particularly those in ranchland and watersheds shared among non-industrial owners, should be maintained by the RCD.

The RCD must also continue to maintain the database into the future, ideally at the RCD's office, to allow public access and consistency in record keeping. Protocols should also be maintained by RCD staff, to maintain the knowledge of what is in the database, and the capability of gathering new information.

Finally, data analysis is not included in this budget. The nature of the LTMP implies that, apart from meeting requirements of the TMDL process or Basin Plan, and apart from testing the assumptions made in this document and timber companies' evaluations, data analysis will occur with information gathered at the five to twenty year level. The RCD must seek further funding or long-term cooperators to maintain the database for its useful life and ultimate utility.

Garcia River Instream Monitoring Plan
Two Year Estimated Budget

| task | no. persons | time | rate | annual cost | two year cost |
|---|---|---|---|---|---|
| **Administration** | | | | | |
| project coordination, data management | 1 | 15 hrs/wk | $18/hr | $14,040 | $28,080 |
| office supplies and copies | | | | $400 | $800 |
| phone | | | $30/month | $360 | $720 |
| travel | | | $.32/mile | $1,000 | $2,000 |
| overhead to RCD for entire project | | | 15% | $10,454 | $20,907 |
| staff benefits | | | 30% | $4,212 | $8,424 |
| **Subtotal - Administration** | | | | **$30,466** | **$60,931** |
| **Field Work** | | | | | |
| fixed plot IMP - site map, substrate composition, gravel permeability, longitudinal profiles, V*, canopy, LWD, recruitment trees and STC's | 2 | Average of 4 days/stream reach, 6 streams/yr. | 1 @ $18/hr. 1 @ $15/hr. | $6,336 | $12,672 |
| temperature | 1 | 6-8 hobos/day; 3x yr. | $18/hr | $1,296 | $2,592 |
| fish counts and spawning surveys | 2 | 4 streams/yr., 2 days/stream, 3x during coho season | 1 @ $18/hr. 1 @ $15/hr. | $6,336 | $12,672 |
| STC's only | 2 | 3 days/yr. | 1 @ $18/hr. 1 @ $15/hr. | $792 | $1,584 |
| cross-sections | 2 | 1 day/yr. | 1 @ $18/hr. 1 @ $15/hr. | $264 | $528 |
| barrier evaluations | 2 | 3 days/yr. | 1 @ $18/hr. 1 @ $15/hr. | $792 | $1,584 |
| staff benefits | | 30% | | $4,745 | $9,490 |
| **Subtotal - Field Work** | | | | **$20,561** | **$41,122** |

| Garcia River Instream Monitoring Plan<br>Two Year Estimated Budget | |
|---|---|
| **Equipment** | |
| DO test kit-Winkler wet titration kit. LaMotte (bm 221788) | $33 |
| Topcon level-AT G7 (bm 100365) | $595 |
| dome head tripod (bm 100174) | $128 |
| Mound city 4.5 m rod (bm 100853) | $105 |
| Keson fiberglass 100 m tape (bm 122733) | $80 |
| Keson fiberglass 30 m tape (bm 122731) | $27 |
| 2 style A form holders (tatums) (bm 102609) | $39 |
| 3 sieves: 6.3 mm, 2.0 mm, 0.83 mm | $143 |
| 22 hobo temps X-T plus housing | $2,617 |
| siphon pump for permeability (200304) | $22 |
| spherical densiometer (102165) | $99 |
| solar pathfinder plus refill horizontal surfaces (Jade equipment) | $120 |
| McNeil sampler | $140 |
| 2 Silva Ranger compasses | $83 |
| diameter logger's tape (121460) | $45 |
| **Subtotal - Equipment** | **$4,274** |
| **Other** | |
| aerial photo turbidity flight (includes pilot, plane and all supplies) | $6,000 |
| 5% miscellaneous and contingencies | $5,924 |
| **Subtotal - Other** | **$11,924** |
| **Total Budget** | **$118,250** |

## 6. *Tributary Selection for Conjunctive Hillslope and Instream Monitoring*

Evaluation of data for the watershed has shown several trends. We have postulated where the erosion rates are the greatest, and determined where that erosion is greater or less than expected. We have seen where data exists, and where it is missing. We have postulated what causal mechanisms may be guiding pollution impacts from the hillslopes into the streams. With this information and speculation, we must select appropriate watersheds for conjunctive monitoring. The synthesis table for impacts is Appendix B; the monitoring summary is Appendix C.

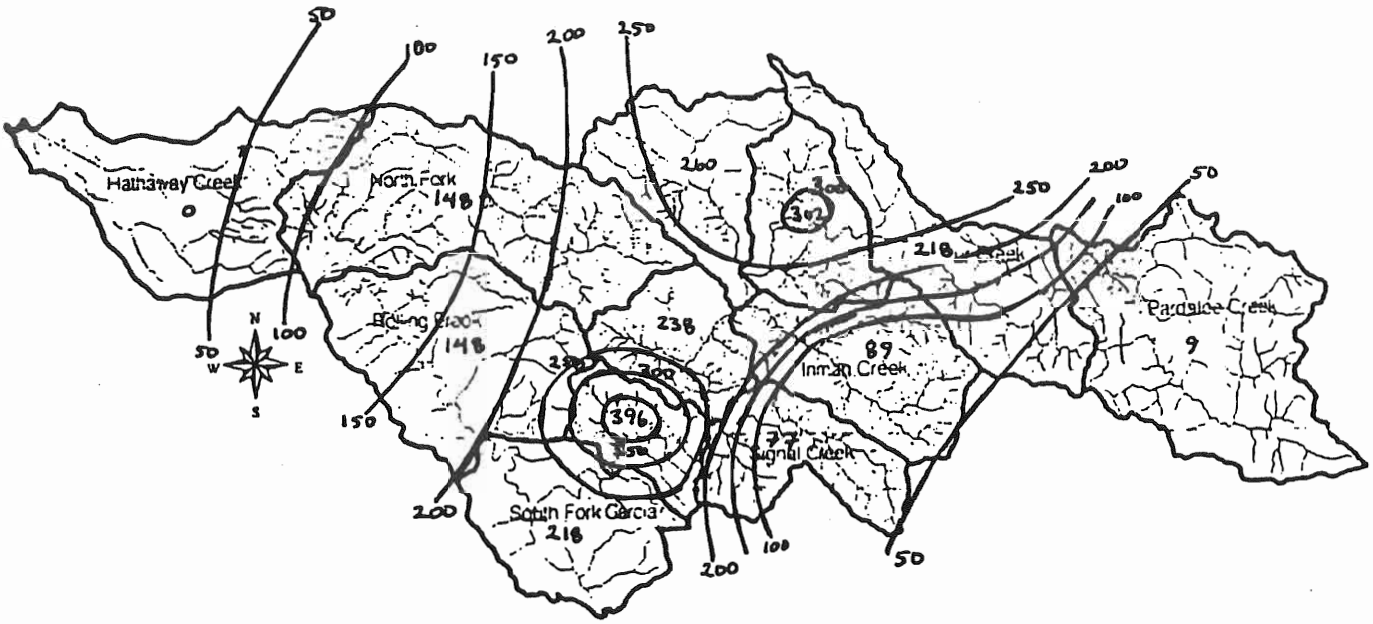
Watershed erosion rates are summarized in Maps 6-1. and 6-2. These maps show lines of equal erosion rates for mass wasting and surface erosion, as developed in Chapter 3. The isolines are based on applying rates to watershed centroids, and determining rate gradients between those points. These maps are presented as analysis tools, because they show the gross pattern of estimated erosion rates in the Garcia watershed.

Consideration of erosion rates shows that the Graphite PW, Basin no. 7022 with Beebe Ck., is both an important producer while it is essentially along the model line (Chapter 4). Review of maps show that it is not only the Graphite that has this kind of topography and land management, but areas of Hot Springs PW, basin no. 7021 with Graphite Ck., which has extremely steep slopes and a recent history of intense harvest. Similar conditions also exist in the North Fork watershed, though with less relief, due to a longer watershed, and greater fish productivity for the same reasons. These areas of very high landslide and road erosion deserve an investigation.

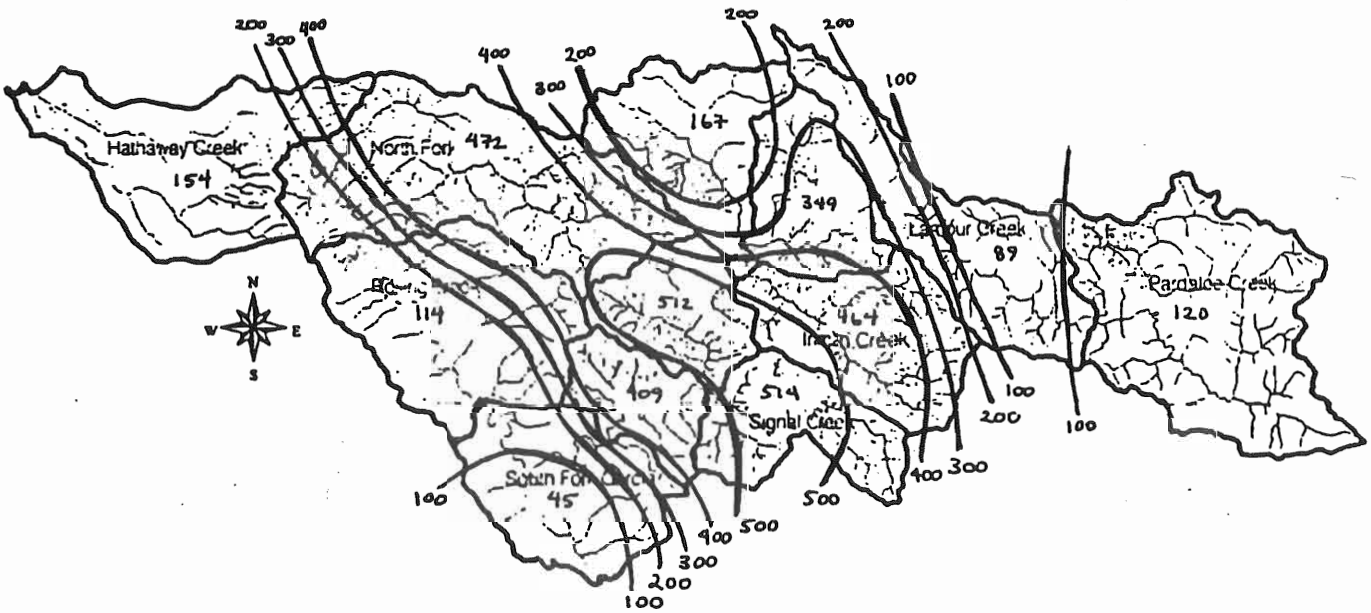
Evaluation of estimated erosion with expected erosion also shows some watersheds as unlikely low producers. Either something is making those watersheds more stable--such as good BMP implementation--or our models need work. In particular, Inman Ck., Signal Ck., and possibly Whitlow Ck. would be good candidates for study. These areas also have good historical fisheries.

The synthesis (Appendix B) finds that, among the existing data, there are very few sites which are considered to have 'good' conditions with 'good' fish populations. It is important to monitor these sites because they may be the most robust refugia for genetic stocks, particularly if the ecosystem were to undergo the stress of drought, floods or management impacts. These sites are also important to monitor because they may be the only sites sensitive enough to respond to environmental impacts. The only stream with low present sediment effects, high complexity, good canopy and fair fish populations--though declined from original levels--was the South Fork Garcia. Some site data conflicts with this interpretation, making its assessment even more important.

Map 6-1. Isomap of Estimated Mass Wasting Rates in t/mi2/y, Garcia River Watershed




Map 6-2. Isomap of Estimated Surface Erosion Rates in t/mi2/y, Garcia River Watershed



An area with low erosion, relatively stable sediment in stream channels and good fisheries is the South Fork PW. Relative to other watersheds, it is in very good condition. The area has been unlogged for the past decade, so it is reasonable to assume that the low impact of land management has allowed the watershed to 'heal.' The South Fork is a good candidate, therefore, because it may be harvested in the near future and it has some of the best fish habitat in the watershed.

It is also important to have sites dominated by road erosion. While Signal Ck., Inman Ck. and North Fork all have similar erosion rates and road / mass wasting balances, the North Fork is a significantly different type of watershed. It is larger, it has greater relief, and it does not appear as dominated by fault- or rock-contact- trending geology. Along with to its fishery history, this appears to make North Fork a good watershed to pair with Inman, Signal or Whitlow Creeks.

Other streams that should be considered are:

- Pardaloe Creek, which has good fisheries, high sedimentation, poor pools and habitat structure in a watershed with relatively little relief. It is not clear where the sediment is coming from, nor why the fish population is doing relatively well.
- Tributaries of the North Fork, particularly Olsen Gulch. Olsen Gulch, however, may have so limited fisheries at this time, and such hazardous conditions due to sedimentation (Maahs 1997), that North Fork will be a more practical stream for assessment.
- Mainstem Garcia. Surveys of summer condition, particularly for temperature and oxygen. While the mainstem channel is quite changeable, it is monitored through a set of cross-sections. V*, LWD, and canopy measures are not particularly suited to the mainstem. Cross-sections should, however, be augmented by longitudinal profiles, to see cumulative effects of timber, gravel extraction and range activities on the mainstem.
- Redwood Creek, Pardaloe watershed. This creek is the closest this watershed has to baseline conditions. While a joint hillslope-instream monitoring program would be hard to implement in anticipation of a harvest, it would be frustrated with this sampling problem, it is important to understand native conditions in these ecosystems and river basins.

Choosing among these as targets for joint monitoring efforts requires the input of timber interests, the Department of Forestry and the RCD. It is clear that joint monitoring for hillslope processes requires both land that has, recently, been harvested, and land that will, soon, be harvested.

The mainstem Garcia, while important, does not fit the correct scale. The scale of the river does not match many of the protocols recommended within the IMP, apart from fishery surveys. The mainstem should be reviewed for bottleneck conditions that would

restrict the validity of the habitat hypothesis, and needs to be monitored for significant point source or STC sediment inputs.

CDF's LTMP should look for recently harvested and soon to be harvested areas with known habitat and clearly good or bad conditions, such as Whitlow, North Fork, South Fork and Graphite Creeks. Control streams should be considered. Evaluating these individual streams would begin to answer questions about hillslope-stream connections for sediment and other timber-related impacts, but in no way evaluate sediment source identification or fisheries reduction in the larger watershed.

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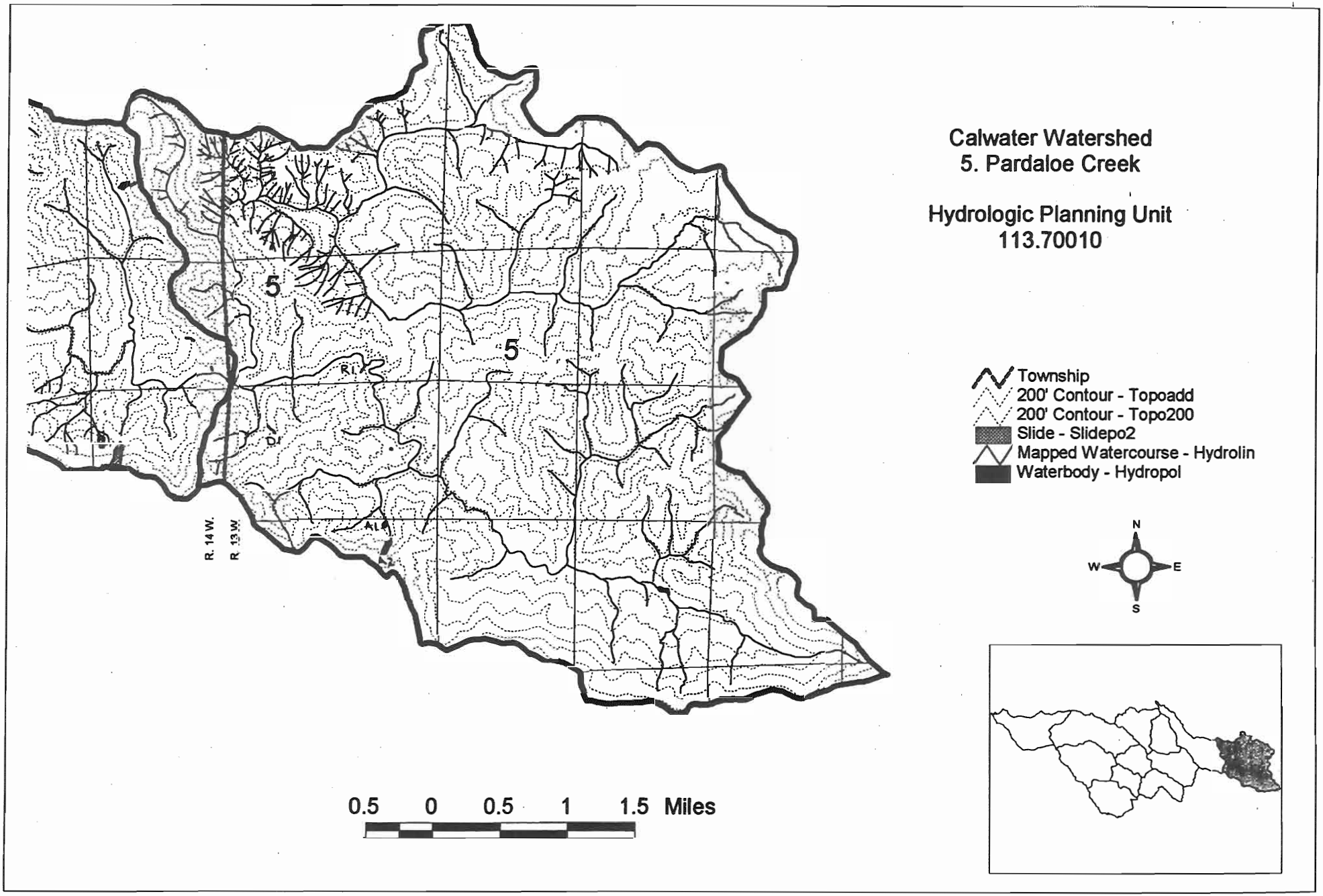
# *APPENDIX A.*

# *LOCATION AND VOLUMES OF MASS WASTING SITES*

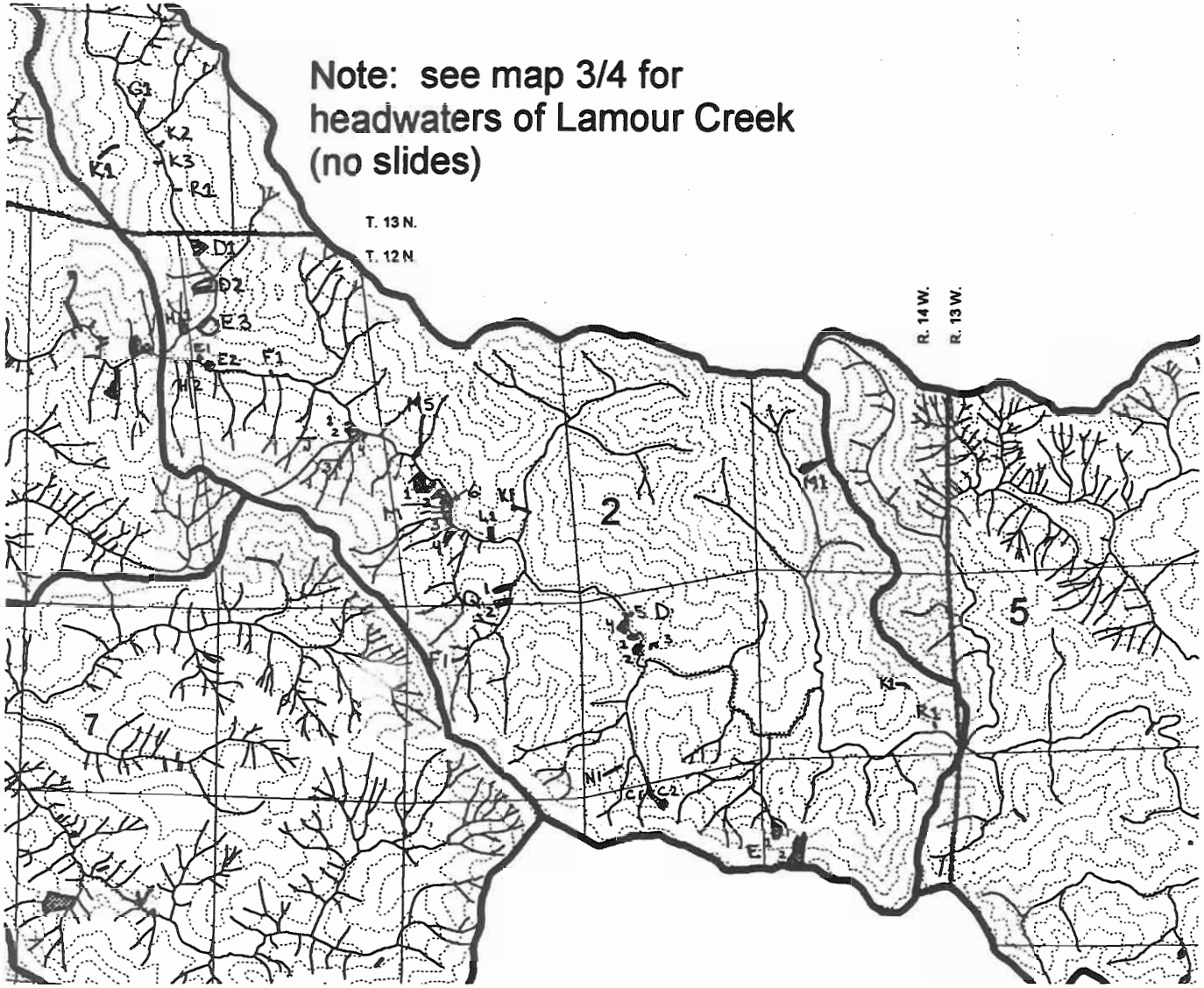
# Garcia Watershed - Basins



# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 5--Pardaloe Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 78 | T12N | R13W | 7 | R | 1 | 5 | SR | D | Y | 4 | R | C | | L | |
| 78 | T12N | R13W | 19 | A | 2 | 5 | SR | D | Y | 1 | N | P | | L | |
| 78 | T12N | R13W | 19 | A | 1 | 5 | SR | D | Y | 1 | N | P | | M | |

# Garcia Watershed - Basins



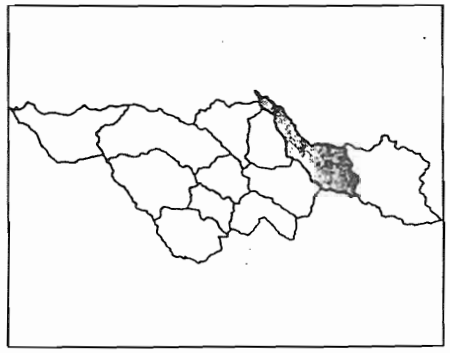

Calwater Watershed
2. Lamour Creek

Hydrologic Planning Unit
113.70011

Township
200' Contour - Topoadd
200' Contour - Topo200
Slide - Slidepo2
Mapped Watercourse - Hydrolin
Waterbody - Hydropol

N
W
E
S

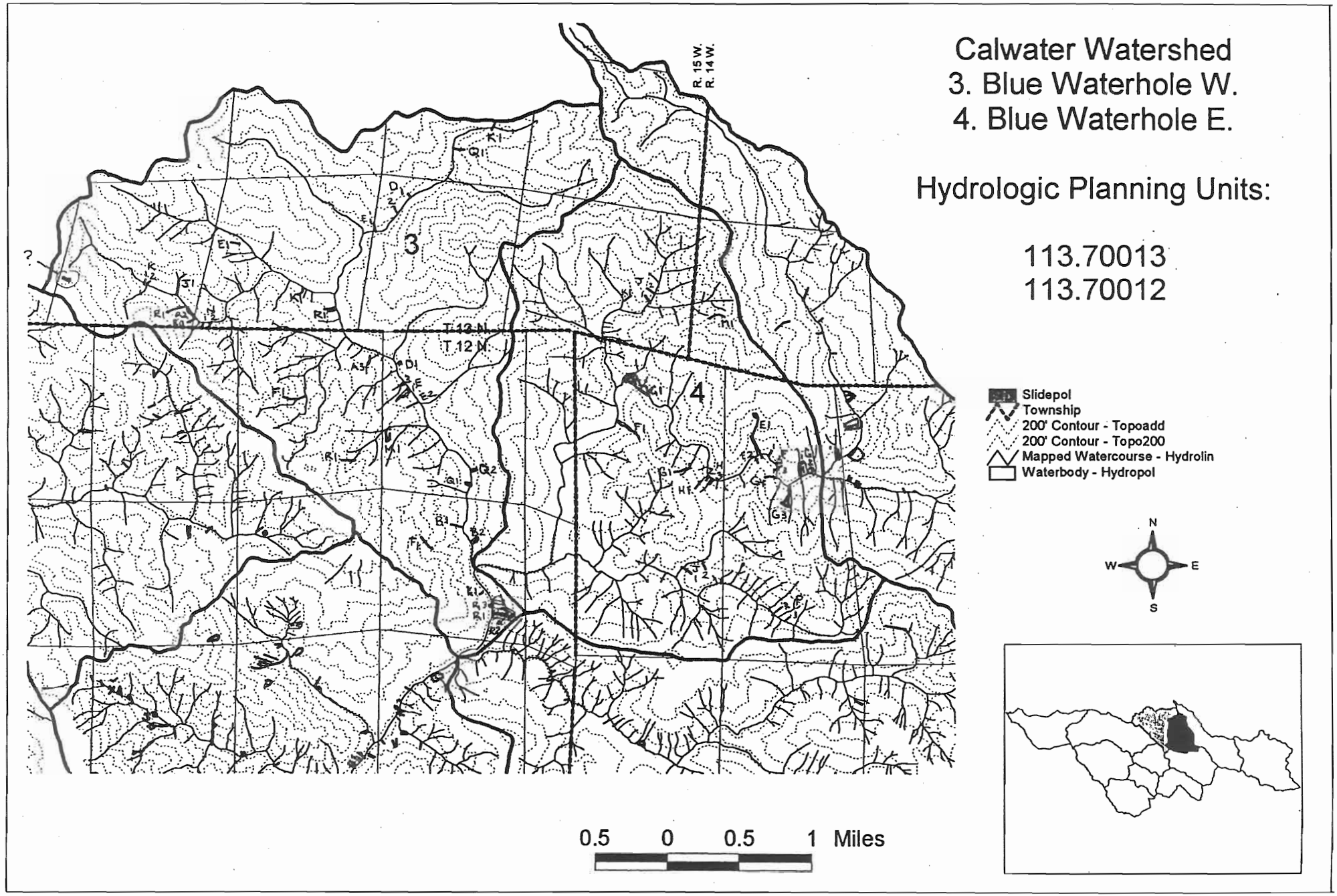
0.5 0 0.5 1 1.5 2 Miles



# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 2--Larmour Cr.

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T13N | R14W | 31 | K | 1 | 2 | DF | P | Y | 2 | R | C | S | | |
| 65 | T12N | R14W | 3 | M | 1 | 2 | LPD | D | Y | 4 | H/IG | C | XL | XL | L |
| 65 | T12N | R14W | 3 | M | 2 | 2 | SR | D | Y | 4 | H/IG | P | XL | L | |
| 65 | T12N | R14W | 3 | M | 3 | 2 | SR | D | Y | 4 | N/IG | C | XL | M | |
| 65 | T12N | R14W | 3 | M | 4 | 2 | SR | P | N | | R | C | M | S | |
| 65 | T12N | R14W | 3 | Q | 1 | 2 | SR | D | Y | 2 | H | C | XL | XL | |
| 65 | T12N | R14W | 3 | Q | 2 | 2 | SR | D | Y | 2 | H | P | XL | L | |
| 65 | T12N | R14W | 4 | E | 2 | 2 | SR | D | Y | 4 | N | D | M | M | M |
| 65 | T12N | R14W | 4 | J | 1 | 2 | SR | D | Y | 4 | H | C | S | | |
| 65 | T12N | R14W | 4 | J | 2 | 2 | SR | D | Y | 4 | H | C | S | | |
| 65 | T12N | R14W | 5 | H | 1 | 2 | SR | D | Y | 2 | N/IG | C | L | | L |
| 65 | T12N | R14W | 5 | H | 2 | 2 | SR | Q | Y | 4 | H | P | M | L | |
| 78 | T12N | R14W | 3 | M | 5 | 2 | DF | Q | Y | 4 | R | C | | L | |
| 78 | T12N | R14W | 4 | J | 3 | 2 | DF | P | Y | 4 | R | P | | L | |
| 78 | T12N | R14W | 3 | K | 1 | 2 | LPD | P | N | | H | P | | L | |
| 78 | T12N | R14W | 4 | D | 1 | 2 | LPD | D | Y | 3 | N | D | | XL | XL |
| 78 | T12N | R14W | 1 | M | 1 | 2 | SR | P | N | | N | D | | L | |
| 78 | T12N | R14W | 11 | D | 2 | 2 | SR | D | Y | 4 | N | C | | L | L |
| 78 | T12N | R14W | 12 | K | 1 | 2 | SR | D | Y | 1 | N | P | | L | |
| 78 | T12N | R14W | 13 | E | 1 | 2 | SR | D | Y | 1 | N | C | | L | |
| 78 | T12N | R14W | 14 | C | 2 | 2 | SR | P | Y | 1 | R | C | | L | L |
| 78 | T12N | R14W | 4 | D | 2 | 2 | SR | P | Y | 3 | R | P | | L | |
| 78 | T12N | R14W | 4 | E | 1 | 2 | SR | D | Y | 4 | N | P | | M | M |
| 78 | T12N | R14W | 11 | D | 1 | 2 | SR | D | Y | 4 | N | C | | M | |
| 78 | T12N | R14W | 11 | D | 3 | 2 | SR | D | Y | 4 | N | C | | M | |
| 78 | T12N | R14W | 11 | D | 4 | 2 | SR | D | Y | 4 | N | C | | M | L |
| 78 | T12N | R14W | 11 | N | 1 | 2 | SR | P | N | | R | C | | M | |
| 78 | T12N | R14W | 14 | C | 1 | 2 | SR | P | Y | 1 | N | C | | S | |
| 78 | T12N | R14W | 12 | R | 1 | 2 | SR | D | Y | 4 | R | P | | S | |
| 78 | T13N | R14W | 31 | R | 1 | 2 | SR | D | Y | 3 | N | P | | S | |
| 78 | T12N | R14W | 13 | E | 2 | 2 | SR | D | N | | R | P | | XL | |
| 96 | T12N | R14W | 3 | M | 6 | 2 | LPD | P | Y | 4 | H | C | | | L |
| 96 | T12N | R14W | 4 | E | 3 | 2 | LPD | D | Y | 2 | R | C | | | L |
| 96 | T12N | R14W | 3 | L | 1 | 2 | SR | D | Y | 4 | N | D | | | L |
| 96 | T12N | R14W | 10 | F | 1 | 2 | SR | P | N | | R | C | | | M |
| 96 | T13N | R14W | 31 | K | 3 | 2 | SR | D | Y | 2 | R | D | | | M |
| 96 | T12N | R14W | 2 | Q | 1 | 2 | SR | D | Y | 4 | R | P | | | S |
| 96 | T12N | R14W | 3 | M | 5 | 2 | SR | D | N | | R | P | | | S |
| 96 | T12N | R14W | 4 | F | 1 | 2 | SR | D | Y | 4 | N | P | | | S |
| 96 | T12N | R14W | 11 | D | 5 | 2 | SR | D | Y | 4 | R | C | | | S |
| 96 | T13N | R14W | 31 | G | 1 | 2 | SR | D | Y | 2 | N | P | | | S |
| 96 | T13N | R14W | 31 | K | 2 | 2 | SR | D | Y | 2 | N | P | | | S |
| 96 | T12N | R14W | 4 | J | 4 | 2 | SR | D | Y | 4 | N | C | | | XL |

# Garcia Watershed - Basins



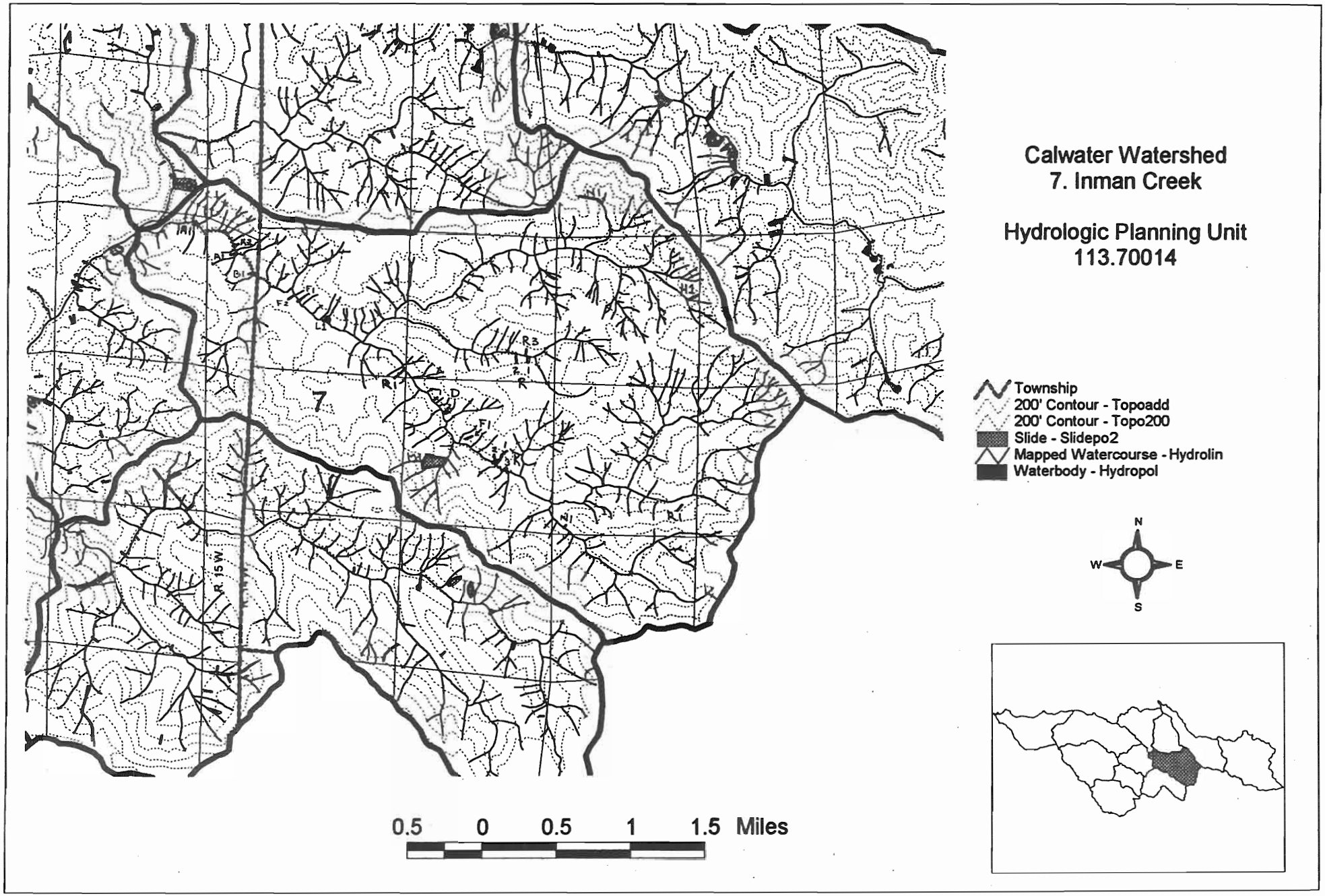
# GARCIA RIVER WATERSHED ASSESSMENT
## APPENDIX A--MASS WASTING INVENTORY DATA
### Calwater Watershed 4--Blue Waterhole E.

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R14W | 5 | E | 1 | 4 | DF | D | Y | 4 | H? | C | L | | |
| 65 | T12N | R14W | 6 | F | 1 | 4 | DF | P | Y | 4 | R | C | L | | |
| 65 | T12N | R14W | 5 | E | 2 | 4 | SR | D | Y | 4 | R | P/C | M | | |
| 65 | T12N | R14W | 5 | P | 1 | 4 | SR | D | Y | 4 | R | C | M | | |
| 65 | T12N | R14W | 6 | H | 1 | 4 | SR | D | Y | 4 | R | C | S | | |
| 65 | T12N | R14W | 6 | H | 2 | 4 | SR | D | Y | 4 | R | C | M | M | |
| 65 | T12N | R14W | 6 | J | 1 | 4 | SR | D | Y | 2 | R | D | L | | |
| 65 | T12N | R14W | 6 | J | 2 | 4 | SR | D | Y | 2 | R | D | M | | |
| 65 | T13N | R15W | 36 | J | 1 | 4 | SR | D | Y | 2 | H | P | L | | |
| 65 | T13N | R15W | 36 | K | 1 | 4 | SR | Q | Y | 2 | R | C | M | | |
| 78 | T12N | R14W | 5 | G | 3 | 4 | DF | P | Y | 4 | R | P | | M | |
| 78 | T12N | R14W | 6 | G | 1 | 4 | DF | P | Y | 2 | R | C | | L | |
| 78 | T12N | R14W | 5 | G | 1 | 4 | LPD | D | Y | 4 | N | P | | XL | XL |
| 78 | T12N | R14W | 5 | G | 2 | 4 | LPD | D | Y | 4 | N | P | | XL | XL |
| 78 | T12N | R14W | 6 | C | 1 | 4 | LPD | P | Y | 4 | H | C | | XL | XL |
| 78 | T12N | R14W | 6 | H | 3 | 4 | SR | P | N | | H | P | | M | |
| 78 | T12N | R14W | 5 | G | 4 | 4 | SR | D | Y | 4 | R | C | | XL | |
| 96 | T12N | R14W | 5 | F | 2 | 4 | SR | D | Y | 4 | R | C | | | S |
| 96 | T12N | R14W | 5 | P | 2 | 4 | SR | D | Y | 2 | R | D | | | L |
| 96 | T13N | R14W | 31 | M | 1 | 4 | SR | D | Y | 1 | N | P | | | L |
| 96 | T12N | R14W | 5 | F | 3 | 4 | SR | D | Y | 4 | R | D | | | M |
| 96 | T12N | R14W | 6 | G | 2 | 4 | SR | D | Y | 4 | N | C | | | M |
| 96 | T13N | R15W | 36 | J | 2 | 4 | SR | P | Y | 2 | R | C | | | M |
| 96 | T12N | R14W | 5 | F | 1 | 4 | SR | D | Y | 4 | R | C | | | M |

# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 3--Blue Waterhole W.

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T13N | R15W | 33 | J | 1 | 3 | DF | D | Y | 2 | R | C | L | | |
| 65 | T13N | R15W | 33 | R | 1 | 3 | DF | P | Y | 2 | H | C | L | | |
| 65 | T12N | R15W | 2 | E | 1 | 3 | LPD | D | Y | 4 | R | P | XL | | |
| 65 | T12N | R15W | 11 | R | 1 | 3 | LPD | D | Y | 4 | H | P | XL | XL | XL |
| 65 | T12N | R15W | 2 | D | 1 | 3 | SR | D | Y | 4 | R | P | M | | |
| 65 | T12N | R15W | 3 | R | 1 | 3 | SR | D | Y | 2 | H | P | M | S | |
| 65 | T12N | R15W | 11 | B | 1 | 3 | SR | P | Y | 4 | R | P | M | | |
| 65 | T12N | R15W | 11 | B | 2 | 3 | SR | P | Y | 4 | H/IG | P | XL | L | |
| 65 | T12N | R15W | 11 | K | 1 | 3 | SR | D | N | | R | P | S | | |
| 65 | T13N | R15W | 33 | R | 2 | 3 | SR | D | Y | 2 | R | P | M | M | |
| 65 | T13N | R15W | 34 | E | 1 | 3 | SR | D | N | | H | D | L | | |
| 65 | T13N | R15W | 34 | N | 1 | 3 | SR | D | Y | 2 | R | D | L | L | |
| 65 | T13N | R15W | 34 | N | 2 | 3 | SR | D | Y | 2 | R | D | M | M | |
| 65 | T13N | R15W | 34 | R | 1 | 3 | SR | D | Y | 4 | R | C | L | M | M |
| 78 | T12N | R15W | 11 | R | 2 | 3 | DF | Q | Y | 4 | N | P | | M | |
| 78 | T12N | R15W | 2 | E | 2 | 3 | SR | D | Y | 3 | R | C | | L | |
| 78 | T12N | R15W | 3 | A | 1 | 3 | SR | D | N | | R | P | | M | |
| 78 | T12N | R15W | 11 | R | 3 | 3 | SR | D | Y | 4 | R | P | | M | |
| 78 | T12N | R15W | 2 | M | 1 | 3 | SR | D | Y | 2 | H | D | | XL | |
| 96 | T12N | R15W | 3 | F | 1 | 3 | SR | Q | Y | 1 | H | C | | | L |
| 96 | T13N | R15W | 26 | K | 1 | 3 | SR | D | Y | 2 | R | C | | | L |
| 96 | T13N | R15W | 26 | Q | 1 | 3 | SR | D | Y | 2 | R | P | | | L |
| 96 | T13N | R15W | 33 | R | 3 | 3 | SR | D | Y | 3 | N | P | | | L |
| 96 | T12N | R15W | 2 | E | 3 | 3 | SR | P | Y | 3 | N | C | | | M |
| 96 | T12N | R15W | 11 | F | 1 | 3 | SR | D | N | | N | P | | | M |
| 96 | T13N | R15W | 34 | K | 1 | 3 | SR | P | Y | 3 | N | C | | | M |
| 96 | T13N | R15W | 35 | D | 1 | 3 | SR | D | Y | 3 | R | P | | | M |
| 96 | T13N | R15W | 35 | D | 2 | 3 | SR | D | Y | 3 | R | P | | | M |
| 96 | T13N | R15W | 35 | E | 1 | 3 | SR | P | Y | 3 | R | D | | | M |
| 96 | T12N | R15W | 2 | Q | 2 | 3 | SR | D | Y | 3 | R | C | | | S |
| 96 | T13N | R15W | 33 | K | 1 | 3 | SR | D | Y | 3 | N | P | | | S |
| 96 | T13N | R15W | 33 | K | 2 | 3 | SR | D | Y | 3 | N | P | | | S |

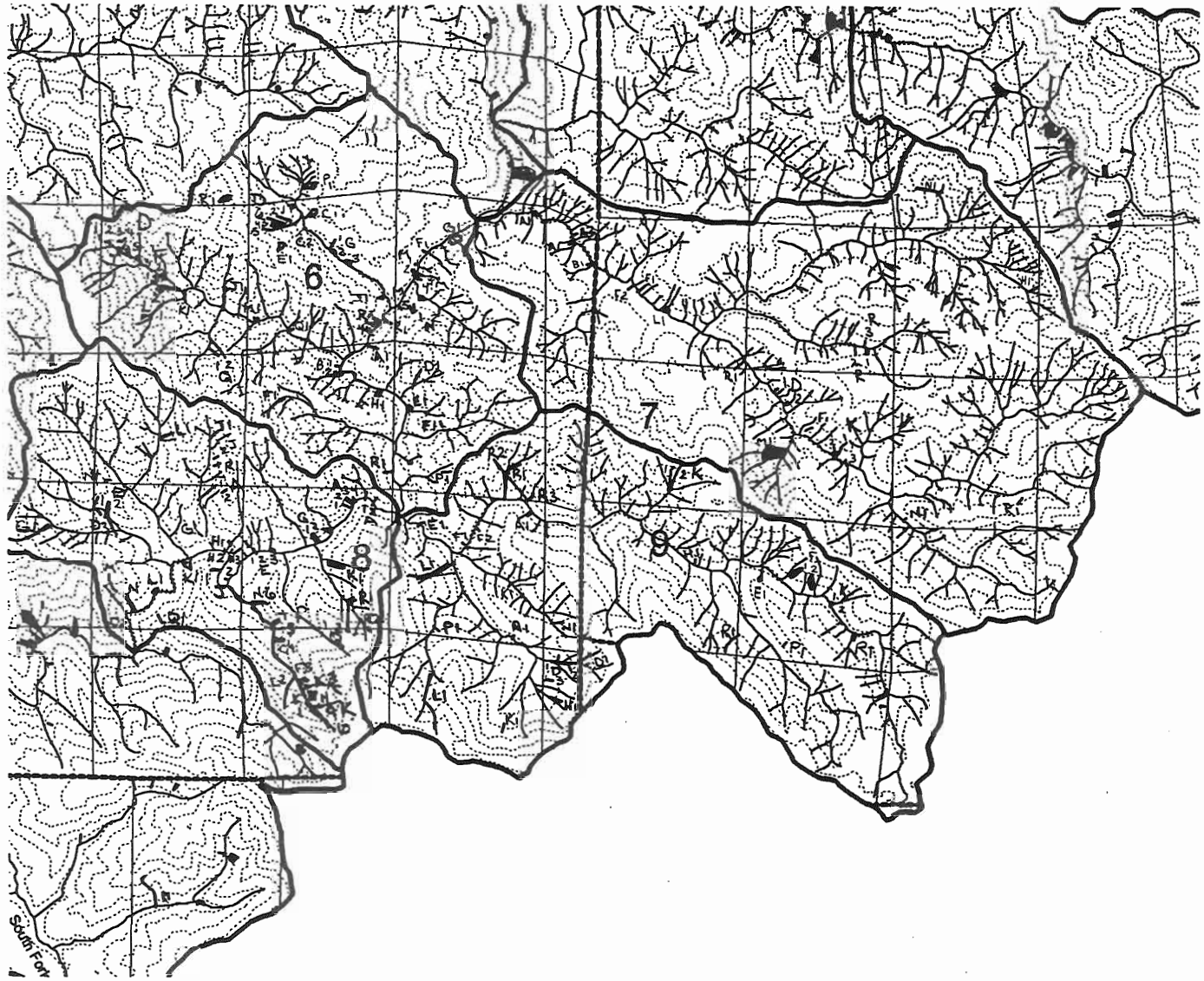
# Garcia Watershed - Basins



# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 7--Inman Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R14W | 4 | N | 1 | 7 | SR | D | Y | 1 | H | P | L | | |
| 65 | T12N | R14W | 7 | F | 1 | 7 | SR | D | Y | 3 | R | C | S | | |
| 65 | T12N | R14W | 8 | R | 1 | 7 | SR | P | Y | 2 | R | P | M | S | |
| 65 | T12N | R15W | 13 | A | 1 | 7 | SR | D | Y | 3 | R | C | M | | |
| 65 | T12N | R15W | 14 | A | 1 | 7 | SR | D | Y | 4 | R | P | S | M | M |
| 78 | T12N | R14W | 8 | R | 2 | 7 | DF | D | Y | 2 | R | P | | M | |
| 78 | T12N | R14W | 9 | H | 1 | 7 | SR | D | Y | 2 | R | D | | M | |
| 78 | T12N | R15W | 13 | A | 2 | 7 | SR | D | Y | 4 | R | P | | M | |
| 78 | T12N | R15W | 13 | B | 1 | 7 | SR | D | Y | 3 | R | P | | M | |
| 78 | T12N | R14W | 16 | R | 1 | 7 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 14 | A | 2 | 7 | SR | D | Y | 4 | R | C | | S | |
| 96 | T12N | R14W | 17 | M | 1 | 7 | LPD | D | Y | 2 | R | C | | | XL |
| 96 | T12N | R14W | 7 | L | 1 | 7 | SR | D | Y | 4 | R | C | | | L |
| 96 | T12N | R14W | 17 | K | 2 | 7 | SR | D | Y | 4 | R | C | | | L |
| 96 | T12N | R14W | 17 | K | 3 | 7 | SR | D | Y | 4 | R | P | | | L |
| 96 | T12N | R14W | 7 | R | 1 | 7 | SR | D | N | | H | P | | | M |
| 96 | T12N | R14W | 8 | R | 3 | 7 | SR | D | Y | 2 | H | D | | | M |
| 96 | T12N | R14W | 17 | D | 2 | 7 | SR | D | Y | 4 | R | C | | | M |
| 96 | T12N | R14W | 17 | F | 1 | 7 | SR | D | N | | R | P | | | M |
| 96 | T12N | R14W | 17 | K | 1 | 7 | SR | D | Y | 4 | R | C | | | M |
| 96 | T12N | R14W | 7 | F | 2 | 7 | SR | P | Y | 4 | R | C | | | S |
| 96 | T12N | R14W | 16 | N | 1 | 7 | SR | D | Y | 3 | R | P | | | S |
| 96 | T12N | R14W | 17 | D | 1 | 7 | SR | D | Y | 4 | R | D | | | S |

# Garcia Watershed - Basins



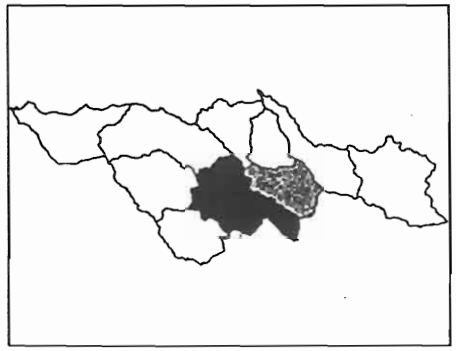

Calwater Watershed
6. Hot Springs Creek
7. Inman Creek
8. Graphite Creek South
9. Signal Creek

Hydrologic Planning Units:
(in similar order)
113.70021
113.70014
113.70022
113.70020

Slidepol
Township
200' Contour - Topoadd
200' Contour - Topo200
Mapped Watercourse - Hydrolin
Waterbody - Hydropol

N
W E
S

0.5 0 0.5 1 1.5 Miles



# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 9--Signal Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 26 | L | 1 | 9 | DF | D | Y | 4 | R | C | L | L | |
| 65 | T12N | R15W | 35 | L | 1 | 9 | DF | P | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 36 | D | 1 | 9 | DF | D | Y | 2 | R | C | M | L | |
| 65 | T12N | R14W | 19 | R | 1 | 9 | SR | D | N | | R | C | L | | |
| 65 | T12N | R14W | 20 | E | 1 | 9 | SR | P | N | | N | D | L | L | |
| 65 | T12N | R15W | 25 | N | 1 | 9 | SR | D | Y | 1 | R | D | L | | |
| 65 | T12N | R15W | 26 | A | 1 | 9 | SR | D | Y | 3 | R | C | S | | |
| 65 | T12N | R15W | 26 | F | 1 | 9 | SR | P | Y | 3 | R | P | S | | |
| 65 | T12N | R15W | 26 | K | 1 | 9 | SR | D | Y | 2 | R | D | S | | |
| 65 | T12N | R15W | 26 | P | 1 | 9 | SR | P | Y | 2 | R | C | M | | |
| 65 | T12N | R15W | 26 | R | 1 | 9 | SR | D | Y | 3 | R | D | S | | |
| 65 | T12N | R15W | 36 | H | 1 | 9 | SR | D | Y | 1 | R | C | L | | |
| 78 | T12N | R15W | 23 | R | 1 | 9 | DF | Q | Y | 4 | R | C | | L | |
| 78 | T12N | R15W | 35 | K | 1 | 9 | SR | P | Y | 1 | R | C | | M | |
| 78 | T12N | R15W | 36 | D | 2 | 9 | SR | D | N | | R | C | | M | |
| 78 | T12N | R15W | 36 | D | 3 | 9 | SR | D | Y | 2 | R | C | | M | |
| 78 | T12N | R14W | 30 | D | 1 | 9 | SR | D | Y | 1 | R | P | | S | |
| 78 | T12N | R15W | 26 | E | 1 | 9 | SR | D | Y | 4 | R | P | | S | |
| 78 | T12N | R15W | 26 | F | 2 | 9 | SR | D | Y | 4 | R | C | | S | |
| 96 | T12N | R14W | 18 | K | 1 | 9 | DF | Q | N | | H | P | | | S |
| 96 | T12N | R14W | 18 | K | 2 | 9 | DF | Q | N | | H | P | | | S |
| 96 | T12N | R14W | 20 | F | 1 | 9 | SR | D | N | | H | C | | | L |
| 96 | T12N | R14W | 20 | F | 2 | 9 | SR | D | N | | H | D | | | L |
| 96 | T12N | R14W | 19 | H | 1 | 9 | SR | D | Y | 3 | R | P | | | S |
| 96 | T12N | R14W | 20 | P | 1 | 9 | SR | D | N | | H | D | | | S |
| 96 | T12N | R14W | 20 | R | 1 | 9 | SR | D | Y | 3 | R | C | | | S |
| 96 | T12N | R15W | 23 | R | 2 | 9 | SR | D | N | | N | D | | | S |
| 96 | T12N | R15W | 23 | R | 3 | 9 | SR | D | N | | R | D | | | S |
| 96 | T12N | R14W | 29 | A | 1 | 9 | SR | D | N | | R | C | | | S |

# GARCIA RIVER WATERSHED ASSESSMENT
## APPENDIX A--MASS WASTING INVENTORY DATA
### Calwater Watershed 6--Hot Springs Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 16 | J | 1 | 6 | DF | P | Y | 2 | R | C | L | L | |
| 65 | T12N | R15W | 16 | L | 1 | 6 | DF | P | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 14 | M | 5 | 6 | SR | P | Y | 2 | H | P | S | | |
| 65 | T12N | R15W | 14 | M | 2 | 6 | SR | D | Y | 5 | R | P | S | M | |
| 65 | T12N | R15W | 14 | N | 1 | 6 | SR | P | N | | H/R | P | L | | |
| 65 | T12N | R15W | 14 | N | 2 | 6 | SR | D | Y | 5 | R | P | M | | |
| 65 | T12N | R15W | 15 | C | 1 | 6 | SR | D | Y | 3 | R | C | L | M | |
| 65 | T12N | R15W | 15 | C | 2 | 6 | SR | D | Y | 3 | R | C | L | XL | M |
| 65 | T12N | R15W | 15 | D | 1 | 6 | SR | D | Y | 3 | H | P | L | S | |
| 65 | T12N | R15W | 15 | D | 2 | 6 | SR | D | Y | 2 | H/R | D/P | L | L | |
| 65 | T12N | R15W | 15 | D | 3 | 6 | SR | D | Y | 2 | R | P | M | M | |
| 65 | T12N | R15W | 15 | D | 4 | 6 | SR | D | Y | 2 | R | P | M | M | |
| 65 | T12N | R15W | 15 | D | 5 | 6 | SR | D | Y | 1 | R | C | M | S | |
| 65 | T12N | R15W | 15 | J | 1 | 6 | SR | D | N | | R | C | M | | |
| 65 | T12N | R15W | 15 | R | 1 | 6 | SR | D | Y | 5 | R | C | L | L | L |
| 65 | T12N | R15W | 15 | R | 2 | 6 | SR | D | Y | 5 | H | P | S | S | S |
| 65 | T12N | R15W | 15 | R | 3 | 6 | SR | D | Y | 5 | H | P | M | M | M |
| 65 | T12N | R15W | 15 | R | 4 | 6 | SR | D | Y | 5 | H | P | M | M | M |
| 65 | T12N | R15W | 16 | D | 5 | 6 | SR | P | Y | 2 | H/IG | P | M | L | |
| 65 | T12N | R15W | 16 | K | 1 | 6 | SR | P | Y | 3 | H | C | M | | |
| 65 | T12N | R15W | 22 | B | 1 | 6 | SR | D | Y | 5 | R | C | S | | |
| 65 | T12N | R15W | 22 | B | 2 | 6 | SR | D | Y | 5 | R | C | M | | M |
| 65 | T12N | R15W | 22 | F | 1 | 6 | SR | P | Y | 2 | R | C | M | | |
| 65 | T12N | R15W | 22 | H | 1 | 6 | SR | D | Y | 5 | R | P | L | | |
| 65 | T12N | R15W | 23 | E | 1 | 6 | SR | D | Y | 5 | R | C | L | | XL |
| 78 | T12N | R15W | 14 | M | 3 | 6 | DF | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 14 | G | 1 | 6 | LPD | P | Y | 5 | R | C | | L | L |
| 78 | T12N | R15W | 16 | F | 1 | 6 | LPD | P | Y | 1 | H | C | | M | M |
| 78 | T12N | R15W | 10 | P | 1 | 6 | SR | D | Y | 2 | R | C | | L | L |
| 78 | T12N | R15W | 15 | G | 1 | 6 | SR | D | Y | 3 | H | P | | L | |
| 78 | T12N | R15W | 22 | A | 1 | 6 | SR | D | Y | 5 | H | P | | L | |
| 78 | T12N | R15W | 14 | F | 1 | 6 | SR | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 14 | M | 1 | 6 | SR | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 14 | M | 4 | 6 | SR | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 15 | M | 1 | 6 | SR | D | Y | 3 | H | P | | M | M |
| 78 | T12N | R15W | 16 | D | 2 | 6 | SR | D | Y | 1 | H | P | | M | |
| 78 | T12N | R15W | 16 | D | 6 | 6 | SR | D | Y | 1 | H | P | | M | M |
| 78 | T12N | R15W | 16 | L | 2 | 6 | SR | D | Y | 2 | H | P | | M | |
| 78 | T12N | R15W | 15 | G | 2 | 6 | SR | D | Y | 3 | R | P | | S | |
| 78 | T12N | R15W | 16 | D | 1 | 6 | SR | P | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 16 | D | 3 | 6 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 16 | D | 4 | 6 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 16 | D | 7 | 6 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 23 | P | 1 | 6 | SR | P | N | | R | C | | S | |
| 96 | T12N | R15W | 15 | D | 6 | 6 | SR | P | Y | 1 | N | D | | | L |
| 96 | T12N | R15W | 16 | F | 2 | 6 | SR | D | Y | 1 | H | P | | | L |
| 96 | T12N | R15W | 23 | D | 1 | 6 | SR | P | N | | R | C | | | L |
| 96 | T12N | R15W | 15 | E | 1 | 6 | SR | P | N | | N | P | | | M |
| 96 | T12N | R15W | 15 | G | 3 | 6 | SR | D | Y | 2 | N | C | | | M |
| 96 | T12N | R15W | 22 | R | 1 | 6 | SR | P | Y | 5 | N | P | | | S |
| 96 | T12N | R15W | 23 | F | 1 | 6 | SR | P | Y | 2 | R | C | | | S |
| 96 | T12N | R15W | 9 | R | 1 | 6 | SR | P | N | | N | C | | | XL |

# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 9--Signal Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 26 | L | 1 | 9 | DF | D | Y | 4 | R | C | L | L | |
| 65 | T12N | R15W | 35 | L | 1 | 9 | DF | P | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 36 | D | 1 | 9 | DF | D | Y | 2 | R | C | M | L | |
| 65 | T12N | R14W | 19 | R | 1 | 9 | SR | D | N | | R | C | L | | |
| 65 | T12N | R14W | 20 | E | 1 | 9 | SR | P | N | | N | D | L | L | |
| 65 | T12N | R15W | 25 | N | 1 | 9 | SR | D | Y | 1 | R | D | L | | |
| 65 | T12N | R15W | 26 | A | 1 | 9 | SR | D | Y | 3 | R | C | S | | |
| 65 | T12N | R15W | 26 | F | 1 | 9 | SR | P | Y | 3 | R | P | S | | |
| 65 | T12N | R15W | 26 | K | 1 | 9 | SR | D | Y | 2 | R | D | S | | |
| 65 | T12N | R15W | 26 | P | 1 | 9 | SR | P | Y | 2 | R | C | M | | |
| 65 | T12N | R15W | 26 | R | 1 | 9 | SR | D | Y | 3 | R | D | S | | |
| 65 | T12N | R15W | 36 | H | 1 | 9 | SR | D | Y | 1 | R | C | L | | |
| 78 | T12N | R15W | 23 | R | 1 | 9 | DF | Q | Y | 4 | R | C | | L | |
| 78 | T12N | R15W | 35 | K | 1 | 9 | SR | P | Y | 1 | R | C | | M | |
| 78 | T12N | R15W | 36 | D | 2 | 9 | SR | D | N | | R | C | | M | |
| 78 | T12N | R15W | 36 | D | 3 | 9 | SR | D | Y | 2 | R | C | | M | |
| 78 | T12N | R14W | 30 | D | 1 | 9 | SR | D | Y | 1 | R | P | | S | |
| 78 | T12N | R15W | 26 | E | 1 | 9 | SR | D | Y | 4 | R | P | | S | |
| 78 | T12N | R15W | 26 | F | 2 | 9 | SR | D | Y | 4 | R | C | | S | |
| 96 | T12N | R14W | 18 | K | 1 | 9 | DF | Q | N | | H | P | | | S |
| 96 | T12N | R14W | 18 | K | 2 | 9 | DF | Q | N | | H | P | | | S |
| 96 | T12N | R14W | 20 | F | 1 | 9 | SR | D | N | | H | C | | | L |
| 96 | T12N | R14W | 20 | F | 2 | 9 | SR | D | N | | H | D | | | L |
| 96 | T12N | R14W | 19 | H | 1 | 9 | SR | D | Y | 3 | R | P | | | S |
| 96 | T12N | R14W | 20 | P | 1 | 9 | SR | D | N | | H | D | | | S |
| 96 | T12N | R14W | 20 | R | 1 | 9 | SR | D | Y | 3 | R | C | | | S |
| 96 | T12N | R15W | 23 | R | 2 | 9 | SR | D | N | | N | D | | | S |
| 96 | T12N | R15W | 23 | R | 3 | 9 | SR | D | N | | R | D | | | S |
| 96 | T12N | R14W | 29 | A | 1 | 9 | SR | D | N | | R | C | | | S |

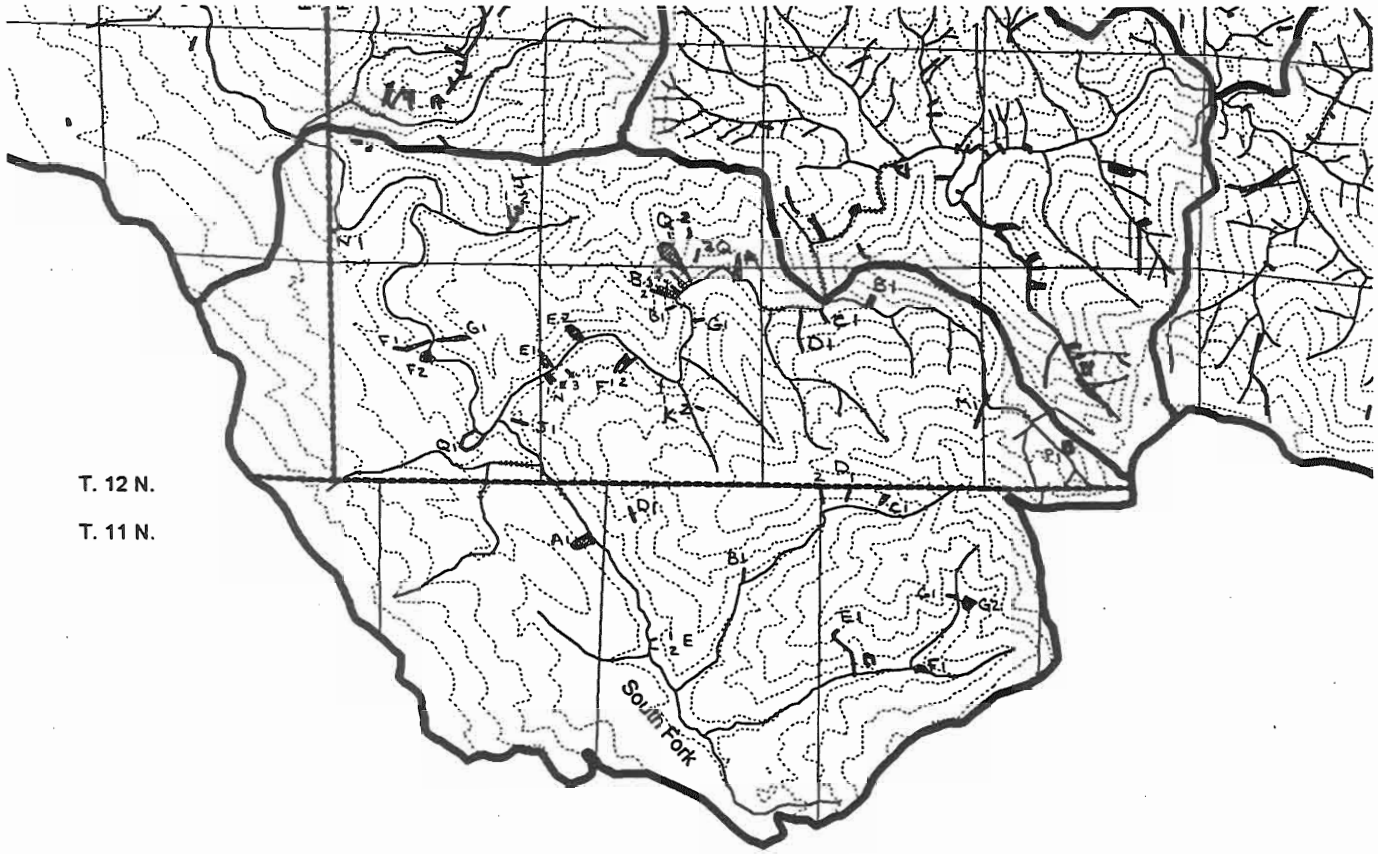
# GARCIA RIVER WATERSHED ASSESSMENT
## APPENDIX A--MASS WASTING INVENTORY DATA
### Calwater Watershed 6--Hot Springs Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 16 | J | 1 | 6 | DF | P | Y | 2 | R | C | L | L | |
| 65 | T12N | R15W | 16 | L | 1 | 6 | DF | P | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 14 | M | 5 | 6 | SR | P | Y | 2 | H | P | S | | |
| 65 | T12N | R15W | 14 | M | 2 | 6 | SR | D | Y | 5 | R | P | S | M | |
| 65 | T12N | R15W | 14 | N | 1 | 6 | SR | P | N | | H/R | P | L | | |
| 65 | T12N | R15W | 14 | N | 2 | 6 | SR | D | Y | 5 | R | P | M | | |
| 65 | T12N | R15W | 15 | C | 1 | 6 | SR | D | Y | 3 | R | C | L | M | |
| 65 | T12N | R15W | 15 | C | 2 | 6 | SR | D | Y | 3 | R | C | L | XL | M |
| 65 | T12N | R15W | 15 | D | 1 | 6 | SR | D | Y | 3 | H | P | L | S | |
| 65 | T12N | R15W | 15 | D | 2 | 6 | SR | D | Y | 2 | H/R | D/P | L | L | |
| 65 | T12N | R15W | 15 | D | 3 | 6 | SR | D | Y | 2 | R | P | M | M | |
| 65 | T12N | R15W | 15 | D | 4 | 6 | SR | D | Y | 2 | R | P | M | M | |
| 65 | T12N | R15W | 15 | D | 5 | 6 | SR | D | Y | 1 | R | C | M | S | |
| 65 | T12N | R15W | 15 | J | 1 | 6 | SR | D | N | | R | C | M | | |
| 65 | T12N | R15W | 15 | R | 1 | 6 | SR | D | Y | 5 | R | C | L | L | L |
| 65 | T12N | R15W | 15 | R | 2 | 6 | SR | D | Y | 5 | H | P | S | S | S |
| 65 | T12N | R15W | 15 | R | 3 | 6 | SR | D | Y | 5 | H | P | M | M | M |
| 65 | T12N | R15W | 15 | R | 4 | 6 | SR | D | Y | 5 | H | P | M | M | M |
| 65 | T12N | R15W | 16 | D | 5 | 6 | SR | P | Y | 2 | H/IG | P | M | L | |
| 65 | T12N | R15W | 16 | K | 1 | 6 | SR | P | Y | 3 | H | C | M | | |
| 65 | T12N | R15W | 22 | B | 1 | 6 | SR | D | Y | 5 | R | C | S | | |
| 65 | T12N | R15W | 22 | B | 2 | 6 | SR | D | Y | 5 | R | C | M | | M |
| 65 | T12N | R15W | 22 | F | 1 | 6 | SR | P | Y | 2 | R | C | M | | |
| 65 | T12N | R15W | 22 | H | 1 | 6 | SR | D | Y | 5 | R | P | L | | |
| 65 | T12N | R15W | 23 | E | 1 | 6 | SR | D | Y | 5 | R | C | L | | XL |
| 78 | T12N | R15W | 14 | M | 3 | 6 | DF | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 14 | G | 1 | 6 | LPD | P | Y | 5 | R | C | | L | L |
| 78 | T12N | R15W | 16 | F | 1 | 6 | LPD | P | Y | 1 | H | C | | M | M |
| 78 | T12N | R15W | 10 | P | 1 | 6 | SR | D | Y | 2 | R | C | | L | L |
| 78 | T12N | R15W | 15 | G | 1 | 6 | SR | D | Y | 3 | H | P | | L | |
| 78 | T12N | R15W | 22 | A | 1 | 6 | SR | D | Y | 5 | H | P | | L | |
| 78 | T12N | R15W | 14 | F | 1 | 6 | SR | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 14 | M | 1 | 6 | SR | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 14 | M | 4 | 6 | SR | D | Y | 5 | R | D | | M | |
| 78 | T12N | R15W | 15 | M | 1 | 6 | SR | D | Y | 3 | H | P | | M | M |
| 78 | T12N | R15W | 16 | D | 2 | 6 | SR | D | Y | 1 | H | P | | M | |
| 78 | T12N | R15W | 16 | D | 6 | 6 | SR | D | Y | 1 | H | P | | M | M |
| 78 | T12N | R15W | 16 | L | 2 | 6 | SR | D | Y | 2 | H | P | | M | |
| 78 | T12N | R15W | 15 | G | 2 | 6 | SR | D | Y | 3 | R | P | | S | |
| 78 | T12N | R15W | 16 | D | 1 | 6 | SR | P | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 16 | D | 3 | 6 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 16 | D | 4 | 6 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 16 | D | 7 | 6 | SR | D | Y | 1 | H | P | | S | |
| 78 | T12N | R15W | 23 | P | 1 | 6 | SR | P | N | | R | C | | S | |
| 96 | T12N | R15W | 15 | D | 6 | 6 | SR | P | Y | 1 | N | D | | | L |
| 96 | T12N | R15W | 16 | F | 2 | 6 | SR | D | Y | 1 | H | P | | | L |
| 96 | T12N | R15W | 23 | D | 1 | 6 | SR | P | N | | R | C | | | L |
| 96 | T12N | R15W | 15 | E | 1 | 6 | SR | P | N | | N | P | | | M |
| 96 | T12N | R15W | 15 | G | 3 | 6 | SR | D | Y | 2 | N | C | | | M |
| 96 | T12N | R15W | 22 | R | 1 | 6 | SR | P | Y | 5 | N | P | | | S |
| 96 | T12N | R15W | 23 | F | 1 | 6 | SR | P | Y | 2 | R | C | | | S |
| 96 | T12N | R15W | 9 | R | 1 | 6 | SR | P | N | | N | C | | | XL |

# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 8--Graphite Creek South

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 27 | G | 1 | 8 | DF | D | Y | 5 | R | D | M | M | M |
| 65 | T12N | R15W | 28 | M | 1 | 8 | DF | D | Y | 5 | R | P | S | | |
| 65 | T12N | R15W | 28 | N | 1 | 8 | DF | D | N | | R | P | M | M | |
| 65 | T12N | R15W | 29 | G | 1 | 8 | DF | D | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 34 | K | 1 | 8 | DF | P | Y | 5 | R | C | XL | | |
| 65 | T12N | R15W | 34 | L | 2 | 8 | DF | Q | Y | 2 | R | C | M | | |
| 65 | T12N | R15W | 21 | L | 1 | 8 | SR | D | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 21 | J | 1 | 8 | SR | D | Y | 2 | R | C | S | | |
| 65 | T12N | R15W | 27 | A | 1 | 8 | SR | D | Y | 5 | R | C | XL | XL | |
| 65 | T12N | R15W | 27 | A | 2 | 8 | SR | D | Y | 5 | R | C | L | M | |
| 65 | T12N | R15W | 27 | B | 1 | 8 | SR | D | Y | 5 | R | C | M | M | |
| 65 | T12N | R15W | 27 | B | 2 | 8 | SR | D | Y | 5 | R | C | M | S | |
| 65 | T12N | R15W | 27 | B | 3 | 8 | SR | D | Y | 5 | R | C | M | M | |
| 65 | T12N | R15W | 27 | B | 4 | 8 | SR | D | Y | 5 | R | C | S | | |
| 65 | T12N | R15W | 27 | N | 6 | 8 | SR | D | Y | 5 | R | C/P | L | L | |
| 65 | T12N | R15W | 27 | P | 5 | 8 | SR | D | Y | 2 | R | P | L | L | |
| 65 | T12N | R15W | 27 | R | 1 | 8 | SR | D | Y | 1 | H | P | L | M | |
| 65 | T12N | R15W | 28 | A | 1 | 8 | SR | P | Y | 2 | R | D | S | | |
| 65 | T12N | R15W | 28 | G | 1 | 8 | SR | D | Y | 2 | R | C | L | | |
| 65 | T12N | R15W | 28 | J | 1 | 8 | SR | D | Y | 5 | H | P | M | | |
| 65 | T12N | R15W | 34 | C | 4 | 8 | SR | D | Y | 2 | R | P | M | S | |
| 65 | T12N | R15W | 34 | K | 3 | 8 | SR | D | Y | 2 | R | D | M | | |
| 65 | T12N | R15W | 28 | J | 2 | 8 | SR | D | Y | 5 | R | P | S | | |
| 78 | T12N | R15W | 27 | K | 1 | 8 | DF | D | N | | R | C | | L | M |
| 78 | T12N | R15W | 27 | Q | 2 | 8 | DF | D | Y | 1 | R | P | | L | |
| 78 | T12N | R15W | 28 | D | 1 | 8 | DF | P | Y | 2 | H | P | | XL | |
| 78 | T12N | R15W | 28 | D | 2 | 8 | DF | D | Y | 2 | H | P | | XL | |
| 78 | T12N | R15W | 34 | F | 8 | 8 | DF | D | Y | 2 | R | C | | L | M |
| 78 | T12N | R15W | 34 | K | 10 | 8 | DF | P | Y | 2 | R | C | | L | |
| 78 | T12N | R15W | 28 | H | 2 | 8 | SR | D | N | | R | P | | L | |
| 78 | T12N | R15W | 27 | E | 2 | 8 | SR | D | Y | 5 | R | P | | M | M |
| 78 | T12N | R15W | 27 | G | 2 | 8 | SR | D | Y | 5 | H | D | | M | |
| 78 | T12N | R15W | 27 | P | 7 | 8 | SR | D | Y | 2 | H | P | | M | L |
| 78 | T12N | R15W | 27 | Q | 1 | 8 | SR | D | Y | 2 | R | P | | M | |
| 78 | T12N | R15W | 27 | R | 1 | 8 | SR | D | Y | 1 | R | P | | M | |
| 78 | T12N | R15W | 28 | Q | 1 | 8 | SR | D | N | | R | C | | M | |
| 78 | T12N | R15W | 34 | G | 1 | 8 | SR | D | N | | R | C | | M | |
| 78 | T12N | R15W | 28 | H | 1 | 8 | SR | D | Y | 5 | H | C | | S | |
| 78 | T12N | R15W | 33 | C | 2 | 8 | SR | D | N | | H | P | | S | |
| 78 | T12N | R15W | 34 | K | 9 | 8 | SR | P | Y | 2 | R | C | | S | |
| 96 | T12N | R15W | 28 | H | 3 | 8 | SR | D | Y | 5 | R | D | | | L |
| 96 | T12N | R15W | 21 | R | 1 | 8 | SR | P | N | | R | C | | | M |
| 96 | T12N | R15W | 28 | D | 3 | 8 | SR | P | Y | 2 | R | C | | | M |
| 96 | T12N | R15W | 28 | L | 1 | 8 | SR | D | Y | 5 | R | C | | | M |
| 96 | T12N | R15W | 21 | J | 2 | 8 | SR | P | N | | R | C | | | S |
| 96 | T12N | R15W | 21 | N | 1 | 8 | SR | D | N | | R | C | | | S |
| 96 | T12N | R15W | 27 | E | 3 | 8 | SR | D | Y | 5 | N | C | | | S |
| 96 | T12N | R15W | 28 | A | 2 | 8 | SR | D | N | | H | C | | | S |
| 96 | T12N | R15W | 28 | K | 1 | 8 | SR | Q | Y | 5 | N | P | | | XL |
| 96 | T12N | R15W | 34 | K | 11 | 8 | SR | D | N | | R | P | | | XL |

# Garcia Watershed - Basins



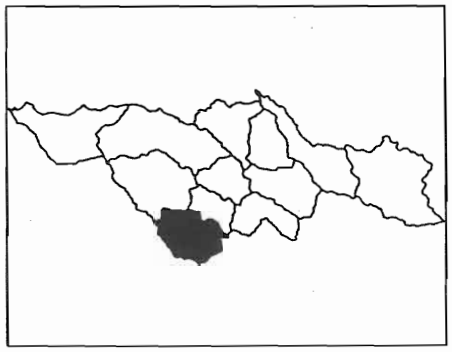

Calwater Watershed
10. South Fork Garcia

Hydrologic Planning Unit
113.70023

Township
200' Contour - Topoadd
200' Contour - Topo200
Slide - Slidepo2
Mapped Watercourse - Hydrolin
Waterbody - Hydropol

N
W E
S

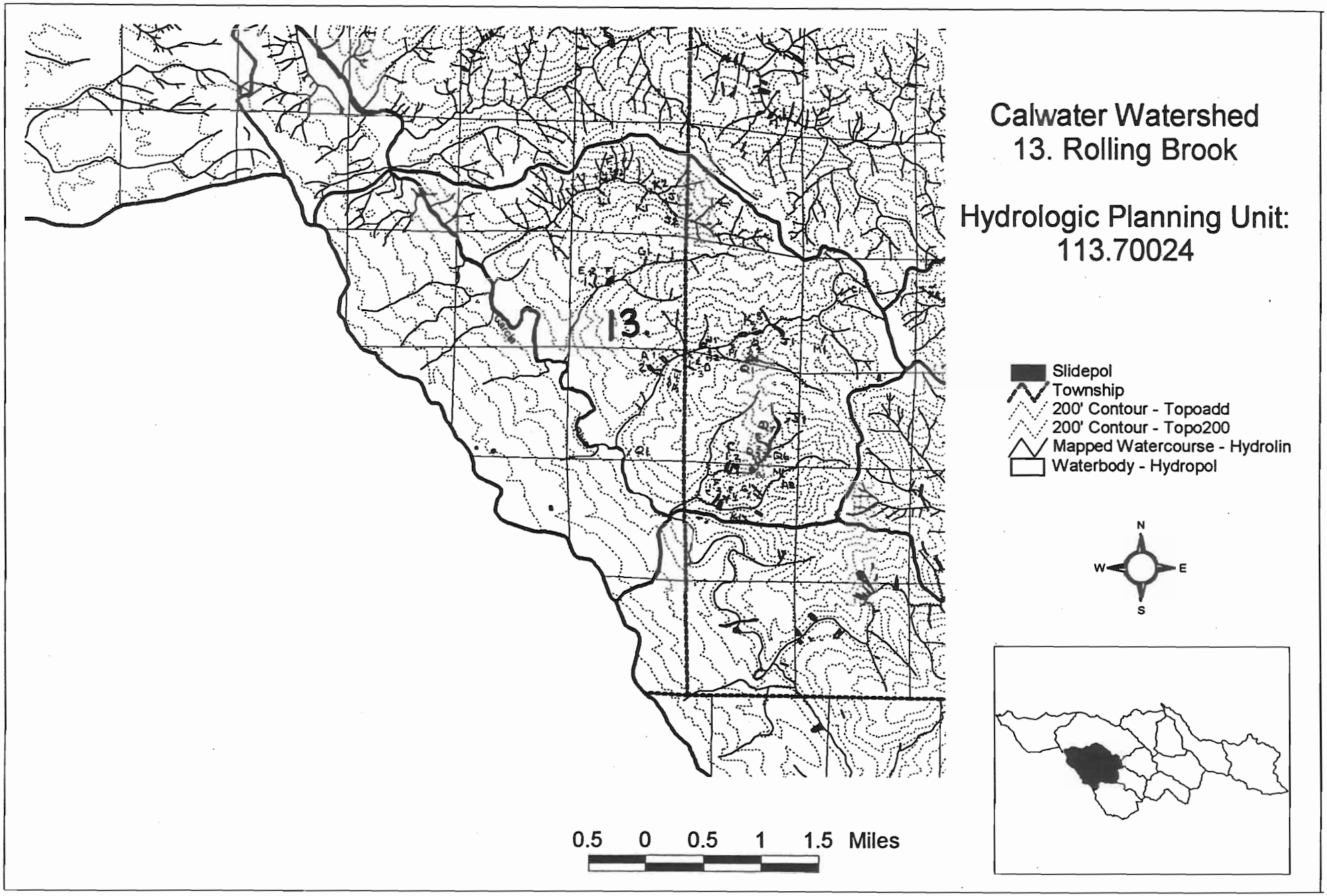
0.5 0 0.5 1 1.5 Miles



# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 10--South Fork Garcia Creek

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T11N | R15W | 3 | E | 1 | 10 | DF | D | Y | 3 | H | C | XL | | |
| 65 | T12N | R15W | 32 | K | 1 | 10 | DF | D | Y | 5 | R | C | M | | |
| 65 | T12N | R15W | 33 | D | 1 | 10 | DF | P | Y | 5 | R | C | M | | |
| 65 | T12N | R15W | 34 | M | 1 | 10 | DF | D | Y | 2 | R | C | M | | |
| 65 | T12N | R15W | 31 | Q | 1 | 10 | LPD | D | Y | 5 | H | P | XL | | |
| 65 | T11N | R15W | 3 | C | 1 | 10 | SR | P | N | | R | P | S | S | |
| 65 | T11N | R15W | 4 | B | 1 | 10 | SR | D | Y | 3 | R/H | P | M | | |
| 65 | T11N | R15W | 3 | J | 1 | 10 | SR | D | Y | 3 | R/IG | P | M | | |
| 65 | T11N | R15W | 5 | A | 1 | 10 | SR | D | Y | 3 | H/R | P | M | | |
| 65 | T12N | R15W | 29 | Q | 1 | 10 | SR | D | Y | 5 | R | C | L | | |
| 65 | T12N | R15W | 31 | F | 1 | 10 | SR | D | Y | 5 | R | C | M | | |
| 65 | T12N | R15W | 31 | J | 1 | 10 | SR | D | N | 5 | R | D | S | | |
| 65 | T12N | R15W | 32 | A | 1 | 10 | SR | D | N | | H | C | M | M | |
| 65 | T12N | R15W | 32 | B | 1 | 10 | SR | D | Y | 5 | H | C | S | | |
| 65 | T12N | R15W | 32 | B | 2 | 10 | SR | D | Y | 5 | R | C | M | S | |
| 65 | T12N | R15W | 32 | B | 3 | 10 | SR | D | Y | 5 | H | C | S | S | |
| 65 | T12N | R15W | 32 | B | 4 | 10 | SR | D | Y | 5 | H | C | S | | |
| 65 | T12N | R15W | 32 | B | 5 | 10 | SR | D | Y | 5 | H | C | S | S | |
| 65 | T12N | R15W | 32 | E | 1 | 10 | SR | Q | Y | 5 | H? | P | M | | |
| 65 | T12N | R15W | 32 | E | 2 | 10 | SR | D | Y | 5 | H | C | M | | |
| 65 | T12N | R15W | 32 | F | 1 | 10 | SR | D | Y | 5 | R | C | M | L | |
| 65 | T12N | R15W | 32 | F | 2 | 10 | SR | D | Y | 5 | R? | C | L | | |
| 65 | T12N | R15W | 32 | N | 1 | 10 | SR | D | Y | 5 | R | P | L | | |
| 65 | T12N | R15W | 32 | N | 2 | 10 | SR | D | Y | 5 | R | P | M | | |
| 65 | T12N | R15W | 32 | N | 3 | 10 | SR | D | N | | R | D | M | | |
| 65 | T12N | R15W | 33 | C | 1 | 10 | SR | D | Y | 5 | H | C | S | | |
| 78 | T12N | R15W | 31 | F | 1 | 10 | LPD | D | Y | 5 | R | C | | XL | |
| 78 | T11N | R15W | 3 | D | 2 | 10 | SR | D | N | | H | P | | M | |
| 78 | T11N | R15W | 4 | E | 1 | 10 | SR | D | Y | 3 | R | C | | M | |
| 78 | T12N | R15W | 30 | J | 2 | 10 | SR | d | Y | 1 | R | C | | M | |
| 78 | T12N | R15W | 31 | G | 1 | 10 | SR | P | N | | R | C | | M | |
| 78 | T12N | R15W | 33 | B | 1 | 10 | SR | D | Y | 2 | H | P | | M | M |
| 78 | T11N | R15W | 3 | D | 1 | 10 | SR | P | N | | R | P | | S | |
| 78 | T11N | R15W | 3 | G | 1 | 10 | SR | D | Y | 2 | H | P | | S | |
| 78 | T12N | R15W | 32 | K | 1 | 10 | SR | P | N | | R | P | | S | |
| 78 | T11N | R15W | 4 | E | 2 | 10 | SR | D | Y | 3 | R | C | | S | |
| 78 | T12N | R15W | 30 | J | 1 | 10 | SR | d | Y | 1 | R | C | | S | |
| 96 | T12N | R15W | 30 | N | 1 | 10 | DF | D | Y | 5 | N | C | | | L |
| 96 | T12N | R15W | 34 | P | 1 | 10 | SR | P | N | | R | P | | | L |
| 96 | T11N | R15W | 3 | F | 1 | 10 | SR | D | Y | 1 | R | P | | | M |
| 96 | T11N | R15W | 3 | G | 2 | 10 | SR | D | Y | 1 | N | D | | | M |
| 96 | T12N | R15W | 32 | G | 1 | 10 | SR | D | Y | 5 | N | P | | | M |
| 96 | T11N | R15W | 4 | D | 1 | 10 | SR | D | Y | 2 | R | P | | | S |
| 96 | T12N | R15W | 29 | Q | 2 | 10 | SR | D | Y | 1 | N | P | | | S |
| 96 | T12N | R15W | 29 | Q | 3 | 10 | SR | D | Y | 2 | H | P | | | S |

# Garcia Watershed - Basins



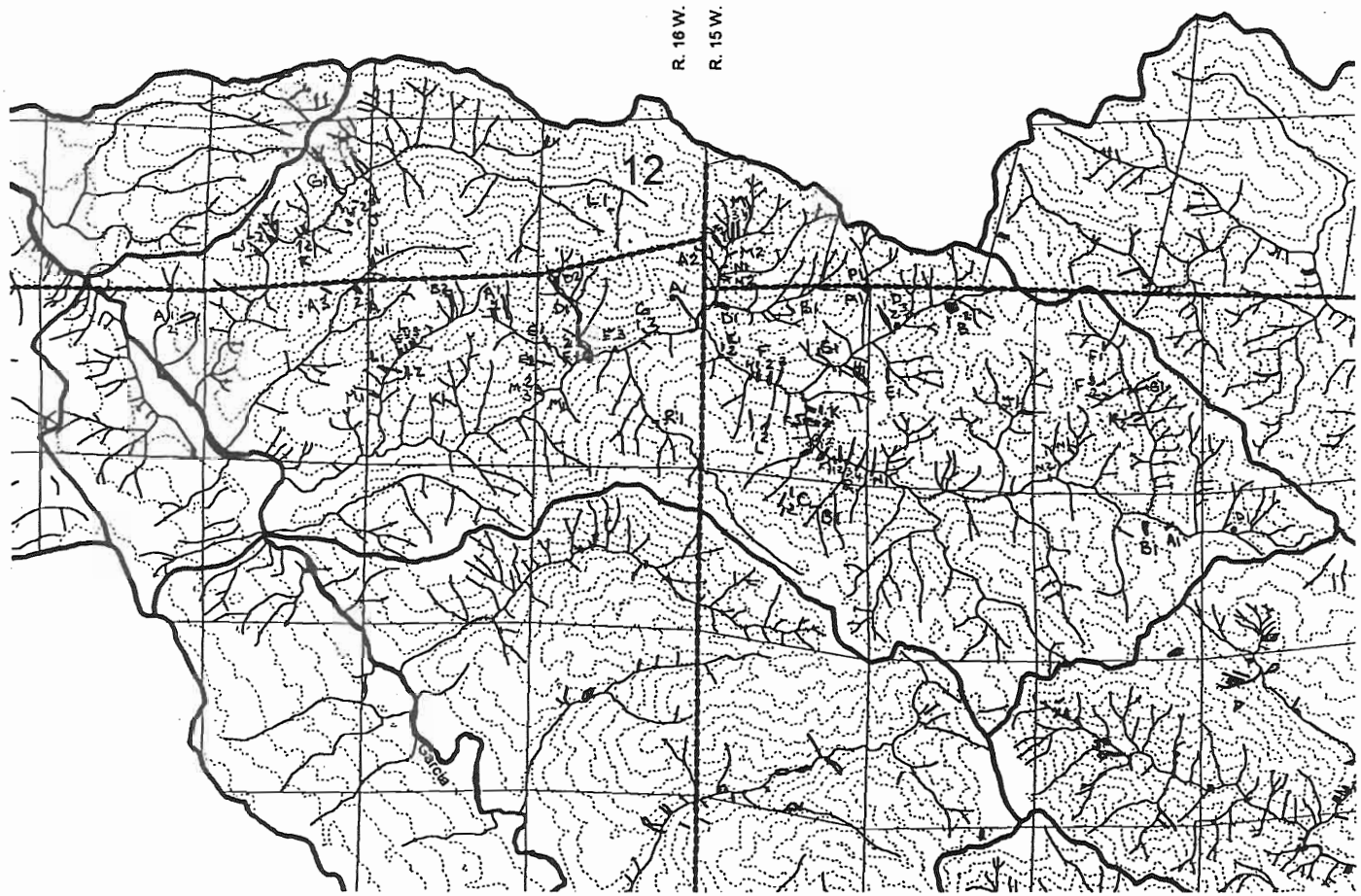
# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 13--Rolling Brook

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 19 | Q | 1 | 13 | DF | P | Y | 2 | R | C | XL | | |
| 65 | T12N | R15W | 18 | J | 1 | 13 | SR | D | Y | 3 | R | C | M | M | |
| 65 | T12N | R15W | 19 | Q | 2 | 13 | SR | D | Y | 2 | R | D | M | | |
| 65 | T12N | R15W | 19 | Q | 3 | 13 | SR | D | Y | 2 | R | D | S | | |
| 65 | T12N | R15W | 19 | Q | 4 | 13 | SR | D | Y | 2 | R | D | M | | |
| 65 | T12N | R16W | 24 | A | 4 | 13 | SR | D | N | | R | D | S | | |
| 65 | T12N | R15W | 30 | A | 1 | 13 | SR | D | Y | 2 | R | C | S | | |
| 65 | T12N | R15W | 30 | A | 2 | 13 | SR | D | Y | 2 | R | D | M | | |
| 65 | T12N | R15W | 30 | B | 1 | 13 | SR | D | Y | 2 | R | D | M | | |
| 65 | T12N | R15W | 30 | C | 1 | 13 | SR | D | Y | 2 | R | P | L | XL | |
| 78 | T12N | R16W | 12 | F | 3 | 13 | DF | D | Y | 3 | R | C | | L | |
| 78 | T12N | R15W | 18 | K | 1 | 13 | SR | D | Y | 3 | N | C | | L | L |
| 78 | T12N | R15W | 18 | Q | 1 | 13 | SR | D | Y | 2 | R | P | | L | |
| 78 | T12N | R15W | 30 | C | 2 | 13 | SR | D | Y | 2 | R | P | | L | M |
| 78 | T12N | R15W | 30 | F | 3 | 13 | SR | D | Y | 3 | R | P | | L | S |
| 78 | T12N | R15W | 30 | K | 1 | 13 | SR | D | N | | R | P | | L | S |
| 78 | T12N | R16W | 12 | K | 1 | 13 | SR | D | Y | 2 | R | P | | L | |
| 78 | T12N | R16W | 12 | L | 1 | 13 | SR | D | Y | 2 | R | D | | L | |
| 78 | T12N | R16W | 13 | F | 1 | 13 | SR | D | Y | 2 | R | C | | L | M |
| 78 | T12N | R16W | 24 | A | 1 | 13 | SR | D | Y | 3 | N | C | | L | M |
| 78 | T12N | R15W | 18 | K | 3 | 13 | SR | D | Y | 3 | N | C | | M | |
| 78 | T12N | R15W | 18 | K | 2 | 13 | SR | D | Y | 4 | N | C | | M | M |
| 78 | T12N | R15W | 18 | P | 1 | 13 | SR | D | Y | 3 | R | P | | M | |
| 78 | T12N | R15W | 19 | Q | 5 | 13 | SR | D | Y | 2 | H | C | | M | |
| 78 | T12N | R15W | 19 | Q | 6 | 13 | SR | D | Y | 2 | R | C | | M | |
| 78 | T12N | R15W | 30 | F | 1 | 13 | SR | D | N | | R | D | | M | |
| 78 | T12N | R15W | 30 | F | 2 | 13 | SR | D | Y | 3 | R | P | | M | L |
| 78 | T12N | R16W | 12 | F | 1 | 13 | SR | D | Y | 3 | N | D | | M | M |
| 78 | T12N | R16W | 12 | F | 2 | 13 | SR | D | Y | 3 | H | P | | M | XL |
| 78 | T12N | R16W | 13 | E | 1 | 13 | SR | P | N | | R | P | | M | |
| 78 | T12N | R16W | 13 | E | 2 | 13 | SR | D | Y | 2 | N | P | | S | |
| 78 | T12N | R15W | 18 | N | 1 | 13 | SR | P | Y | 3 | N | P | | S | |
| 78 | T12N | R15W | 18 | N | 2 | 13 | SR | D | Y | 3 | N | P | | S | |
| 78 | T12N | R15W | 18 | Q | 2 | 13 | SR | D | Y | 2 | R | P | | S | |
| 78 | T12N | R15W | 19 | D | 1 | 13 | SR | D | Y | 3 | R | P | | S | |
| 78 | T12N | R15W | 19 | D | 2 | 13 | SR | D | Y | 3 | R | P | | S | |
| 78 | T12N | R15W | 19 | J | 1 | 13 | SR | D | N | | R | C | | S | |
| 78 | T12N | R16W | 24 | A | 3 | 13 | SR | D | Y | 3 | R | C | | S | |
| 78 | T12N | R16W | 24 | A | 2 | 13 | SR | D | Y | 3 | N | C | | XL | |
| 96 | T12N | R15W | 18 | Q | 3 | 13 | LPD | P | Y | 2 | H | P | | | XL |
| 96 | T12N | R15W | 19 | D | 3 | 13 | SR | D | N | | R | C | | | S |
| 96 | T12N | R15W | 17 | C | 1 | 13 | SR | P | N | | R | C | | | M |
| 96 | T12N | R15W | 17 | M | 1 | 13 | SR | P | N | | N | C | | | M |
| 96 | T12N | R15W | 30 | F | 4 | 13 | SR | D | N | | R | C | | | M |
| 96 | T12N | R15W | 30 | G | 1 | 13 | SR | D | Y | 2 | R | C | | | M |
| 96 | T12N | R15W | 30 | G | 2 | 13 | SR | D | Y | 2 | N | P | | | M |
| 96 | T12N | R16W | 12 | F | 4 | 13 | SR | D | Y | 3 | H | C | | | M |
| 96 | T12N | R16W | 13 | G | 1 | 13 | SR | D | Y | 2 | N | C | | | M |
| 96 | T12N | R16W | 12 | J | 1 | 13 | SR | D | Y | 3 | N | C | | | S |
| 96 | T12N | R16W | 12 | J | 2 | 13 | SR | P | Y | 2 | N | D | | | S |
| 96 | T12N | R16W | 12 | K | 2 | 13 | SR | D | Y | 3 | H | D | | | S |
| 96 | T12N | R16W | 24 | Q | 1 | 13 | SR | P | N | | R | P | | | S |

# Garcia Watershed - Basins

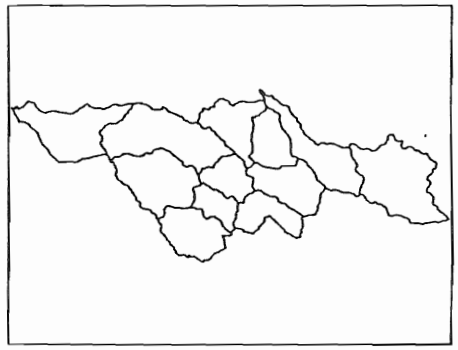
Calwater Watershed
12 North Fork Garcia River

Hydrologic Planning Unit:
113.70025




Slidepol
Township
200' Contour - Topoadd
200' Contour - Topo200
Mapped Watercourse - Hydrolin
Waterbody - Hydropol

N
W
E
S



0.6 0 0.6 1.2 Miles

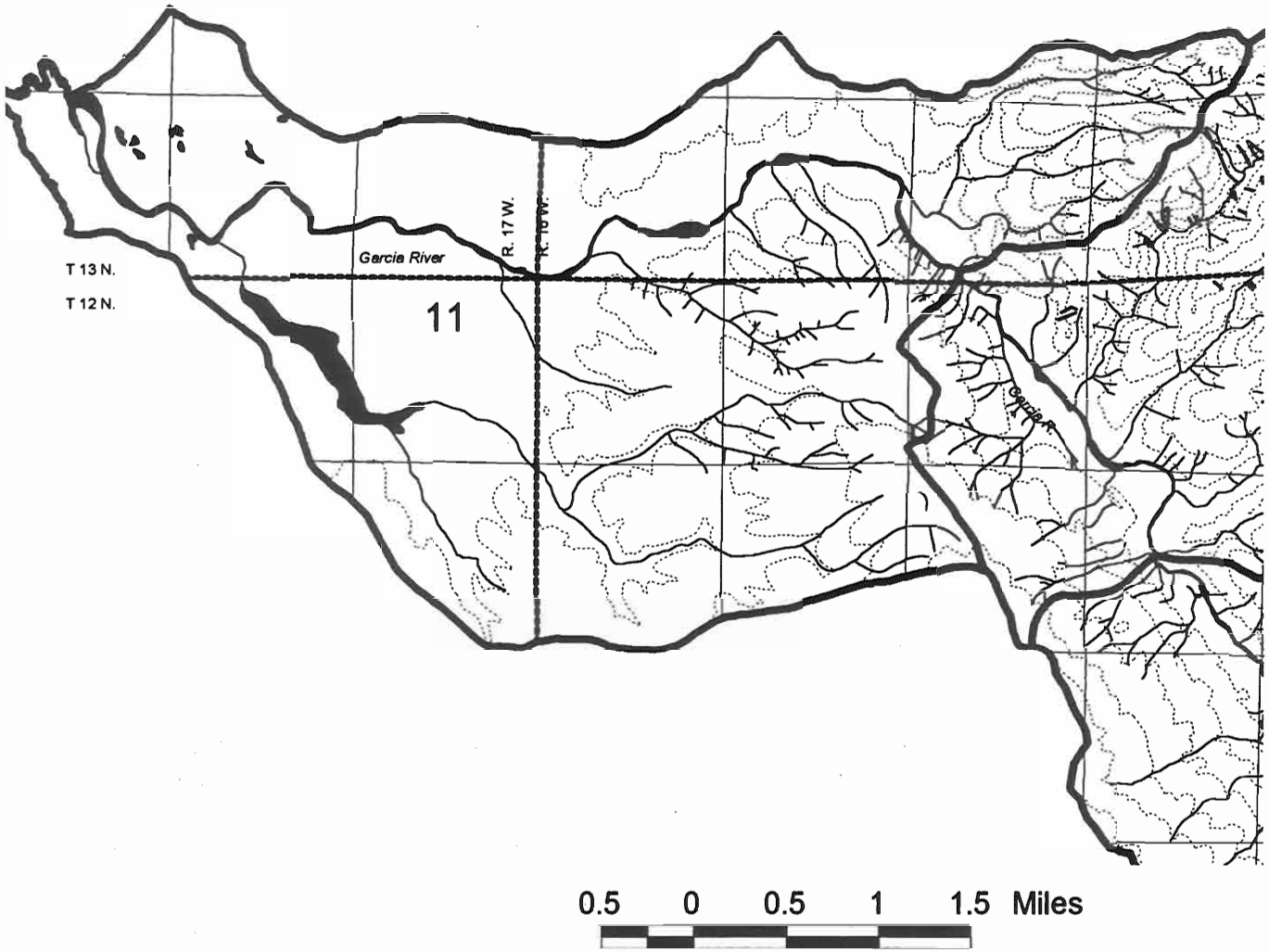
# GARCIA RIVER WATERSHED ASSESSMENT
# APPENDIX A--MASS WASTING INVENTORY DATA
## Calwater Watershed 12--North Fork Garcia River

| Photo Yea | Township | Range | Section | Init Loc | Feature # | Sub Water | Process | Confidenc | Delivery | Stream Or | Land use | Slope Sha | 1965 Size | 1978 Size | 1996 Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | T12N | R15W | 6 | R | 2 | 12 | DF | D | Y | 4 | H | P | L | | S |
| 65 | T12N | R15W | 4 | F | 1 | 12 | SR | D | Y | 2 | H | P | M | | |
| 65 | T12N | R15W | 4 | F | 2 | 12 | SR | D | Y | 1 | H | P | M | | |
| 65 | T12N | R15W | 4 | K | 1 | 12 | SR | D | Y | 2 | R | P | M | | |
| 65 | T12N | R15W | 4 | K | 2 | 12 | SR | D | Y | 2 | R | P | M | | |
| 65 | T12N | R15W | 4 | N | 1 | 12 | SR | D | Y | 2 | H | C | L | | |
| 65 | T12N | R15W | 5 | B | 1 | 12 | SR | D | Y | 2 | R | C | XL | XL | |
| 65 | T12N | R15W | 6 | Q | 1 | 12 | SR | D | Y | 4 | H/R/IG | D | S | S | |
| 65 | T12N | R15W | 6 | Q | 2 | 12 | SR | P | Y | 4 | R/IG | C | M | | |
| 65 | T12N | R15W | 6 | R | 1 | 12 | SR | D | Y | 4 | R/IG | P | M | | |
| 65 | T12N | R15W | 9 | A | 1 | 12 | SR | D | Y | 3 | H | P/C | M | | |
| 65 | T12N | R15W | 10 | D | 1 | 12 | SR | D | Y | 2 | H | P/C | L | | |
| 78 | T12N | R15W | 5 | D | 1 | 12 | DF | P | Y | 1 | R | C | | S | M |
| 78 | T12N | R15W | 5 | E | 1 | 12 | DF | P | Y | 2 | N | C | | M | |
| 78 | T12N | R15W | 6 | L | 2 | 12 | DF | D | Y | 4 | R | C | | L | |
| 78 | T12N | R16W | 2 | M | 1 | 12 | DF | D | Y | 2 | N | P | | L | |
| 78 | T12N | R16W | 1 | F | 2 | 12 | LPD | D | Y | 4 | N | P | | M | L |
| 78 | T12N | R15W | 6 | F | 2 | 12 | SR | D | Y | 4 | H | P | | S | S |
| 78 | T12N | R15W | 6 | F | 3 | 12 | SR | D | Y | 4 | H | C | | L | |
| 78 | T12N | R15W | 6 | F | 4 | 12 | SR | D | Y | 4 | H | C | | L | S |
| 78 | T12N | R15W | 6 | H | 1 | 12 | SR | D | Y | 2 | R | C | | L | |
| 78 | T12N | R15W | 6 | K | 1 | 12 | SR | D | Y | 4 | R | C | | L | M |
| 78 | T12N | R15W | 6 | K | 2 | 12 | SR | D | Y | 4 | R | P | | L | L |
| 78 | T12N | R16W | 1 | E | 1 | 12 | SR | D | Y | 2 | R | C | | L | |
| 78 | T12N | R16W | 1 | F | 1 | 12 | SR | D | Y | 4 | N | P | | L | |
| 78 | T12N | R16W | 2 | L | 2 | 12 | SR | D | Y | 2 | R | D | | L | |
| 78 | T12N | R16W | 2 | L | 3 | 12 | SR | D | Y | 2 | H | D | | L | L |
| 78 | T12N | R16W | 3 | A | 2 | 12 | SR | D | Y | 1 | R | P | | L | |
| 78 | T12N | R16W | 4 | A | 1 | 12 | SR | D | N | | N | P | | L | |
| 78 | T12N | R16W | 4 | A | 2 | 12 | SR | D | N | | N | P | | L | |
| 78 | T13N | R16 | 31 | N | 2 | 12 | SR | D | Y | 2 | H | D | | L | |
| 78 | T13N | R16W | 34 | J | 1 | 12 | SR | D | N | | R | P | | L | |
| 78 | T13N | R16W | 34 | J | 2 | 12 | SR | D | N | | R | D | | L | |
| 78 | T13N | R16W | 34 | J | 4 | 12 | SR | D | N | | H | P | | L | |
| 78 | T13N | R16W | 34 | L | 2 | 12 | SR | D | Y | 4 | H | P | | L | L |
| 78 | T12N | R15W | 4 | G | 1 | 12 | SR | P | Y | 2 | R | C | | M | |
| 78 | T12N | R15W | 5 | D | 3 | 12 | SR | D | Y | 2 | R | P | | M | |
| 78 | T12N | R15W | 5 | J | 1 | 12 | SR | D | Y | 2 | H | C | | M | |
| 78 | T12N | R15W | 6 | A | 1 | 12 | SR | D | Y | 2 | R | P | | M | |
| 78 | T12N | R15W | 6 | B | 1 | 12 | SR | D | N | | R | P | | M | |
| 78 | T12N | R15W | 6 | D | 1 | 12 | SR | D | Y | 2 | N | P | | M | L |
| 78 | T12N | R15W | 6 | E | 1 | 12 | SR | D | Y | 4 | H | P | | M | |
| 78 | T12N | R15W | 6 | F | 1 | 12 | SR | D | Y | 4 | H | P | | M | M |
| 78 | T12N | R15W | 6 | L | 1 | 12 | SR | P | N | 4 | R | D | | M | |
| 78 | T12N | R15W | 6 | R | 3 | 12 | SR | P | Y | 4 | H | C | | M | S |
| 78 | T12N | R15W | 6 | R | 4 | 12 | SR | P | Y | 4 | H | C | | M | |
| 78 | T12N | R15W | 7 | C | 1 | 12 | SR | D | Y | 1 | R | C | | M | |
| 78 | T12N | R16W | 1 | A | 1 | 12 | SR | D | Y | 3 | N | P | | M | |
| 78 | T12N | R16W | 2 | K | 1 | 12 | SR | D | Y | 2 | N | C | | M | |
| 78 | T12N | R16W | 3 | A | 1 | 12 | SR | D | Y | 1 | R | P | | M | |
| 78 | T13N | R15W | 31 | M | 2 | 12 | SR | D | Y | 2 | H | C | | M | |
| 78 | T13N | R15W | 32 | P | 1 | 12 | SR | D | Y | 2 | R | P | | M | |
| 78 | T13N | R16W | 34 | K | 1 | 12 | SR | D | Y | 3 | H | P | | M | |
| 78 | T12N | R16W | 3 | A | 3 | 12 | SR | D | N | | R | P | | S | |
| 78 | T13N | R16W | 34 | K | 2 | 12 | SR | D | Y | 3 | H | P | | S | M |
| 78 | T12N | R15W | 4 | F | 3 | 12 | SR | D | N | | H | C | | S | |
| 78 | T12N | R15W | 5 | D | 2 | 12 | SR | D | Y | 2 | H | P | | S | M |
| 78 | T12N | R15W | 6 | E | 2 | 12 | SR | D | Y | 4 | N | P | | S | |
| 78 | T12N | R15W | 7 | C | 2 | 12 | SR | D | N | | R | P | | S | |
| 78 | T12N | R16W | 1 | M | 1 | 12 | SR | D | Y | 4 | R | D | | S | |
| 78 | T13N | R15 | 31 | N | 1 | 12 | SR | D | Y | 2 | N | P | | S | |
| 78 | T13N | R15W | 31 | M | 1 | 12 | SR | P | Y | 2 | R | C | | S | |
| 78 | T13N | R16W | 35 | N | 1 | 12 | SR | D | Y | 1 | H | P | | S | S |
| 78 | T12N | R16W | 2 | L | 1 | 12 | SR | D | Y | 2 | H | D | | XL | |
| 78 | T13N | R16W | 34 | J | 3 | 12 | SR | D | N | | R | D | | XL | |
| 78 | T13N | R16W | 34 | L | 1 | 12 | SR | D | Y | 3 | H | C | | XL | |
| 78 | T13N | R16W | 34 | L | 3 | 12 | SR | D | Y | 5 | H | P | | XL | |
| 96 | T12N | R16W | 1 | A | 2 | 12 | DF | D | Y | 4 | N | P | | | XL |
| 96 | T12N | R16W | 1 | D | 1 | 12 | DF | D | Y | 4 | R | C | | | XL |
| 96 | T13N | R16W | 34 | G | 1 | 12 | DF | D | Y | 2 | R | C | | | |
| 96 | T12N | R15W | 6 | K | 3 | 12 | LPD | P | N | | N | P | | | L |
| 96 | T12N | R15W | 5 | B | 2 | 12 | SR | D | Y | 2 | R | C | | | L |
| 96 | T12N | R15W | 9 | B | 1 | 12 | SR | D | Y | 3 | N | C | | | L |
| 96 | T12N | R16W | 1 | D | 2 | 12 | SR | D | Y | 1 | R | P | | | L |

# GARCIA RIVER WATERSHED ASSESSMENT
## APPENDIX A--MASS WASTING INVENTORY DATA
### Calwater Watershed 12--North Fork Garcia River

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | T12N | R16W | 1 | E | 2 | 12 | SR | D | | | R | D | | | L |
| 96 | T12N | R16W | 2 | A | 1 | 12 | SR | D | Y | 1 | R | C | | | L |
| 96 | T12N | R16W | 2 | A | 2 | 12 | SR | D | N | | R | D | | | L |
| 96 | T12N | R16W | 2 | B | 2 | 12 | SR | D | Y | 2 | R | C | | | L |
| 96 | T12N | R16W | 2 | L | 4 | 12 | SR | D | Y | 2 | H | D | | | L |
| 96 | T12N | R15W | 6 | Q | 3 | 12 | SR | D | Y | 1 | R | P | | | M |
| 96 | T12N | R15W | 7 | B | 1 | 12 | SR | D | Y | 2 | N | P | | | M |
| 96 | T12N | R16W | 1 | F | 2 | 12 | SR | D | Y | 2 | H | P | | | M |
| 96 | T12N | R16W | 1 | G | 1 | 12 | SR | D | Y | 4 | N | P | | | M |
| 96 | T12N | R16W | 2 | L | 5 | 12 | SR | D | Y | 2 | H | D | | | M |
| 96 | T13N | R15W | 31 | M | 3 | 12 | SR | Q | Y | 2 | R | D | | | M |
| 96 | T12N | R16W | 1 | M | 3 | 12 | SR | D | Y | 4 | R | C | | | M |
| 96 | T12N | R15W | 4 | N | 2 | 12 | SR | D | Y | 3 | N | C | | | S |
| 96 | T12N | R16W | 1 | G | 2 | 12 | SR | D | Y | 4 | N | P | | | S |
| 96 | T12N | R16W | 1 | M | 2 | 12 | SR | D | Y | 4 | R | C | | | S |
| 96 | T13N | R15W | 31 | M | 4 | 12 | SR | Q | Y | 2 | R | D | | | S |
| 96 | T13N | R16W | 36 | L | 1 | 12 | SR | D | N | | R | D | | | S |
| 96 | T12N | R15W | 5 | N | 1 | 12 | SR | D | Y | 3 | R | P | | | |
| 96 | T13N | R16W | 34 | H | 1 | 12 | SR | D | Y | 2 | R | C | | | |
| 96 | T13N | R16W | 34 | H | 2 | 12 | SR | D | Y | 2 | R | D | | | |

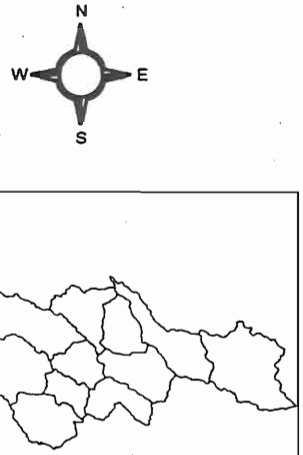
# Garcia Watershed - Basins




Calwater Watershed
11. Hathaway Creek

Hydrologic Planning Unit
113.70026

Township
200' Contour - Topoadd
200' Contour - Topo200
Slide - Slidepo2
Mapped Watercourse - Hydrolin
Waterbody - Hydropol



# *APPENDIX B.*

# *MATRIX OF RESOURCE CONDITION AND SENSITIVITY*

| | Location | | | | Watershed Characteristics | | | | | Erosion Rates | | | | Reported Conditions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | watershed | | tributaries | land use | mainstem | size | relief | relative relief | landslides | landslides | road erosion | road erosion | annual rainfall | erodiblity | erodibility 2 | (high) temp | DO |
| | SWRCB no. | CFL name | CDF name | | | | acres | feet | relief per acre | | 0-100 low, | 100-300 med, | 300 + high | | | | | |
| sources: | 1 | 5 | 4 | 1, 5, 7 | 4 | 1, 4 | 8 | 7 | | 3 | t/mi2/y | 3 | t/mi2/y | 8 | 8 | 6 | 1, 2 | 1, 2 |
| | 70010 | pardaloe | pardaloe | mainstem | range-timber | upper | 10473 | 1790 | 0.17 | m | 9 | m | 120 | 60 | m-h | | | |
| | 70010 | | | mill | | | | | | | | | | | | | 67 | |
| | 70010 | | | redwood | | | | | | | | | | | | | | |
| | 70010 | | | monahan | | | | | | | | | | | | | | |
| | 70010 | | | pardaloe | | | | | | | | | | | | | 73 | |
| | 70011 | larmour | larmour | mainstem | timber-range | upper | 6550 | 2092 | 0.32 | l | 213 | l | 89 | 65 | m-h | | 80 | |
| | 70011 | | | larmour | | | | | | | | | | | | | | |
| | 70011 | | | grants' camp | | | | | | | | | | | | | 75 | |
| | 70011 | | | east end | | | | | | | | | | | | | | |
| | 70012 | blue waterhole e | no name 4 | mainstem | timber-range | mid-upper | 3972 | 2292 | 0.58 | h | 302 | h | 349 | 65 | m-h | | 83 | |
| | 70012 | | | stansbury | | | | | | | | | | | | | ok | |
| | 70012 | | | whitlow | | | | | | | | | | | | | | |
| | 70013 | blue waterhole w | no name 3 | | timber-range | none | 4929 | 2096 | 0.43 | m | 260 | m | 167 | 65 | m-h | | | |
| | 70013 | | | blue waterhole | | | | | | | | | | | | | 83 | |

| Location | | | | Reported Conditions, cont. | | | | | | Synthesis | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | watershed | | tributaries | shade, canopy | complexity | fine sediment | habitat | comments | fish | Is the land sensitive to use here? | Are the fish sensitive to land use here? | model results |
| SWRCB no. | CFL name | CDF name | | ave = average beneficial value | "+ = better; ++=far better, etc. | | | | | relative ratings | relative ratings | rel. relief v. landslides |
| 1 | 5 | 4 | 1, 5, 7 | 1, 5 | 1, 5 | 1, 5 | 1, 2, 5, 6 | 1, 2, 5, 9 | 1, 2, 5, 6 | synthesis | synthesis | synthesis |
| 70010 | pardaloe | pardaloe | mainstem | | | | | | | | | under-estimate |
| 70010 | | | mill | | | hi | limited | ok pools | poor, good steelhead, lampreys | yes | yes | |
| 70010 | | | redwood | | ok | | limited | | | | | |
| 70010 | | | monahan | | | | | | | | | |
| 70010 | | | pardaloe | poor | low | hi | poor | poor pools | good | yes | yes | |
| 70011 | larmour | larmour | mainstem | | | hi | | site of falls blasting | good | | | ok |
| 70011 | | | larmour | poor | | | limited | falls, no other data | | ? | no | |
| 70011 | | | grants' camp | | ok | | limited | small pools | | | | |
| 70011 | | | east end | | | | | | | | | |
| 70012 | blue waterhole e | no name 4 | mainstem | | ok | | | | | | | ok |
| 70012 | | | stansbury | | poor | | limited | debris jam | poor / none | | no | |
| 70012 | | | whitlow | poor, ave+ | poor | hi | | | coho runs into '70s | yes | | |
| 70013 | blue waterhole w | no name 3 | | | | | | | | | | ok |
| 70013 | | | blue waterhole | ave+ | ok | hi | good | boulder cover, low slope | good | yes | yes | |

| | Location | | | | Watershed Characteristics | | | | | Erosion Rates | | | | Reported Conditions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | watershed | | tributaries | land use | mainstem | size | relief | relative relief | landslides | landslides | road erosion | road erosion | annual rainfall | erodiblity | erodibility 2 | (high) temp | DO |
| | SWRCB no. | CFL name | CDF name | | | | acres | feet | relief per acre | | 0-100 low, | 100-300 med, | 300 + high | | | | | |
| sources: | 1 | 5 | 4 | 1, 5, 7 | 4 | 1, 4 | 8 | 7 | | 3 | t/mi2/y | 3 | t/mi2/y | 8 | 8 | 6 | 1, 2 | 1, 2 |
| | 70014 | inman | inman | | timber-range | none | 5481 | 1956 | 0.36 | 1 | 82 | h | 464 | 75 | m | | | |
| | 70014 | | | inman | | | | | | | | | | | | | 76 | |
| | 70020 | signal | signal | | timber | none | 3954 | 1985 | 0.50 | 1 | 77 | h | 514 | 70 | m-x | m-x | | |
| | 70020 | | | signal | | | | | | | | | | | | | 63 | |
| | 70021 | hot springs ck, graphite ck. n | no name 6 | mainstem | timber | mid | 3425 | 2064 | 0.60 | m | 238 | h | 512 | 65 | m-h | h | hi | |
| | 70021 | | | graphite | | | | | | | | | | | | | | |
| | 70021 | | | caspar | | | | | | | | | | | | | 60 | |
| | 70022 | graphite ck s | no name 8 | mainstem | timber | low-mid | 2624 | 2180 | 0.83 | h | 396 | h | 409 | 60 | m-h | h | 70 | |
| | 70022 | | | beebe | | | | | | | | | | | | | | |

| Location | | | | Reported Conditions, cont. | | | | | | Synthesis | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | watershed | | tributaries | shade, canopy | complexity | fine sediment | habitat | comments | fish | Is the land sensitive to use here? | Are the fish sensitive to land use here? | model results |
| SWRCB no. | CFL name | CDF name | | ave = average bene ficial value | "+ = better; ++=far better, etc. | | | | | relative ratings | relative ratings | rel. relief v. landslides |
| 1 | 5 | 4 | 1, 5, 7 | 1, 5 | 1, 5 | 1, 5 | 1, 2, 5, 6 | 1, 2, 5, 9 | 1, 2, 5, 6 | synthesis | synthesis | synthesis |
| 70014 | inman | inman | | | | | | | | | | under-estimate |
| 70014 | | | inman | poor, ave+, ave- | ave- | hi, ave+, deep | limited | embeddedness 40-80%, 5-10 ft of stored sed in alluv. reaches, slow recovery | good, few '95, more '96 | yes | | |
| 70020 | signal | signal | | | | | | | | | | |
| 70020 | | | signal | poor, ave++ | ave++ | ave- | limited | recovery mode, fire in '94 | good, fair | | | |
| 70021 | hot springs ck, graphite ck. n | no name 6 | mainstem | ave-- | poor, ave- | hi, ave+ | | algae, minor downcutting | fair, fewer than expected | | | |
| 70021 | | | graphite | ave+ | | | limited | barrier, steep | none | | | |
| 70021 | | | caspar | ave+ | | | limited | steep | none | | | |
| 70022 | graphite ck s | no name 8 | mainstem | poor, ave-- | ave- | ave+ | limited | no pools, limited recovery | steelhead likely | | | ok |
| 70022 | | | beebe | poor, ave+ | ok | | limited | | fair | | | |

| | Location | | | | Watershed Characteristics | | | | | Erosion Rates | | | | Reported Conditions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | watershed | | tributaries | land use | mainstem | size | relief | relative relief | landslides | landslides | road erosion | road erosion | annual rainfall | erodiblity | erodibility 2 | (high) temp | DO |
| | SWRCB no. | CFL name | CDF name | | | | acres | feet | relief per acre | | 0-100 low, | 100-300 med, | 300 + high | | | | | |
| sources: | 1 | 5 | 4 | 1, 5, 7 | 4 | 1, 4 | 8 | 7 | | 3 | t/mi2/y | 3 | t/mi2/y | 8 | 8 | 6 | 1, 2 | 1, 2 |
| | 70023 | south fork | south fork | mainstem | timber | lower | 5595 | 2090 | 0.37 | m | 218 | 1 | 45 | 55 | l-h | m-h-x | 75 | |
| | 70023 | | | south fork | | | | | | | | | | | | | 63 | |
| | 70023 | | | fleming | | | | | | | | | | | | | | |
| | 70024 | rolling brook | rolling brook | mainstem | timber | lower | 7999 | 2224 | 0.28 | m | 148 | m | 114 | 55 | m-h | m-h | 63 | |
| | 70024 | | | rolling brook | | | | | | | | | | | | | 65, >64 | |
| | 70024 | | | hutton glch | | | | | | | | | | | | | 61 | |
| | 70024 | | | mill ck | | | | | | | | | | | | | 61 | |
| | 70024 | | | lee | | | | | | | | | | | | | 59 | |

| Location | | | | | Reported Conditions, cont. | | | | | Synthesis | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | watershed | | tributaries | shade, canopy | complexity | fine sediment | habitat | comments | fish | Is the land sensitive to use here? | Are the fish sensitive to land use here? | model results |
| SWRCB no. | CFL name | CDF name | | ave = average bene ficial value | "+ = better; ++=far better, etc. | | | | | relative ratings | relative ratings | rel. relief v. landslides |
| 1 | 5 | 4 | 1, 5, 7 | 1, 5 | 1, 5 | 1, 5 | 1, 2, 5, 6 | 1, 2, 5, 9 | 1, 2, 5, 6 | synthesis | synthesis | synthesis |
| 70023 | south fork | south fork | mainstem | | 1 | hi | | | | | | over-estimate |
| 70023 | | | south fork | good | good | low, hi | decline d | underground flows, decline in habitat quality, sediment in storage in S Fk, San Andreas Fault | fair | yes | yes | |
| 70023 | | | fleming | good | good | low | limited | | | | | |
| 70024 | rolling brook | rolling brook | mainstem | | | | | | | | | under-estimate ? |
| 70024 | | | rolling brook | | fair | | limited | | fair, coho present | yes | yes | |
| 70024 | | | hutton glch | no openings | poor | hi | | | | yes | | |
| 70024 | | | mill ck | | hi | | | | good | ? | ? | |
| 70024 | | | lee | | | | limited | | fair | | | |

| | Location | | | | Watershed Characteristics | | | | | Erosion Rates | | | | Reported Conditions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | watershed | | tributaries | land use | mainstem | size | relief | relative relief | landslides | landslides | road erosion | road erosion | annual rainfall | erodiblity | erodibility 2 | (high) temp | DO |
| | SWRCB no. | CFL name | CDF name | | | | acres | feet | relief per acre | | 0-100 low, | 100-300 med, | 300 + high | | | | | |
| sources: | 1 | 5 | 4 | 1, 5, 7 | 4 | 1, 4 | 8 | 7 | | 3 | t/mi2/y | 3 | t/mi2/y | 8 | 8 | 6 | 1, 2 | 1, 2 |
| | 70025 | north fork | north fork | mainstem | timber | lower | 10373 | 2265 | 0.22 | m | 148 | h | 472 | 50 | l-h | m-h | 70 | low? |
| | 70025 | | | olsen ck | | | | | | | | | | | | | good | |
| | 70025 | | | john olsen ck | | | | | | | | | | | | | good | |
| | 70025 | | | alder ck | | | | | | | | | | | | | | |
| | 70025 | | | north fork | | | | | | | | | | | | | good | |
| | 70026 | hathaway ck. | hathaway ck. | mainstem | agri-timber | estuary | 7847 | 1700 | 0.22 | 1 | 0 | m | 154 | 45 | l-m | | 72 | low |
| | 70026 | | | bentonite | | | | | | | | | | | | | | |
| | 70026 | | | allen glch | | | | | | | | | | | | | | |
| | 70026 | | | hathaway | | | | | | | | | | | | | 56 | |

| Location | | | | | Reported Conditions, cont. | | | | | Synthesis | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | watershed | | tributaries | shade, canopy | complexity | fine sediment | habitat | comments | fish | Is the land sensitive to use here? | Are the fish sensitive to land use here? | model results |
| SWRCB no. | CFL name | CDF name | | ave = average beneficial value | "+ = better; ++=far better, etc. | | | | | relative ratings | relative ratings | rel. relief v. landslides |
| 1 | 5 | 4 | 1, 5, 7 | 1, 5 | 1, 5 | 1, 5 | 1, 2, 5, 6 | 1, 2, 5, 9 | 1, 2, 5, 6 | synthesis | synthesis | synthesis |
| 70025 | north fork | north fork | mainstem | | | | | | poor | | | under-estimate |
| 70025 | | | olsen ck | ave++ | low, ave+ | hi, ave- | limited | severely affected by harvest, well along the road to recovery, sediment 20+ ft | none, many | yes | no | |
| 70025 | | | john olsen ck | good, ave++ | med, ave+ | hi, ave- | | | many | | | |
| 70025 | | | alder ck | ave++ | ave+ | hi, ave- | limited | | good | | | |
| 70025 | | | north fork | ave++ | poor, ave+ | hi, ave- | poor | severe reduction, good pop below falls | good | yes | yes | |
| 70026 | hathaway ck. | hathaway ck. | mainstem | | low | hi | | | | | | under-estimate |
| 70026 | | | bentonite | good | poor | hi | poor | believed used | fair | yes | yes | |
| 70026 | | | allen glch | | | hi | | | fair / none | | | |
| 70026 | | | hathaway | good | | hi | good | once plentiful | poor | yes | yes | |

Key

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4. NRCS / CDF 1997. Soil Resource Assessment and Soil Survey of Mendocino County.
   Prepared for this study, with Soil Descriptions from *Eastern 1/2 of County.
5. Coastal Forestlands, Ltd. 1997. Sustained Yield Plan. DRAFT
6. Louisiana Pacific. 1997. Sustained Yield Plan.
7. USGS. 1977, 1991. Topographic maps. 1:24,000.
8. CDF. 1997. Coast Cascade Region GIS Data.

# *APPENDIX C.*

# *INVENTORY HISTORY IN THE GARCIA RIVER WATERSHED*

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 70010 Pardaloe | Pardaloe Creek | Late summer flows measured (WEP). Flow estimated by % area above Eureka Br. at bankful discharge. (LFA) | from topos | MCRCD did x-secs at restoration sites | | | |
| | Box Canyon Ck. | | | | | | |
| | Monahan Ck. | | | | | | |
| | Newton Ck. | | | | | | |
| | Unnamed | | | | | | |
| | Mill Creek | | from topos | | | | |
| | North Mill | | from topos | | | | |
| | Sled Creek | | from topos | | | | |
| | Redwood Creek | | from topos | | | | |
| | Cabin Creek | | from topos | | | | |
| | | | | | | | |
| 70011 Larmour | mainstem Garcia from Mill to Larmour Creek | 1948 F&G est. of flow. Flow estimated by % area above Eureka Br. at bankful discharge. (LFA) | from topos | | | | |
| | Larmour | | from topos, GWAG observations | | | | |
| | Grant's Camp | F&G 1967 stream survey estimate. | F&G 1967 steam survey description. | | | F&G 1967 stream survey estimate. | |
| | East End | | | | | | |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70010 Pardaloe | Pardaloe Creek | | | | WEP 1992, habitat typing iden. 2 dom. substrate size classes and % exposed sub. F&G 1994 stream survey of 102 meters, estimated. % sub. composition | |
| | Box Canyon Ck. | | | | | |
| | Monahan Ck. | | | | | |
| | Newton Ck. | | | | | |
| | Unnamed | | | | | |
| | Mill Creek | | | | F&G 1994 stream survey, 126 meter reach. | |
| | North Mill | | | | | |
| | Sled Creek | | | | | |
| | Redwood Creek | | | | 1994 consultant for Mailliard particle size dist. (McNeil) | |
| | Cabin Creek | | | | | |
| | | | | | | |
| 70011 Larmour | mainstem Garcia from Mill to Larmour Creek | | from 1952 & 1988 aerial photos | | no data | aerial photos of 1952 showed lots of sediment |
| | Larmour | from topos | | | | |
| | Grant's Camp | | F&G 1967 stream survey estimate. | | F&G 1967 stream survey. | |
| | East End | | | | | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70010 Pardaloe | Pardaloe Creek | WEP 1992 Hab. typing | | | | WEP hab. typing (Flosi & Reynolds) Lower 4.1 miles. F&G Stream Survey, 1994. No known continuous monitoring of temp. MCWA (1997) |
| | Box Canyon Ck. | | | | | |
| | Monahan Ck. | | | | | |
| | Newton Ck. | | | | | |
| | Unnamed | | | | | |
| | Mill Creek | | | | | F&G 1994 Stream Survey. Mailliard consultant 1994, hobos. MCWA (1997) |
| | North Mill | | | | | |
| | Sled Creek | | | | | |
| | Redwood Creek | | 1994 consultant for Mailliard particle size dist. (McNeil) | | | F&G 1994 Stream Survey. Mailliard consultant 1994, hobos. |
| | Cabin Creek | | | | | |
| | | | | | | |
| 70011 Larmour | mainstem Garcia from Mill to Larmour Creek | | | | | 1948 F&G survey from Zeni Ranch to Garcia Falls; CFL hobo in summer 1995, MCWA 1997. |
| | Larmour | | | | | GWAG observations of canopy 1997 |
| | Grant's Camp | | | | | F&G 1967 stream survey. |
| | East End | | | | | |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70010 Pardaloe | Pardaloe Creek | | WEP 1992, Direct Underwater Observation Method, (Hankin and Reeves,) and ocular est., river mile 0-4.4. Salmon Trollers survey 1995-96. | WEP observations 1992. Salmon Trollers survey, 1995-96 . | | WEP 1992, Hab. typing, lower 4.1 miles. F&G Stream Survey, 1994. |
| | Box Canyon Ck. | | | | | WEP 1992, Hab. typing in lower reaches |
| | Monahan Ck. | | | | | |
| | Newton Ck. | | | | | |
| | Unnamed | | | | | |
| | Mill Creek | | F&G 1994 Stream Survey, electro-shock fish and amphibians. | Salmon Trollers winters 1995-96, 1996-97. | Salmon Trollers winters 1995-96, 1996-97. | F&G 1994 Stream Survey. |
| | North Mill | | | | | |
| | Sled Creek | | | | | |
| | Redwood Creek | | Mailliard consultant 1994, fish and amphibs. | | | |
| | Cabin Creek | | | | | |
| | | | | | | |
| 70011 Larmour | mainstem Garcia from Mill to Larmour Creek | | 1948 F&G survey from Zeni Ranch to Garcia Falls; 1993 field notes from F&G.; 1987 F&G population study (elect) .25 miles from East End Ck. | 1993 field notes from F&G.; | | no data for this reach, 1948 F&G stream survey from Zeni Ranch to Garcia Falls est. good spawning areas. One pool measured CFL 1995. |
| | Larmour | | | | | |
| | Grant's Camp | | F&G 1967 stream survey noted frogs and newts. | | | |
| | East End | | | | | |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| | | | | | |
| 70010 Pardaloe | Pardaloe Creek | | WEP 1992, Hab. typing, lower 4.1 miles. F&G Stream Survey, 1994. | | WEP, Hab. typing (Flosi & Reynolds) Lower 4.1 miles. |
| | Box Canyon Ck. | | | | |
| | Monahan Ck. | | | | |
| | Newton Ck. | | | | |
| | Unnamed | | | | |
| | Mill Creek | | F&G 1994 Stream Survey. | | |
| | North Mill | | | | |
| | Sled Creek | | | | |
| | Redwood Creek | | | | |
| | Cabin Creek | | | | |
| | | | | | |
| 70011 Larmour | mainstem Garcia from Mill to Larmour Creek | | CFL 1995 describes cover in hobo pool | | |
| | Larmour | GWAG observations of canopy 1997 | | | GWAG observations of 75 foot falls 1997 |
| | Grant's Camp | | F&G 1967 stream survey. | F&G 1967 stream survey. | F&G 1967 stream survey. |
| | East End | | | | |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| 70012 Stansbury Creek, Whitlow Creek, Garcia River | mainstem Garcia from Larmour to Blue Waterhole | Flow estimated by % area above Eureka Br. at bankful discharge.(LFA) | from topos | MCRCD 1995 established x-secs to monitor restoration work of New Growth Forestry. | | F&G 1948 stream survey observations. | |
| | Stansbury | | from topos | | | | |
| | Whitlow | | from topos | GWAG notes creek w/wide, flat channel w/vertical, unprotected banks. | | | |
| 70013 Blue Waterhole Creek | mainstem Garcia | | (CFL) With clinometer at 100 ft. intervals along sample reaches and averaged. | | | (CFL) bankful channel width at 3 prominent riffles w/ a surveying tape | (CFL) Average of 10 equally spaced depths across bankful channel at 3 riffles w/stadia rod. |
| | Blue Waterhole Creek | GWAG noted good summer flows 1997. Flow estimated by % area above Eureka Br. at bankful discharge.(LFA) F&G 1967 stream survey estimate. | from topos and CDF GIS | MCRCD x-secs to monitor New Growth Forestry restoration sites. | | F&G 1967 stream survey observations and estimates. | |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| | | | | | | |
| **70012 Stansbury Creek, Whitlow Creek, Garcia River** | **mainstem Garcia from Larmour to Blue Waterhole** | | 1952 and 1988 aerial photo measurements. | | F&G 1948 stream survey observations. | 1952 aerial photos. |
| | **Stansbury** | | | | GWAG info of rock gorge. | |
| | **Whitlow** | | | | CFL consultant 1996 noted .5 miles of creek w/heavy impact by recent sediment. (THP MEN).; GWAG noted 1997, high fines. | |
| | | | | | | |
| **70013 Blue Waterhole Creek** | **mainstem Garcia** | Measured out from bankful at 3 riffles (same spot as bankful and pebble cts.). averaged from 3 sites for overall v.w. for reach. | | | | |
| | **Blue Waterhole Creek** | | F&G 1967 stream survey observations and estimates. | | F&G 1967 stream survey observations. NCRWQCB & CDF study measured RASI, D50 and V*. | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| 70012 Stansbury Creek, Whitlow Creek, Garcia River | mainstem Garcia from Larmour to Blue Waterhole | | | | | FrOG 1995 w/hobo. |
| | Stansbury | | | | | |
| | Whitlow | | | | GWAG notes lack of pools 1997. | |
| 70013 Blue Waterhole Creek | mainstem Garcia | | Wolman pebble cts. in 3 potential spawning riffles. 100 particles. Several indices of substrate size calculated and averaged for reach. | (CFL) Inventories within bankful channel for entire reach, as per Bilby and Ward (1989). | 3 pools/reach residual depth, residual length, and residual width. V=(1/12pi)x(l, w, d) | |
| | Blue Waterhole Creek | | | | F&G 1967 stream survey observations and estimates NCRWQCB & CDF study measured pools/1000 m, max pool depth. | F&G stream survey 1967 Aug. temp. FrOG 1993 1 station; 1994, 3; 1995, 4 stations. Summer temps. CFL consultant 1995. |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70012 Stansbury Creek, Whitlow Creek, Garcia River | mainstem Garcia from Larmour to Blue Waterhole | | 1948 F&G stream survey noted fish. | | | |
| | Stansbury | | Steelhead seen in 1995 (GWAG). | GWAG noted no spawning in 1993-94. | | |
| | Whitlow | | CFL consultant THP 1996 noted number of juvenile fish, no redds. | CFL consultant THP 1996 noted number of juvenile fish, no redds. | | No data, CFL consultant notes lack of LWD, sinuosity and good pool/riffle ratio. THP 1996 |
| | | | | | | |
| 70013 Blue Waterhole Creek | mainstem Garcia | | | | | |
| | Blue Waterhole Creek | | F&G stream survey 1967 observed fish and amphibs. | | | F&G 1967 stream survey observations and estimates. NCRWQCB & CDF study measured LWD volume/1000m. GWAG noted boulder cover 1997. |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| | | | | | |
| 70012 Stansbury Creek, Whitlow Creek, Garcia River | mainstem Garcia from Larmour to Blue Waterhole | | | | |
| | Stansbury | GWAG notes good canopy from mouth to upper fork. | | | GWAG note of logjam barrier .5 mile up from mouth. Passage opened 1992 by blasting of Garcia Falls. |
| | Whitlow | GWAG notes moderate at best, (max 65%), 1997. | CFL THP 1996 states cover is s simplistic, lacks pool forming elements. | | no known barriers (LFA). |
| | | | | | |
| 70013 Blue Waterhole Creek | mainstem Garcia | (CFL) % closure visually est. above bankful at 100 ft. intervals (decid. & everg.), averaged for reach. | | | |
| | Blue Waterhole Creek | GWAG noted 1997 poor cover w/good volunteer revegetation efforts. | | F&G stream survey 1967 observed abundant food. | GWAG noted barriers, rock barriers, falls and landing site blocks. |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 70014 Inman Creek | Inman Creek | Flow estimated by % area above Eureka Br. at bankful discharge (LFA). GWAG 1997 estimated summer flows a 1.5 cfs and winter flows at 26-32 cfs. | from topos; (CFL) 3 sites with clinometer at 100 ft. intervals along sample reaches and averaged. | | | (CFL) bankful channel width at 3 prominent riffles w/ a surveying tape | (CFL) Average of 10 equally spaced depths across bankful channel at 3 riffles w/stadia rod. |
| | North Fork Inman | | from topos | | | | |
| | Pepperwood Creek | | from topos | | | | |
| | | | | | | | |
| 70020 Signal Creek | Signal Creek | Flow estimated by % area above Eureka Br. at bankful discharge.(LFA) | (CFL) 3 sites with clinometer at 100 ft. intervals along sample reaches and averaged. From topos (LFA). L-P Channel Network map of source/response reaches. | | | (CFL) bankful channel width at 3 prominent riffles w/ a surveying tape | (CFL) Average of 10 equally spaced depths across bankful channel at 3 riffles w/stadia rod. |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70014 Inman Creek | Inman Creek | Measured out from bankful at 3 riffles (same as bankful and pebble cts.). averaged from 3 sites for overall v.w. for reach. | GWAG observations. | | 1994 (CFL) Particle size distribution (4 McNeil samples) at 2 stations at pool/riffle crests. 1995 (CFL) McNeil sample at mouth. CFL THP 1996 observations. GWAG notes, 1997. New Growth Forestry reported substrate conditions 1990. | |
| | North Fork Inman | | | | | |
| | Pepperwood Creek | | | | | |
| | | | | | | |
| 70020 Signal Creek | Signal Creek | Measured out from bankful at 3 riffles (same as bankful and pebble cts.). averaged from 3 sites for overall v.w. for reach. | L-P's Channel sensitivity map; SYP 1997. GWAG notes. Aerial photo interp., (LFA) | | F&G 1987, 98 meter survey estimated substrate comp. F&G 1995 repeated survey, 108 meters. GWAG 1997 observations. | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70014 Inman Creek | Inman Creek | CFL THP 1996 observations and #s. ("checked embed.?") | Wolman pebble cts. in 3 potential spawning riffles. 100 particles. Several indices of substrate size calculated and averaged for reach. | CFL Inventories within bankful channel for entire reach, as per Bilby and Ward (1989). Mendocino Watershed Service, inc. observed lack of woody debris 1995. CFL THP 1996 observations of woody debris. GWAG notes that woody debris is low. | 3 pools/reach residual depth, residual length, and residual width. V=(1/12pi)x(l, w, d); CFL THP 1996 observations of pool abundance. | 1994 & 1995 CFL consultant collected summer temps at mouth. |
| | North Fork Inman | | | | | |
| | Pepperwood Creek | | | | | |
| | | | | | | |
| 70020 Signal Creek | Signal Creek | | Wolman pebble cts. in 3 potential spawning riffles. 100 particles. Several indices of substrate size calculated and averaged for reach. | (CFL) Inventories within bankful channel for entire reach, as per Bilby and Ward (1989). GWAG 1997 woody debris observations. Mendocino Watershed Services installed woody debris before 1995. | 3 pools/reach residual depth, residual length, and residual width. V=(1/12pi)x(l, w, d) | F&G 1987stream survey estimated temp. F&G 1995 repeated survey. |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70014 Inman Creek | Inman Creek | | F&G 1987 fish pop. survey. CFL 1994 consultant conducted fish pop. survey. L-P 1995 conducted fish pop. survey. Salmon Trollers 1995-96 conducted spawning survey. | Salmon Trollers 1995-96 conducted redd survey. | Salmon Trollers 1995-96 conducted carcass survey. | New Growth Forestry for restoration grant reported habitat conditions 1990. GWAG notes that spawning habitat is okay. |
| | North Fork Inman | | | | | CFL THP 1996 observations of adequate habitat for salmonids.. |
| | Pepperwood Creek | | | | | WEP 1992, Hab. typing in lower reaches. |
| | | | | | | |
| 70020 Signal Creek | Signal Creek | | F&G 1987, 98 meter survey counted fish. F&G 1995 repeated fish count survey, 108 meters. Salmon Trollers Assoc. spawning survey 1995-96. Repeated survey 1996-97. CFL observations 1992. | Salmon Trollers Assoc. spawning survey counted redds 1995-96. Repeated survey 1996-97. CFL observations 1992. GWAG notes. | Salmon Trollers Assoc. spawning survey counted redds 1995-96. Repeated survey 1996-97. | F&G 1987, 98 meter survey estimated hab. types F&G 1995 repeated survey, 108 meters. GWAG 1997 spawning hab. observations. |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| | | | | | |
| 70014 Inman Creek | Inman Creek | (CFL) % closure visually est. above bankful at 100 ft. intervals (decid. & everg.), averaged for reach. New Growth Forestry for restoration grant reported canopy conditions 1990. | GWAG notes that woody debris is low. CFL THP 1996 observed amount of cover. | CFL THP 1996 consultant observations. | New Growth Forestry for restoration grant reported barriers 1990. |
| | North Fork Inman | | | | New Growth Forestry for restoration grant reported barriers 1990. |
| | Pepperwood Creek | | | | New Growth Forestry for restoration grant reported barriers 1990. |
| | | | | | |
| 70020 Signal Creek | Signal Creek | (CFL) % closure visually est. above bankful at 100 ft. intervals (decid. & everg.), averaged for reach. | F&G 1987, 98 meter survey estimated instream objects F&G 1995 repeated survey, 108 meters. GWAG 1997 cover observations. | | GWAG notes on steep bedrock falls. |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| 70021 Casper Ck, Graphite Ck., Garcia River | mainstem Garcia | Flow estimated by % area above Eureka Br. at bankful discharge.(LFA) L-P reports mean annual volume runoff. | CDF GIS; L-P SYP Channel Network Map 1997. (CFL) With clinometer at 100 ft. intervals along sample reaches and averaged. | | | (CFL) bankful channel width at 3 prominent riffles w/ a surveying tape. GWAG notes that channel is very wide. | (CFL) Average of 10 equally spaced depths across bankful channel at 3 riffles w/stadia rod. |
| | Casper Creek | | CDF GIS; L-P SYP Channel Network Map 1997. | | | | |
| | Graphite Creek | | CDF GIS; L-P SYP Channel Network Map 1997. 1988 aerial photos show lg. drop-off at mouth. | | | | |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| | | | | | | |
| 70021 Casper Ck, Graphite Ck., Garcia River | mainstem Garcia | Measured out from bankful at 3 riffles (same spot as bankful and pebble cts.). averaged from 3 sites for overall v.w. for reach. | 1852 and 1988 aerial photos. L-P Channel Sensitivity map. | | CFL consultant collected particle size dist. data downstream from Blue Waterhole Creek 1995. L-P SYP 1997 Channel Substrate Predicted Particle Size map. | |
| | Casper Creek | | L-P SYP 1997 Channel Sensitivity map from slope and confinement; method unknown. (LFA) | | L-P SYP 1997 Channel Substrate Predicted Particle Size map. | |
| | Graphite Creek | | L-P SYP 1997 Channel Sensitivity map from slope and confinement; method unknown. (LFA) | | L-P SYP 1997 Channel Substrate Predicted Particle Size map. GWAG notes. | |
| | | | | | | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| 70021 Casper Ck, Graphite Ck., Garcia River | mainstem Garcia | | Wolman pebble cts. in 3 potential spawning riffles. 100 particles. Several indices of substrate size calculated and averaged for reach. | (CFL) Inventories within bankful channel for entire reach, as per Bilby and Ward (1989). | 3 pools/reach residual depth, residual length, and residual width. V=(1/12pi)x(l, w, d) | GWAG notes warm temps, lots of algal growth. |
| | Casper Creek | | | | | L-P conducted pop.distrib. survey in 1995 & 96, incld. temp. |
| | Graphite Creek | | | | | |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| 70021 Casper Ck, Graphite Ck., Garcia River | mainstem Garcia | | F&G 1987 conducted electro. pop. survey. GWAG observations. | GWAG observations. | | |
| | Casper Creek | | L-P conducted pop. dist.. survey in 1995 & 96, incld. fish and amphib counts. | | | L-P conducted pop.distrib. survey in 1995 & 96, incld. hab. types. |
| | Graphite Creek | | Salmon Trollers conducted survey from Dec 1996-Jan. 1997, 1 mile. Repeated from Feb-April, 1997, 0.3 miles. | Salmon Trollers conducted survey from Dec 1996-Jan. 1997, 1 mile. Repeated from Feb-April, 1997, 0.3 miles. | Salmon Trollers conducted survey from Dec 1996-Jan. 1997, 1 mile. Repeated from Feb-April, 1997, 0.3 miles. | |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| | | | | | |
| 70021 Casper Ck, Graphite Ck., Garcia River | mainstem Garcia | (CFL) % closure visually est. above bankful at 100 ft. intervals (decid. & everg.), averaged for reach. | | | |
| | Casper Creek | | | | |
| | Graphite Creek | | GWAG notes. | | 1988 aerial photos note lg. drop-off at mouth. GWAG notes barrier where road crosses stream. |
| | | | | | |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| 70022 Beebe Creek, Garcia River | mainstem Garcia | | CDF GIS. L-P SYP Channel Network Map 1997. CFL; with clinometer at 100 ft. intervals along sample reaches and averaged. | | | (CFL) bankful channel width at 3 prominent riffles w/ a surveying tape. GWAG notes mainstem wide with shallow pools. | (CFL) Average of 10 equally spaced depths across bankful channel at 3 riffles w/stadia rod. |
| | Beebe Creek | F&G 1989 stream survey estimated flow over log. | From topos LFA; L-P SYP Channel Network Map 1997. | | | | |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| 70022 Beebe Creek, Garcia River | mainstem Garcia | Measured out from bankful at 3 riffles (same spot as bankful and pebble cts.). averaged from 3 sites for overall v.w. for reach. | Aerial photos 1952 & 1988. LFA. L-P SYP 1997 Channel Sensitivity map from slope and confinement; method unknown. (LFA) | | L-P SYP 1997 Channel Substrate Predicted Particle Size map. | |
| | Beebe Creek | | L-P SYP 1997 Channel Sensitivity map from slope and confinement; method unknown. (LFA) | | F&G stream survey 1989. L-P SYP 1997 Channel Substrate Predicted Particle Size map. GWAG observations. | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| 70022 Beebe Creek, Garcia River | mainstem Garcia | | Wolman pebble cts. in 3 potential spawning riffles. 100 particles. Several indices of substrate size calculated and averaged for reach. | (CFL) Inventories within bankful channel for entire reach, as per Bilby and Ward (1989). | 3 pools/reach residual depth, residual length, and residual width. V=(1/12pi)x(l, w, d) | FrOG collected near Hot Springs Camp Aug.-Oct. 1994.GWAG notes mainstem wide with warm temps. |
| | Beebe Creek | | | | | |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| 70022 Beebe Creek, Garcia River | mainstem Garcia | | | | | GWAG notes mainstem wide with shallow pools. |
| | Beebe Creek | | F&G 1989 pop. survey using Smith-Root Type VII electrofisher. | | | F&G 1989 fish pop. stream survey of 100 ft. w/hab. types. |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| 70022 Beebe Creek, Garcia River | mainstem Garcia | (CFL) % closure visually est. above bankful at 100 ft. intervals (decid. & everg.), averaged for reach. | GWAG notes mainstem wide with shallow pools. | | |
| | Beebe Creek | | F&G 1989 fish pop. stream survey of 100 ft. noting cover. | F&G 1989 stream survey reported insects. | GWAG observations of bedrock barrier near Garcia Haul Road. |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | F&G 1967 stream survey w/summer flows and winter predictions. | CDF GIS. L-P Channel Network map in SYP, 1997. | | | GWAG notes wide channel. | |
| | South Fork | F&G stream surveys Aug. 1987, Oct.1988, 89, 91, 92. GWAG notes 1997. | CDF GIS (source??). L-P Channel Network map in SYP, 1997. GWAG notes. | | | F&G 1987-92. L-P SYP 1996. | |
| | Fleming Creek | F&G stream surveys measured flow in Aug. 1987 & Oct. 1989, 90, Nov. 1991 & Oct. 1992. | From topos. L-P SYP Channel Network Map 1997. | | | F&G 1987-89 & 1991-92 stream surveys. | |
| | Little South Fork | | | | | | |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | | 1952 & 1988 aerial photos. L-P Channel Sensitivity Map SYP 1997. | | L-P SYP 1997 Channel Substrate Predicted Particle Size model. | GWAG notes braided/aggraded sediment load. |
| | South Fork | | L-P Channel Sensitivity Map SYP 1997. | | F&G stream surveys 1887-89 & 1991-92, est. sub. comp. L-P Channel substrate Predicted Particle Size map. | |
| | Fleming Creek | | GWAG notes upper reaches well confined. L-P SYP 1997 reports. | | F&G stream surveys 1887-89 & 1991-92, est. sub. comp. L-P Channel substrate Predicted Particle Size map. F&G McNeil samples at mouth in late 1980's. | GWAG notes high instream-stored sediment. |
| | Little South Fork | | | | | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | | | | | FrOG hobo temps on mainstem above S.Fork.1995. CFL consultant 1995 installed hobo. |
| | South Fork | | | L-P 1995 stream survey. | L-P 1995 stream survey pool depths. Salmon Trollers 1989-90 spawning survey, mean pool depth. | Salmon Trollers winter spawning survey 1989-90. FrOG hobo temp at mouth 1995-96. L-P 1994-95 stowaways at mouth. GWAG notes. |
| | Fleming Creek | | | | | GWAG notes good canopy, prob. good temps. |
| | Little South Fork | | | | | |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | | F&G 1967 stream survey reported poor spawning hab. due to high winter flows. GWAG notes spawning downstream of mouth of S. Fork. | | | F&G 1967 stream survey. GWAG notes nice bedrock pools. |
| | South Fork | | F&G stream surveys 1987-89 and 1991-92 counted fish/m2. . F&G 1988 planted Noyo River coho. Salmon Trollers spawning survey 1989-90, 90-91 & 96-97. L-P 1994-96 pop dist. #s at 3 locs on S. Fork. GWAG notes 1997 of abundant steelhead and hist. coho. | Salmon Trollers spawning survey 1989-90, 1990-91 1996-97. F&G stream surveys est. spawning substrate/hab. 1987-89 & 1991-92. | Salmon Trollers spawning survey 1989-90, 1990-91 1996-97. | F&G stream surveys 1987 89 and 1991-1992. L-P 1995 stream survey. |
| | Fleming Creek | | F&G stream surveys 1987-89 & 1991-92 counted fish/m2. L-P 1994-96 pop dist. #s | F&G stream surveys est. spawning substrate/hab.1987-89 & 1991-92. | | F&G stream surveys 1987 89 & 1991-92. |
| | Little South Fork | | GWAG notes 1997 of abundant steelhead and hist. coho. | | | |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | | GWAG notes 1997 simple channel, little cover. | | |
| | South Fork | F&G stream surveys 1987 89, 1991-92. | F&G stream surveys 1987 89 and 1991-92. L-P 1995 stream survey. | | GWAG notes sediment barriers where water flows underground in late summer. |
| | Fleming Creek | F&G stream surveys 1987 89, 1991-92. | F&G stream surveys 1987 89 & 1991-92. | | GWAG notes culvert which blocks fish passage. |
| | Little South Fork | | | | |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | | F&G 1967 stream survey reported poor spawning hab. due to high winter flows. GWAG notes spawning downstream of mouth of S. Fork. | | | F&G 1967 stream survey. GWAG notes nice bedrock pools. |
| | South Fork | | F&G stream surveys 1987-89 and 1991-92 counted fish/m2. . F&G 1988 planted Noyo River coho. Salmon Trollers spawning survey 1989-90, 90-91 & 96-97. L-P 1994-96 pop dist. #s at 3 locs on S. Fork. GWAG notes 1997 of abundant steelhead and hist. coho. | Salmon Trollers spawning survey 1989-90, 1990-91 1996-97. F&G stream surveys est. spawning substrate/hab. 1987-89 & 1991-92. | Salmon Trollers spawning survey 1989-90, 1990-91 1996-97. | F&G stream surveys 1987 89 and 1991-1992. L-P 1995 stream survey. |
| | Fleming Creek | | F&G stream surveys 1987-89 & 1991-92 counted fish/m2. L-P 1994-96 pop dist. #s | F&G stream surveys est. spawning substrate/hab.1987-89 & 1991-92. | | F&G stream surveys 1987 89 & 1991-92. |
| | Little South Fork | | GWAG notes 1997 of abundant steelhead and hist. coho. | | | |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| 70023 South Fork | mainstem Garcia | | GWAG notes 1997 simple channel, little cover. | | |
| | South Fork | F&G stream surveys 1987 89, 1991-92. | F&G stream surveys 1987 89 and 1991-92. L-P 1995 stream survey. | | GWAG notes sediment barriers where water flows underground in late summer. |
| | Fleming Creek | F&G stream surveys 1987 89, 1991-92. | F&G stream surveys 1987 89 & 1991-92. | | GWAG notes culvert which blocks fish passage. |
| | Little South Fork | | | | |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| 70024 Rolling Brook | mainstem Garcia | MCWA 1996-97. | CDF GIS | 2 x-secs at Eureka Hill Bridge, (Jackson, 1996) | | | |
| | Mill Creek | GWAG notes subsurface flows during summer due to sediment delta at mouth. F&G 1967 stream survey. | CDF GIS. L-P Channel Sensitivity map and Channel Network map, SYP 1997. | | | F&G 1967 stream survey. | |
| | Rolling Brook | F&G 1967 est. at mouth. F&G 1987 measured summer flow. | CDF GIS. L-P Channel Sensitivity map and Channel Network map, SYP 1997. | | | F&G 1967 stream survey. F&G 1987. L-P 1995 habitat survey. | F&G 1967 stream survey. |
| | Lee Creek | F&G 1989 stream survey. L-P 1996 pop. dist. survey. | CDF GIS. L-P Channel Sensitivity map and Channel Network map, SYP 1997. | | | F&G 1989 stream survey. | |
| | Hutton Gulch | F&G 1967 stream survey estimates. Save Our Salmon memo 1986 observation of underground flow. CDF confirms. | CDF GIS. L-P Channel Sensitivity map and Channel Network map, SYP 1997. GWAG notes. | | | F&G 1967 stream survey. | |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| 70024 Rolling Brook | mainstem Garcia | | | | Oct. 1992, USGS measured surface bed material along transect. Dec 1992-Feb 1993 USGS measured particle dist. of bedload. | USGS Dec 1992-May 1993 measured suspended sediment from Eureka Hill Bridge (PWA gravel management report). |
| | Mill Creek | | F&G 1967 stream survey. L-P Channel Sensitivity map, SYP 1997. | | F&G 1967 stream survey. L-P Channel Substrate Predicted Particle Size map, SYP 1997. | GWAG notes subsurface flows due to sediment delta mouth. |
| | Rolling Brook | | F&G 1967 stream survey notes. L-P Channel Sensitivity Map, SYP 1997. | | F&G stream survey in 1967 & 1987. L-P 1995 hab.typing est. subsurface fines. L-P Channel Substrate Predicted Particle Size map, SYP 1997. | GWAG notes subsurface flows due to sediment delta mouth. |
| | Lee Creek | | L-P Channel Sensitivity Map SYP 1997. | | F&G 1989 stream survey. L-P SYP 1997 Channel Substrate Predicted Particle Size model. | |
| | Hutton Gulch | | L-P Channel Sensitivity Map SYP 1997. GWAG notes. | | F&G 1967 stream survey. F&G 1978 THP review. 1986 Save Our Salmon memo. CDF memo 1987. L-P SYP 1997 Channel Substrate Predicted Particle Size model. GWAG notes | |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| 70024 Rolling Brook | mainstem Garcia | | | | | |
| | Mill Creek | | | | F&G 1967 stream survey notes. | F&G 1967 stream survey notes. FrOG at mouth since 1995. |
| | Rolling Brook | L-P 1995 hab.typing est. pool tail embedd. | | | | F&G 1967 and 1987 measured temp. FrOG at mouth since 1994. L-P 1995 summer temps. |
| | Lee Creek | | | | F&G 1989 stream survey. | F&G 1989 stream survey. FrOG summer temps since 1994. |
| | Hutton Gulch | | | | F&G 1967 stream survey predicting | F&G 1967 stream survey. F&G 1977. FrOG from mouth in 1995. |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| 70024 Rolling Brook | mainstem Garcia | | | | | |
| | Mill Creek | | L-P pop. dist. survey by electroshock, 1996. F&G 1967 stream survey counted fish. | F&G 1967 stream survey notes. | | F&G 1967 stream survey notes. L-P pop. dist. survey 1996. |
| | Rolling Brook | | F&G 1967 notes, F&G 1987 electrofished. L-P 1994-96 electrofished. GWAG notes. | F&G 1967 stream survey notes spawning gravels. | | F&G 1967 stream survey notes hab. types and spawning gravels. F&G 1987 hab. types. L-P 1995 hab. typing one one reach. GWAG notes instream structures in lower 1 mile. |
| | Lee Creek | | F&G 1989 stream survey observations. L-P 1996 pop. dist. survey. GWAG notes hist. coho migrations. | | | F&G 199 stream survey. GWAG notes instream structures. |
| | Hutton Gulch | | F&G 1967 stream survey observations. GWAG notes 1997. Save Our Salmon raised salmonids in ponds at mouth in `970s&80s. | | | F&G 1967 stream survey. |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| 70024 Rolling Brook | mainstem Garcia | | | | |
| | Mill Creek | | F&G 1967 stream survey notes. | F&G 1967 stream survey notes. | F&G 1967 stream survey noted log jam barrier to migration and gradient in 2nd and 3rd tribs.. |
| | Rolling Brook | | F&G stream survey 1967, 1987. L-P habitat typing 1995. | F&G 1967 notes. | F&G 1967 notes. |
| | Lee Creek | | F&G 1989 stream survey. | | |
| | Hutton Gulch | | F&G 1967 stream survey. | | F&G 1967 stream survey noted steep gradient. F&G, CDF and Save Our Salmon all note subsurface flows. |

| SWRCB no., Subwatershed | monitoring reach | flow | channel gradient | cross-sections | longitudinal profiles | bankful width | bankful depth |
|---|---|---|---|---|---|---|---|
| 70025 North Fork | North Fork | Late summer flows measured (WEP 1992). 0.5 miles up from mouth wter goes sub-surface in summer** (LFA, 1997). | (CFL) 3 sites with clinometer at 100 ft. intervals along sample reaches and averaged. from topos, (LFA, 1997) | CFL (1989-96). | | (CFL) bankful channel width at 3 prominent riffles w/ a surveying tape | (CFL) Average of 10 equally spaced depths across bankful channel at 3 riffles w/stadia rod. |
| | Alder Creek | | | | | | |
| | Olsen Gulch | | CDF GIS (LFA 1997). | MCRCD 1995. | | F&G 1967. | F&G 1967. |
| | John Olsen Creek | GWAG (LFA 1997). | GWAG (LFA 1997). | | | | |
| | Garcia River | discharge at bankful higher than expected (Cafferata), steep hydrographs. MCWA, (1996-97) | CDF GIS (LFA 1997). | 3 x-secs at Connor Hole (MCWA, RCD WA 1991; Jackson, 1997), MCWA 1996-97. | | GWAG notes wide channel (LFA, 1997), Jackson, (1997). | Jackson 1997 (LFA, 1997) |
| | | | | | | | |
| 70026 Hathaway Creek | Hathaway Creek | F&G survey 1986. | CDF GIS (LFA 1997). | | | | |
| | Allen Gulch | | LFA 1997. | | | | |
| | lower 7 miles & estuary | Late summer flows measured by Pygmy flowmeter (WEP 1992). Discharge at bankful higher than expected (Cafferata), steep hydrographs. | CDF GIS (LFA 1997). | 40 x-secs (WEP 1992). 2 x-secs on Kendall property, (MCWA, RCD WA 1991; Jackson, 1996). | Done for WEP 1992, from topos. | WEP, 1992. Leopold & McBain 1996. | WEP, 1992. Leopold & McBain 1996. |

| SWRCB no., Subwatershed | monitoring reach | valley width | confinement | turbidity | substrate composition | sediment |
|---|---|---|---|---|---|---|
| 70025 North Fork | North Fork | Measured out from bankful at 3 riffles (same as bankful and pebble cts.). averaged from3 sites for overall v.w. for reach. | Very confined **(LFA, 1997). | CFL (199?). | !967 F&G survey. CDF memo 1989 (LFA, 1997). McNeil samples (CFL, 1989-1995; G-P 1994). | McNeil samples (CFL, 1997; G-P 1994) |
| | Alder Creek | | | | | high sediment in creek **(LFA). |
| | Olsen Gulch | | F&G 1967. | | 1967 F&G survey. | lots of sediment instrea**(LFA, 1997). |
| | John Olsen Creek | | GWAG (LFA 1997). | | GWAG (LFA 1997). | |
| | Garcia River | | RWCQB, EPA(LFA, 1997), Jackson (1997). | | Jackson (1997). | |
| 70026 Hathaway Creek | Hathaway Creek | | LFA (1997). | | F&G survey 1986. | |
| | Allen Gulch | | Flooded at mouth channel confined ((LFA, 1997). | | | |
| | lower 7 miles & estuary | WEP, 1992. Leopold & McBain 1996. | WEP, 1992. Leopold & McBain 1996. | | WEP 1992 pebble counts, AT&T sed. sampling (Pacifc Watersheds Assoc., 1994) , P.Williams 1996. | Sediment strata trenches at 4 estuary sites and one adjoining field. AT&T sed. sampling (Pacifc Watersheds Assoc., 1994) |

| SWRCB no., Subwatershed | monitoring reach | embeddedness | pebble counts | woody debris | pools | temperature |
|---|---|---|---|---|---|---|
| 70025 North Fork | North Fork | | (CFL 1997) Wolman pebble cts. in 3 potential spawning riffles. 100 particles. Several indices of substrate size calculated and averaged for reach. | (CFL) Inventories within bankful channel for entire reach, as per Bilby and Ward (1989). (LFA, 1997). | 3 pools/reach residual depth, residual length, and residual width. V=(1/12pi)x(l, w, d). Good pools upstream (LFA, 1997) | G-P 1994. |
| | Alder Creek | | | | | |
| | Olsen Gulch | | | Sections w/good LWD** (LFA, 1997). | Sections w/good pools** (LFA, 1997). | F&G, 1967. |
| | John Olsen Creek | | | | | GWAG (LFA 1997). |
| | Garcia River | | | | | USGS (1964-79) |
| 70026 Hathaway Creek | Hathaway Creek | | | | | FrOG (??) |
| | Allen Gulch | | | | | |
| | lower 7 miles & estuary | WEP Habitat Typing 1992 | WEP 1992 pebble counts | | Pool depth improving, pool bottoms may be low in DO (LFA, 1997) | Habitat typing recorded late summer temps. for river mile .86-8.31, (WEP 1992), FrOG 1994-97. MCWA, 1997. |

| SWRCB no., Subwatershed | monitoring reach | dissolved oxygen | fish | redds/spawning substrate | carcasses | habitat types & distributions |
|---|---|---|---|---|---|---|
| 70025 North Fork | North Fork | | WEP 1992, Direct Underwater Observation Method, (Hankin and Reeves,) and ocular est. river mile 0.5-5.9. F&G 1967. G-P 1994. | G-P (1994). | G-P (1994). | MCRCD WEP 1992 Hab. typing, river mile .5-5.05; CDF&G (1967, 1983), CFL 1997 |
| | Alder Creek | | F&G survey**(LFA). | | | |
| | Olsen Gulch | RWQCB 1989-90, MCWA 1996 | F&G 1967 (LFA, 1997). | | | F&G 1967. Monschke 1995 (LFA, 1997). |
| | John Olsen Creek | | no modern fish data | Silted gravels, ok for spawning?**(LFA, 1997). | | GWAG (LFA 1997). |
| | Garcia River | MCWA 1996 | 1952 F&G study, active spawning. Cressey 1993 electrofished. | potential spawning and rearing habitat | | F&G 1953, P. Williams 1996. |
| | | | | | | |
| 70026 Hathaway Creek | Hathaway Creek | | F&G survey 1986 | | | F&G survey 1986. |
| | Allen Gulch | | no modern fish sightings (LFA, 1997). | | | |
| | lower 7 miles & estuary | MCWA 1997, Water Quality tests by NCRWQCB 1989-90. | WEP 1992, Direct Underwater Observation Method, and ocular est. Three sites in estuary seined. P.Williams & Assoc. (1996), F&G 1953. | | | Habitat typing , river mile .86-8.31, RCD for WEP (1992). F&G 1987, P.Williams & Assoc. (1996). |

| SWRCB no., Subwatershed | monitoring reach | canopy | instream cover | invertebrates/ food supply | barriers |
|---|---|---|---|---|---|
| 70025 North Fork | North Fork | (CFL) % closure visually est. above bankful at 100 ft. intervals (decid. & everg.), averaged for reach. Good alder canopy** (LFA, 1997). | | F&G 1967. | F&G, log jam barriers. (1967). Waterfall 2-4 miles from mouth (LFA, 1997). |
| | Alder Creek | | | | mouth perched above NF forming barrier** (LFA, 1997). |
| | Olsen Gulch | | F&G 1967. | F&G 1967 (LFA, 1997). | F&G 1967 (LFA, 1997) |
| | John Olsen Creek | GWAG (LFA 1997). | | | |
| | Garcia River | | | | |
| | | | | | |
| 70026 Hathaway Creek | Hathaway Creek | F&G 1986. | F&G survey 1986. | | |
| | Allen Gulch | | | | |
| | lower 7 miles & estuary | | F&G 1987, P.Williams & Assoc. (1996). | AT&T bentonite spill survey, Huffman & Assoc. (1992). | Habitat typing river mile .86-8.31 identified barriers, (WEP 1992) |

key

AW - Adopt-a-Watershed
CDF - Calif. Dept. of Forestry and Fire Protection
CDFG - Calif. Dept. of Fish and Game
CFL - Coastal Forestlands, Ltd.
FrOG - Friends of the Garcia River
G-P - Georgia Pacific
L-P - Louisiana-Pacific
MCRCD - Mendocino County Resource Conservation District
MCWA - Mendocino County Water Agency

# APPENDIX D.

## SELECTED PROTOCOLS

1. PLOT LOCATION & SITE MAP
2. STREAM TEMPERATURE
3. CROSS-SECTIONS
4. LONGITUDINAL PROFILES
5. POOL FILLING BY FINE SEDIMENTS - V*
6. CANOPY MEASURES
7. LARGE WOODY DEBRIS
8. RECRUITMENT TREES
9. GRAVEL SAMPLING
10. SUBSTRATE PERMEABILITY
11. SEDIMENT TRANSPORT CORRIDORS (STCs)

# *APPENDIX D.*

# *SELECTED PROTOCOLS*

## *1. PLOT LOCATION & SITE MAP*

## Locating Fixed Stream Plots

There are many sampling strategies employed in stream monitoring studies. The eventual choice of strategies depends on the size of the watershed or sub-watershed and reflects an experimental design or a long term methodology already in place. For example, the Pilot Watershed Monitoring Program designed and trialed by CDF is based on stream morphology and samples the first 1000 meters of a contiguous similar channel type stream reach.

Another common method is to establish stream plots at regular intervals along the channel. These plots may be fixed permanently if possible for long term monitoring. The length of a sample should ideally represent the length of two stream meanders. Upon arriving at a stream this can be measured beginning at the mid-point between two meander turns, continuing upstream past the first mid-point and beyond to the second mid-point. Since the objective is to sample 15% of the selected stream reach, the sample size (two meander lengths) should be 15% of the overall sample reach.

Use the equation ***15% or .15x = sample length***, whereby the sample length is the length of two meanders (measured) and $x$ is the overall sample reach you are trying to determine.

Example: Two meanders measures 50 meters = sample length.

Therefore $.15x = 50$ ***meters*** and $x = 50/.15$, and, $x = 333$ ***meters***. In this case, you should round up your sample reach length to 350 meters.

**Example:** Arrive at the stream, marking 0 as your starting point. (20 M above roads etc...) Begin sampling 50 meters upstream to the top of your plot and then continue upstream 300 meters more to meter location 350. This is the beginning of your second sample from meter 350 to 400. This second sample reach will then stretch up to 700 meters where you will begin your third sample from 700 - 750 meters, extending up to 1050 meters in total.

## Establishing Plot Center

Plot center can be established and monumented using the following two methods:

a) A plot center offset stake should be securely located out of the active channel or possible alternate channels. This offset stake should be placed in one of the four cardinal directions, out of the active channel. The distance from there to the stream plot center (mid-plot) and the azimuth direction should be written on the datasheet and drawn into the sketch. Distances should be rounded to the nearest foot. When revisiting a plot for long term monitoring, check tag on plot offset stake, tree numbers and tree data to make

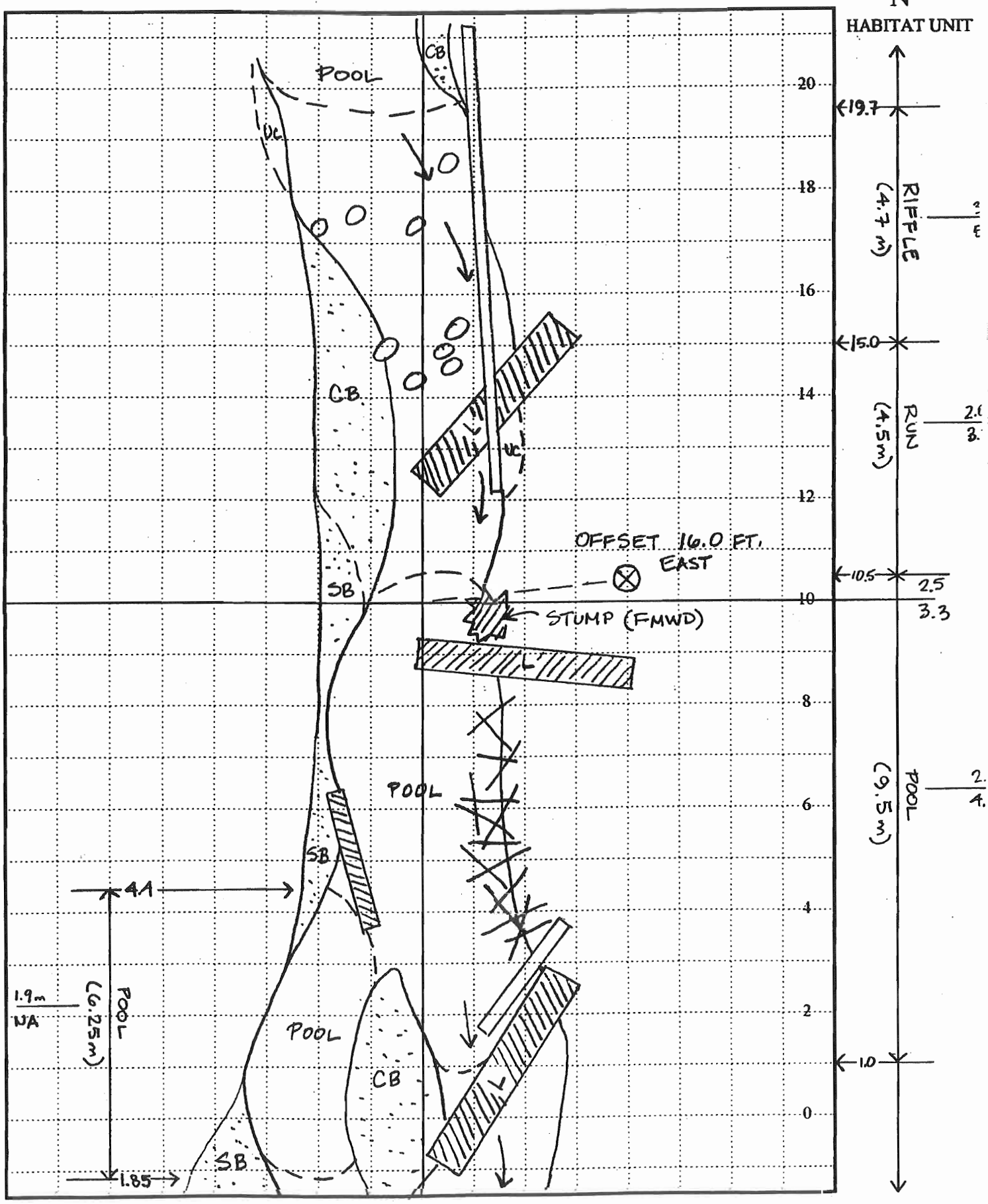
sure that you are in the right plot. If the plot tag is missing, verify your position from a known plot location and make a new tag. Check to see that the offset stake is undisturbed and securely positioned.

b) The second method of plot center reference uses witness trees and works best when property owners do not want permanent plot markers left behind. The plot center should be referenced using three witness trees to maximize triangulation. The trees should be located clearly outside of the active channel and outside of any possible alternate channels. For each witness tree, record the azimuth and distance from the plot center to the tree center in the plot sketch map notes and in the data spreadsheet for that plot. To aid in the location of the witness trees, a plot tag can be attached at either the base or at breast height, facing the stream, or a small blaze can be etched into the tree at the base of the tree (not into the cambium!), facing the plot center. The area can be painted with dayglo paint and a nail can be driven part way into the tree at this low height. Witness trees should be chosen from the largest trees at the site. Smaller trees are often uprooted during high flows. It is easiest to relocate plots when witness trees are greater than 25 inches dbh. If some witness trees have died since the last plot visit, add suitable replacements.

# BFRS STREAM INVENTORY SHEET

Stream GADDIS Crew SD, JS, KC, SB Date 7/14/97

Plot No. 15 Plot Location (m) -180 to -200 m Prepared by J. STELLA



## PLOT NOTES

**Channel:**

**Woody Debris:**

**Habitat:**

**Site Notes:**

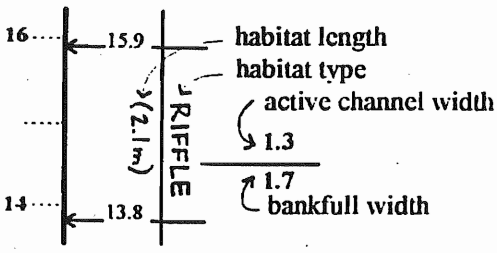
---

## SYMBOL KEY

### North Arrow

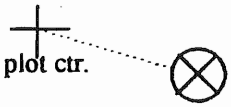
mark True North in circle

### Habitat Unit Dimensions (m)




### Locating Plot Center

indicate offset stake azimuth (cardinal direction) and distance (in feet) from plot center



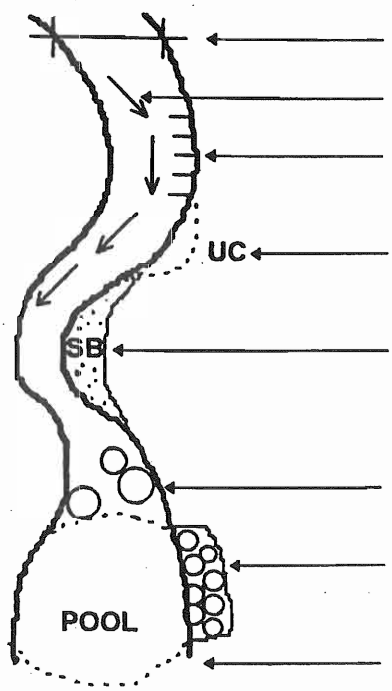

offset 25.0 ft. West

### Prominent Trees

label tree number from vegetation inventory

label species (use Blodgett two-letter code)

### Channel Features




active (wetted) channel

thalweg (deepest channel line)

incised bank

undercut area (eg. bank, trees) (label "UC")

sediment bar--label
"SB" = sand bar
"GB" = gravel bar
"CB" = cobble bar

boulders

man-made retaining wall (label)

pool (label "pool")

### Woody Debris

(Note: "Functional" denotes within active channel and affects observed flow. "Non-functional" denotes within bankfull channel and has no effect on observed flow)

functional small debris and live branches < 10 cm diam.

functional medium woody debris (FMWD) 10-50 cm diam.

non-functional medium woody debris (NFMWD) 10-50 cm diam.

functional large woody debris (FLWD) > 50 cm diam.

non-functional large woody debris (NFLWD) > 50 cm diam.

# *APPENDIX D.*

# *SELECTED PROTOCOLS*

## *2. STREAM TEMPERATURE*

# HOBO® XT

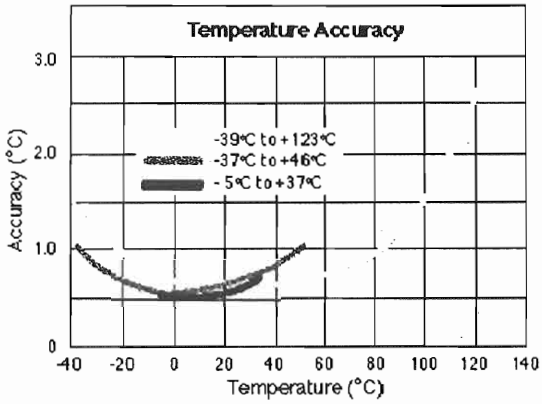
The HOBO XT temperature logger utilizes an external thermistor cable which is ideal for recording temperature in hard-to-reach locations. Start the logger, readout, and plot the data with BoxCar® Pro (Windows), BoxCar® (Windows or Mac) or LogBook® (Mac) software.

## Features

- Three standard ranges: -5°C to +37°C, -37°C to +46°C, -39°C to +123°C
- Two year battery life (user replaceable)
- Precision external thermistor probe on a flexible cable (ordered separately)
- Standard cable lengths are 1, 2 and 6 feet
- Operating temperature of logger is -39°C to +75°C, non-condensing
- Optional submersible case rated to 400' depth
- Small size: 1.8" tall x 1.9" wide x 0.6" thick and 0.9 oz.
- Nonvolatile EEPROM memory retains data even when the battery has been removed
- Stores up to 1800 measurements
- Sampling intervals from 0.5 seconds to 4.8 or 9.0 hours, depending on the software
- Blinking LED light confirms operation
- Data readout in less than thirty seconds
- Data exportable to spreadsheet programs (Lotus, Excel, etc.)

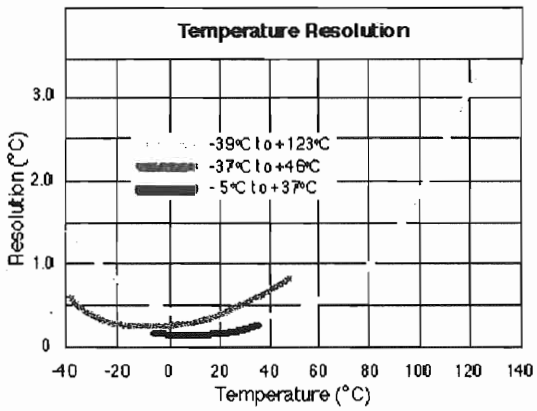
**Temperature accuracy**
The HOBO XT's maximum error is shown below in Plot A. This error assumes that all contributing factors to the error are at their maximum values and are aligned so their values add together. These errors include: thermistor error, resistor value errors and quantization error (step errors in the digital representation of the temperature). In a typical logger all errors will be substantially lower.

**Plot A**




**Temperature resolution**
The HOBO XT's resolution (difference between the temperature steps) is shown below in Plot B. Note the similarity between the resolution (Plot B) and accuracy (Plot A) for the widest range loggers, where most of the error is due to the quantization error.

**Plot B**




**Thermal time constant**
The thermal time constant (90% response to a step change in temperature) of a HOBO XT's external sensor shows a time constant of less than three minutes in air and less than fifteen seconds in stirred water.

D-2374-B

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*Return to Temperature Product List*
*Return to Home Page*

**Request complete product literature and pricing via mail.**

**Contact webmaster@onsetcomp.com with any questions or problems with this service.**
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FFFC
Taylor, 1996

## Summer Water Temperature

Summer water temperature is an important water quality parameter that is a potential limiting factor of juvenile salmonid production; especially coho salmon, steelhead, and coastal cutthroat trout which rear in freshwater for a year or more. The concerns of regulatory agencies of timber harvesting impacts on water temperature (from riparian disturbance and/or sedimentation of pools) has motivated most companies to intensely monitor summer water temperature. With the recent development of inexpensive electronic thermograph units (such as HOBOs, Stowaways, or Dataloggers), summer water temperatures are inexpensive data sets to generate. Once triggered, the thermograph units take temperature readings at established intervals for six or more months. The data are easily downloaded into a computer and stored in spreadsheets for tabular or graphic display of daily maximum peaks and diurnal fluctuations.

The FFFC Technical Committee established its own protocol, combining the temperature monitoring experiences of committee members in various coastal watersheds with information gleaned from the TFW stream temperature survey protocol (Scheutt-Hames et al. 1994). The protocol addresses two primary questions:

- Are temperature thresholds for coho (or other salmonids) being exceeded in a given stream reach?

  If so, what is the temporal and spatial extent of the threshold exceedence?

- If a stream has excessively high summer temperatures, does the stream have cooler reaches or areas of thermal refugia within the warm reaches?

  If so, how much of this preferred habitat exists?

  Are the juvenile salmonids utilizing this habitat?

The protocol to record summer water temperature and assess threshold exceedance entails the following:

- Prior to use, all thermograph units should be calibrated at room temperature and in an ice water bath to insure that they are operating within the manufacture's specified accuracy range. 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?). Calibrate all thermograph units with a high quality laboratory thermometer (no standard recommended, just one of higher quality than a pocket, field-type thermometer) to room temperature and freezing point as follows:

1) When launching, synchronize all thermograph units to a common watch/clock that will be used to time the recording intervals of the reference thermometer. Set the record interval of each thermograph to a short period, six to 30 seconds.

2) Place the reference thermometer and the thermographs in a five gallon pail filled with about three gallons of water that has stabilized overnight to room temperature. Make sure the casings of all thermograph units are completely submerged. Stir the water, just prior to, and during the calibration period to prevent any thermal stratification.

3) After allowing 10 minutes for the thermographs to stabilize; record the time, the reference thermometer temperature, and the thermograph temperatures - for the time interval set when the units were launched for 10 minutes. After all readings are completed, calculate the difference between the reference thermometer and each of the thermograph units for each reading and calculate the mean difference.

4) Any thermographs not operating within their specified accuracy range should be considered suspect. If a particular unit is off on individual temperature readings, but is still precise, then a correction factor (addition or substraction) could be applied to the data. However, if units are inaccurate and imprecise do not use them. Always consider placing the most accurate thermograph units in stream reaches where excessive temperatures are suspected.

5) 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 thermographs in the five gallon pail. Again, make sure that the casings are completely submerged.

6) Repeat step #3 with ice water bath.

7) Calibration should also be repeated when thermographs are retrieved at the end of the sampling season.

8) Always refer to each thermograph by serial number when recording calibration results.

- The number of thermograph units employed would vary with 1) drainage area of the watershed, 2) numbers and sizes of inflow tributaries, 3) changes in elevation, and 4) proximity to coastal fog zone. In all circumstances, a thermograph unit should be located as far downstream as surface water flows during the summer. In watersheds with multiple thermograph units, locate the recorders in a lower/upper or lower/middle/upper distribution.

- Always calculate and record the watershed drainage area above each thermograph location. Record the serial number of thermographs at each sample location. Mark all thermograph locations on a USGS topo map, aerial photo, or GIS map.

- All thermographs should be located at the downstream end of a thermal reach, so as to characterize that entire reach as opposed to local conditions. Generally, a thermal reach is about 600 meters (or 2000 feet) of stream with similar riparian and channel conditions, but lengths will vary depending on stream-specific characteristics. This measure helps insure that thermographs are not located directly below a cool tributary or seep that would alter the true temperature profile of the entire stream reach. Characterizing the influence of cool water inputs (tributaries, springs, or seeps) is discussed in the procedures to identify thermal refugia.

- All thermographs are placed preferably in riffle thalwegs to insure a complete mixing of the water, or other areas of mixed water if riffles are too shallow. This measure insures that thermographs are not selectively placed in cooler areas such as stratified pools, springs, or seeps that would misrepresent a stream reach's temperature profile.

- The time interval between successive temperature readings can vary, however past results indicate that 1.2 to 2.4 hours were adequate intervals to capture daily peaks. The shorter intervals limit the instream duration of the thermographs - 1994 and 1995 HOBO models could operate for three months at 1.2 hours or six months at 2.4 hours.

- Launch thermographs to capture the entire period of interest, which will probably 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).

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

If a temperature threshold is ever reached or exceeded, then additional thermographs should be employed to address the amount of thermal refugia available for juvenile salmonids. The placement of additional thermographs would be dictated by the hypotheses to be tested rather than by a rigid protocol. Additional thermographs should address: 1) the locations and amounts of cold water refugia, 2) the thermal regime of the refugia, and 3) the thermal regime of the habitats actually occupied by the salmonid species of concern.

The following steps should be considered when temperatures above thresholds are recorded:

- Is air temperature contributing to the thermal regime in the stream reach of interest? If so, consider deploying a thermograph to record air temperature. These situations may occur in more inland areas where stream reaches may be exposed to hot, direct sunlight in prairie-type settings.

- If a thermograph in a lower stream reach records excessive temperatures, spatially, where does the temperature break (above/below threshold) occur upstream? Additional thermographs should be distributed along the channel at thermal reaches to determine the spatial extent of the high temperature stream reach.

- Within the stream reach experiencing excessive temperatures an investigation of thermal refugia should occur. Thermal refugia are usually located in three places: 1) thermally stratified pools; 2) below cool water tributaries; and 3) near springs or seeps. This investigation should include:

    1) Quantifying the number of thermal refugia locations within the stream reach of interest. These sites are easily located by snorkeling the stream reach during the afternoon and noting changes in water temperature. Use a handheld thermometer to record the temperature of all cool spots, for comparison to the main stream reach's temperature. A laminated aerial photo or USGS topo map and grease pencil are helpful for marking the location of all thermal refugia. Also note if salmonids are utilizing the refugia during the initial survey.

    2) Estimating the size (area and/or volume) of specific thermal refugia. The most accurate estimate would entail using multiple thermographs spaced accordingly to detect the longitudinal, lateral, and vertical extent of the cool water plume which defined the refugia's boundaries. However, the lack of additional thermographs may require the use of handheld thermometer, snorkeling gear, a tape measure, and water-proof field notebook or dive slate to estimate the size of individual thermal refugia. Conduct this exercise in the afternoon when main channel temperatures are at their highest.

    3) Determining if thermal refugia is, in fact, utilized by juvenile salmonids. Snorkel surveys by Humboldt State University Fisheries students on the South Fork of the Eel River determined that juvenile steelhead (young-of-the-year, 1+, 2+ fish) utilized thermal refugia only when main channel temperatures were excessive (Roelofs, personal communication). The thermal refugia on the South Fork Eel was often located in side channel pools where cool water percolated through main channel alternate point bars.

The FFFC Technical Committee has yet to agree on how summer water temperature data should be analyzed. To date, temperature results have been presented graphically to show diurnal fluctuations and daily maximum peaks. However, protocols should be developed for better analyzing temperature data sets. The following aspects should be considered:

- Establish threshold(s) temperatures for juvenile salmonids. Several thresholds may be appropriate - each one higher and of greater significance to the species of concern.

- Analyze data with respect to: 1) total days that thresholds are exceeded, 2) duration, in minutes or hours, (each day) that thresholds are exceeded, and 3) total time (in hours or in percentage) that thresholds are exceeded during the sampling period.

- The appropriate temperature thresholds could be easily drawn in as a line across the graphic display of the seasonal data. Then the analysis (as suggested in the prior bullet) would focus on all data points above the thresholds.

Establishing temperature thresholds for juvenile salmonids is a difficult task. The existing literature of laboratory and field experiments concerning temperature thresholds of salmonids was thoroughly reviewed by the FFFC Technical Committee (Appendix C). However, the FFFC Technical Committee has not reached a concensus on a single temperature value to adopt as a threshold that impacts juvenile salmonids. Instead the Technical Committee has suggested analyzing summer temperature data with respect to several thresholds cited in the fisheries literature.

# *APPENDIX D.*

# *SELECTED PROTOCOLS*

## *3. CROSS-SECTIONS*

CROSS SECTIONS

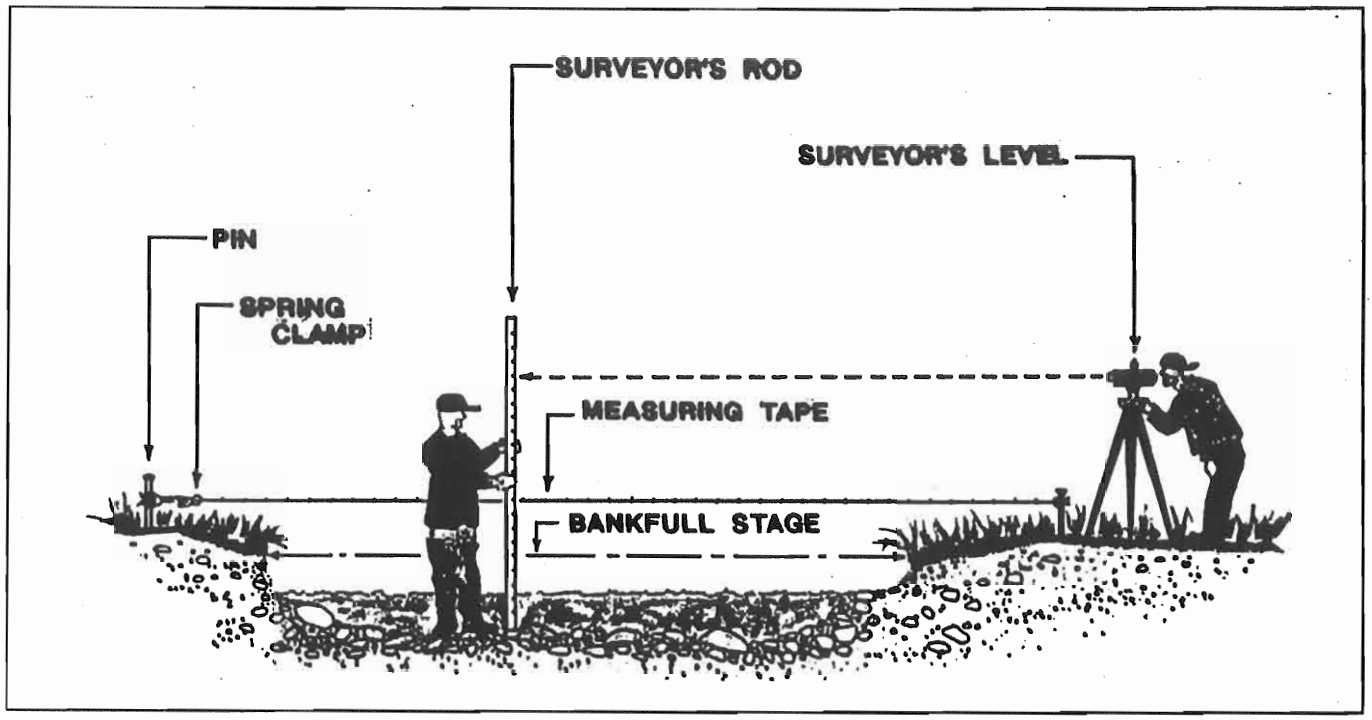


FIGURE 5-15. Measuring a stream channel cross-section.

Rosgen, 1996

## 16-3 Making a Discharge Measurement without a Current Meter by the Use of Floats

Dunne & Leopold, 1978

Because so many planning problems involve flow in channels where no gauging station exists, it is necessary to develop an approximate rating curve by cross-sectional survey and one or more direct measurements of discharge. But the environmental planner may not have easy access to a Price current meter, the standard device for measuring discharge in the United States. Measurement by float gives good results when done with care. Float measurements of velocity are often the only way of obtaining a velocity during a flood, even if a meter is available.

### *Problem*

Measure in the field the discharge in a channel using a cross-sectional survey and float velocity.

### *Procedure*

Equipment needed includes a watch with a second hand, surveyor's rod, sharp knife, notebook, pencil, 100-foot or 30-meter tape, staff gauge consisting of marked lumber, meter stick, enamel plate or other scale for installation, light maul, hammer, and nails.

Choose a straight reach, preferably with an obvious or well-developed pool-and-riffle sequence, and channel banks relatively uniform. Install the staff gauge in a vertical position near the foot of the pool or just upstream of the riffle. The easiest way to put in a staff gauge is to drive vertically a steel fencepost and tie with wire the gauge plate to the steel. The lower end of the gauge is driven an inch or more into the stream bed so that even at the lowest flow the water level can be read on the scale of the plate. Place the gauge plate near the bank but facing the shore from which it will be read. A vertical wooden stake carrying the plate must be braced by diagonals to the bank, but a steel post driven well into the stream bed will stand without braces (Figure 16-3).

A cross section will be measured at or very close to the staff gauge. Stretch a tape across the stream so that it is taut and more or less horizontal. The zero end of the tape is on the left bank (left, facing downstream). The tape is used to measure horizontal position but not elevation.

Very near the tape and above it a cord is stretched. Carpenter's string is best because it is strong and can be stretched taut. The cord is adjusted until it is horizontal at any arbitrary distance above the ground. A string level or hand level is useful to assure that the string is horizontal.

Using the taut string as a datum, measure downward from the string to the ground or stream bed at such horizontal intervals that the cross section is well represented by straight lines drawn from point to point in the plot. The vertical distance of the ground surface below the string is measured with a surveyor's rod held vertically at the chosen location, a reading taken where the string passes the scale on the rod. About 50 points are needed. In a channel 20 feet wide, horizontal spacing of points might be 1 foot. Continue the cross section for one channel width on each side of the stream, so if the channel were 10 feet wide, the cross section should be at least 30 feet long. Note the position of left edge and right edge of water for the present flow. Plot the cross section in the field notebook, and compute the cross-sectional area of the water.

Stretch the tape along the channel bank for a distance equal to at least 10 times the channel width in the straightest reach near the cross section. Cut floats from wooden matches, tree branches, or sticks. There should be about eight pieces of wood large enough to be seen as they float down the channel. Near the upper end of the taped distance, throw in a float a few feet above the beginning of the measurement reach. As the float passes the zero point, note the time on the second hand of the watch. Record in seconds the time the float required to go the measured distance. Record the position of the float relative to the channel centerline, the time of travel, and the distance.

Repeat, using another float, and in total make five to eight float measurements at mid-channel, one-third of the width from the left bank, one-third of the width from the right bank, or other positions. Discard data for any float that becomes stalled in a swirl or hangs up on a rock.

Average the float times, and get an average speed in feet per second or meters per second. Multiply the float velocity by 0.8 to convert surface velocity to mean flow velocity. Multiply mean velocity by cross-sectional area to obtain discharge.

Be sure to note the water surface reading (gauge height) on the gauge plate. This gauge reading and the corresponding discharge give one point on the rating curve.

# *APPENDIX D.*

# *SELECTED PROTOCOLS*

## *4. LONGITUDINAL PROFILES*

Tier 2

# Stream Inventory Project

## *Low Flow Channel (Thalweg) Profile*

### Importance

Major watershed features are determined by a variety of physical processes operating within a stream channel, associated riparian areas, and adjacent floodplain. This parameter was developed to capture basic information on stream gradient and bank condition for assessment, long-term monitoring of stream conditions and changes over time. This protocol will also help establish special study areas (reference reaches) within a watershed for more detailed assessment.

### Method

Teams will establish in-channel longitudinal transects, referenced by permanent benchmarks, to establish channel crossections (covered by a separate protocol), low flow channel longitudinal profile, and bank characteristics (protocol to be developed). Standard survey methodologies will be employed along with field maps of channel features.

### Equipment

- Automatic level and tripod
- Telescoping survey rod
- Engineering field notebook
- Cloth measuring tape (300')
- Hand-held Calculator
- Pocket level
- Small sledge
- Wire flags (3 colors)
- Rebar stakes (2' long)
- Fluorescent paint
- Survey tape (pink)
- Indelible makers
- *Stream Channel Reference Sites: An Illustrated Guide to Field Techniques* by Cheryl Harrelson, C.L. Rawlins and John P. Potyondy. U.S.D.A. Forest Service General Technical Report RM-245. This report contains a much more thorough treatment of various field survey techniques for stream process delineation and is highly recommended for teams conducting using this protocol.

## Constraints

Many creeks will be difficult to access within the channel because of dense vegetation, fallen trees, and private property.

## Quality Assurance

The primary method for insuring accuracy is to perform a "closed" survey. This process is described fully below, but in essence, entails surveying back to the original starting point to assess the degree of additive error in profile readings.

## Data Value

Information gathered from the low flow channel profile provides essential information on the natural processes of channel maintenance. The low flow channel profile also provides data on the location and interval of pools, riffles, and debris jams; important parameters for evaluation of fisheries and amphibian habitat.

## Starting Point for Channel Survey[1]

If the entire stream is being surveyed, the starting point for all data gathering should be the upstream extent of tidal inundation or the nearest upstream point at which the low flow channel (thalweg) is exposed. If a shorter portion of the stream is to be surveyed, begin surveys at the downstream end and proceed upstream.

It is best to conduct a thalweg survey during periods of minimal flow (preferably when the stream is dry) to avoid damage to the aquatic ecosystem and to insure safety of volunteers. Do not attempt this protocol during high flow periods.

## Establishing Starting Point

A basic field survey establishes the horizontal and/or vertical location of a series of points in relation to a starting point (called a benchmark). The benchmark is the original reference point for the survey. The U.S. Geological Survey (USGS) and various city and county public works departments have established a network of reference points throughout the Bay Area. If possible, contact your local public works department for a listing of benchmark locations within the vicinity of the creek you are surveying. If you are working in an urban area, it is possible that a surveyed benchmark is located near your starting point.

In many cases, however, you will need to establish a new benchmark. The elevation of this benchmark may be assumed (100 is normally used; but if the survey will ultimately extend further downstream, a higher number should be used) or tied into a project datum or mean sea level at a later date.

Locate the benchmark outside the channel (and floodplain, if possible) yet near enough to be clearly visible. The best placement is on a permanent natural feature of the site, such as an outcropping of bedrock, the highest point of a boulder, a bridge abutment or other substantial manmade structure (Figure 1). Other methods include driving a 3-4' long 1/2" diameter piece of "rebar" vertically into the ground to within 1/2" of the ground surface (Figure 2). Cover the exposed end with a rebar cap for safety. A spike monument in a healthy large-diameter tree can also be used. This method consists of a 40-80 penny nail driven into the base of a tree (parallel to the ground) with enough of the head exposed to allow the rod to rest securely on the nail (Figure 3). It is also advisable to establish backup benchmarks in case the primary benchmark is moved or destroyed.

In the field notebook, draw a detailed map of the pertinent site features which will allow relocation of the benchmark(s) (Figure 4).

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[1] This protocol draws heavily upon the survey methodology described in the U.S. Forest Service publication Stream Channel Reference Sites: An Illustrated Guide to Field Technique, by Cheryl Harrelson, C.L. Rawlins and John Potyondy (General Technical Report RM-245). Many of the data illustrations are from this report. It is highly recommended that this publication be used as an important supplement to this protocol since it contains more detailed information on protocol elements.

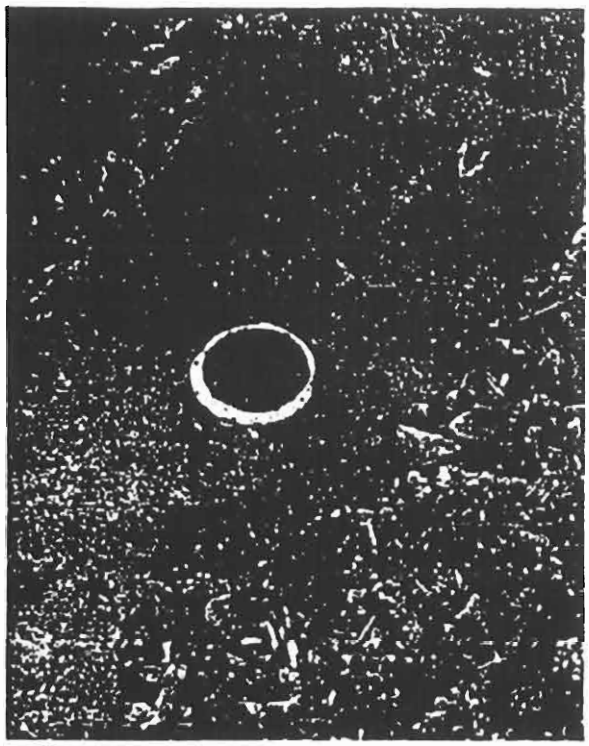

*Figure 1. Monument on bridge abutment.*

*Figure 2. Rebar benchmark with plastic cap.*

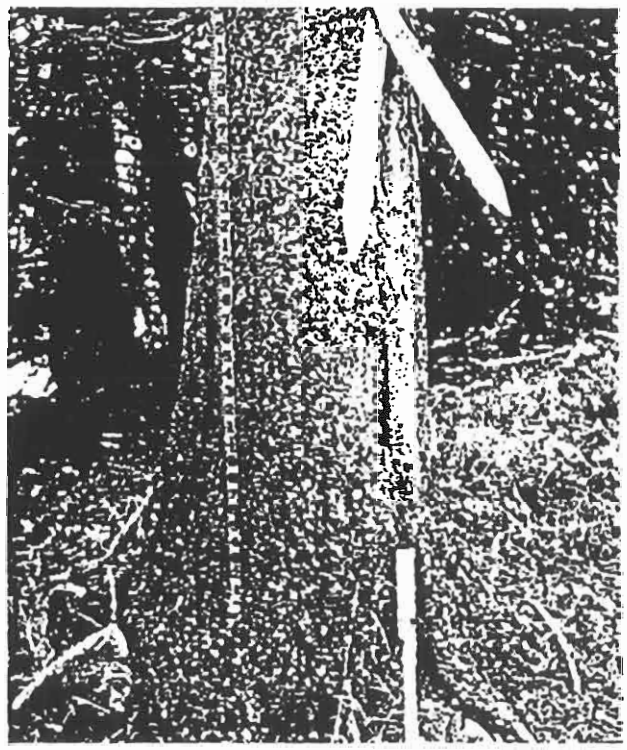

*Figure 3. Spike monument in tree.*

## Laying Out Channel Centerline

Establish the centerline of the average flow of the stream and drive a piece of rebar into the channel substrate. In a wetted channel the centerline may be determined by dividing the wetted area in half. In a dry channel, the average flow area may be determined by examining the channel for evidence of flow such as the outside edge of gravel bars, areas devoid of non-woody vegetation, or remnant patches of dried algae.

Attach the end of the 300' tape to the rebar and begin paying out the tape upstream following the centerline of the channel. Extend the tape entirely and leave the tape in the channel. Use rocks or additional pieces of rebar to bend the tape to conform to channel meanders. At 30 foot intervals, attach small pieces of fluorescent flagging with the station number written as 0+30, 0+60..3+00. These stations will be used by the bank condition team to locate themselves during their

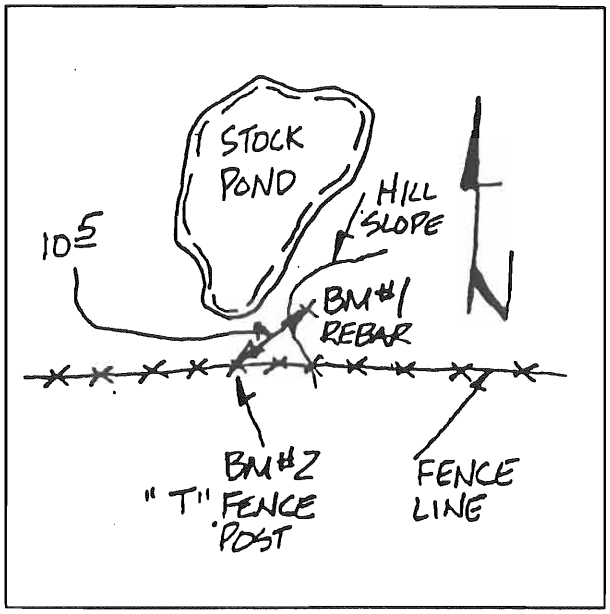


*Figure 4. Site map showing location of benchmarks.*

data collection process. The tape will be used to locate the rod person as he/she traces the path of the low flow channel upstream.

## Setting Up Survey Level

The survey level should be set up in a location which affords a relatively unobstructed view of the creek channel, benchmark or turning point (defined later in this protocol). Maximize the location by picking a sight which will afford a view of the creek as far upstream as possible.

Spread the legs of the tripod to the maximum extent possible to afford stability. Make sure that the legs are well anchored in the soil and that the extended legs do not pose a problem in seeing through the level's eyepiece as the level is rotated. If the surface is uneven, adjust the legs so that the head of the tripod is as level as possible. This will make the leveling of the instrument proceed faster. Make certain that activity around the level is kept to a minimum to insure that it is not accidentally moved. <u>If the level is moved while taking a rod reading the entire set of data will need to be regathered!</u>

If not already done, attach the level securely to the tripod. Move the leveling screws one at a time or in pairs to bring the bubble into the target circle of the vial. Rotate the scope 90° and relevel if necessary. Repeat until the bubble stays level through 360° of rotation. The scope is now ready for use.

### Care of Survey Instruments

Because malfunctions in survey instruments can cause tremendous losses of time and field data (not to mention riparian station budgets), a few general rules are in order.

- When transporting instruments, protect them from impact and vibration. (When you have the choice of allowing your friend, your dog or your level to ride on the seat, choose the level. Secure it in place with a seat belt.)
- Place the level on a firm base in the vehicle rather than on top of other equipment.
- Store many lens caps or tripod caps in the level case while the level is in use.
- Keep the case closed while the instrument is in use.
- Don't run while carrying the level, don't drop it, and *never* fall with it. If you do, the level may need repair and recalibration. (*See Two-Peg Test in U.S. Forest Service publication RM-245.*)
- Never force screws or parts when adjusting or maintaining level.
- Cover or remove level when raining. Never allow the level to become submerged in water.
- *Never leave the level unattended.*

## Profile Leveling

Essentially, profile leveling is a process of differential leveling with many intermediate foresights between turning points. This process is the one used to plot the progress of the low flow channel upstream.

As shown in Figure 8 and 9, foresights taken from setup #1 are each subtracted from HI at this setup to determine the elevations of the intermediate points between BM#1 and TP#1. Find the elevations of points (features in the low flow channel) between TP#1 and TP#2 in the same manner.

| | Differential Leveling of Bench Marks Wild Creek | | | | |
|---|---|---|---|---|---|
| STA | BS | HI | FS | ELEV | Distance Paced |
| | (+) | | (-) | (FEET) | (FEET) |
| | | | | | |
| BM1 | 5.62 | 105.62 | | 100.00 | |
| | | | 3.21 | | 321 |
| TP 1 | 4.87 | 107.28 | | 102.41 | |
| | | | 4.21 | | 299 |
| TP 2 | 4.50 | 107.57 | | 103.07 | |
| | | | 3.85 | | 308 |
| BM 3 | 3.64 | 107.36 | | 103.72 | |
| | | | 4.19 | | 318 |
| TP 3 | 3.30 | 106.47 | | 103.17 | |
| | | | 5.18 | | 275 |
| TP 4 | 3.72 | 105.01 | | | |
| | | | 4.99 | | 302 |
| BM 1 | | | | 100.2 | |

*Figure 7. Field notes for differential leveling.*

These figures also illustrates a "closed loop" survey since the end point of the survey is the first temporary bench mark used in the beginning as an initial reference point. By doing this you detect errors in level accuracy. This method should be employed wherever possible to insure a minimum of error.

It is also essential that data be plotted while still in the field. This helps to catch errors and gives you a better sense of the stream processes at work.

## Thalweg Profile Mapping

As previously mentioned, the profile survey technique is used to plot the course of the low flow channel or thalweg. The key features of the low flow channel are noted by the rod person as the station number (read from the tape laid out along the center line of the channel) is given to the recorder. The instrument person then reads the rod elevation and signals the rod person the data have been recorded. The rod person then moves on to the next significant feature of the low flow channel. At a minimum, measurements of low flow channel should be taken at least every 50 feet in areas with a uniform channel substrate.

A significant feature is anything which affects the flow of water. These may include the following:

- **Pools** - record the inlet and outlet of all pools as well as the deepest portion of the pool. In long pools take several measurements of the pool bottom.

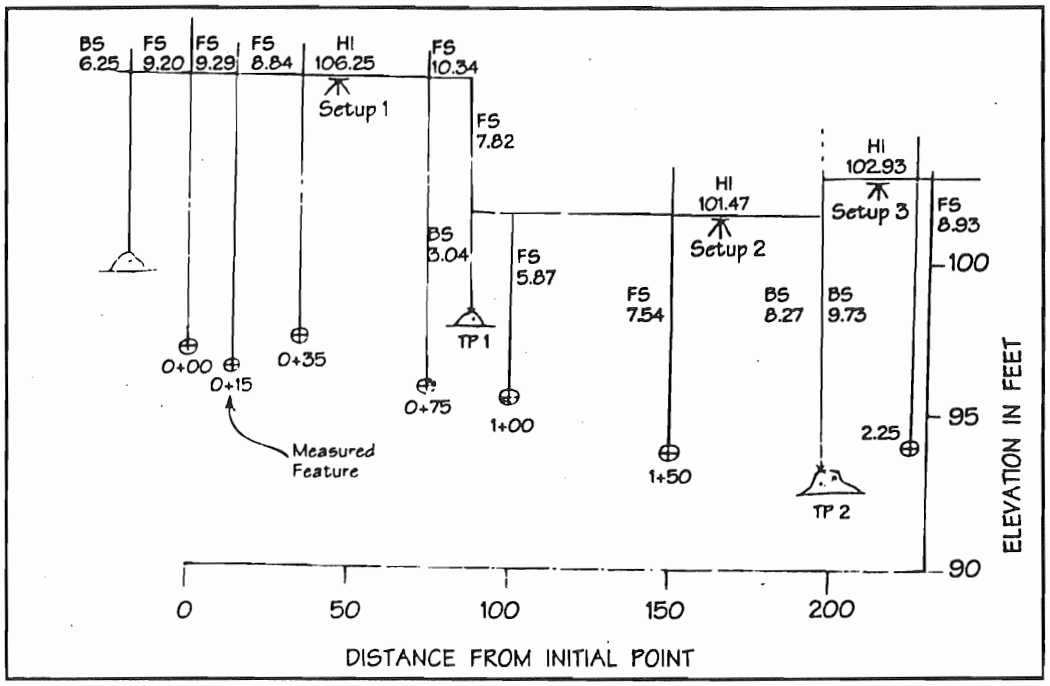


*Figure 8. Diagram of profile leveling.*

- **Riffles** - record the beginning, end and at least one mid-point location.
- **Debris jams or large woody debris** - record the upstream and downstream extent as well as one mid-point.
- **Man-made structures** - record the base and maximum height of the feature if the slope is constant. If the slope is not constant, record enough values to plot the profile of the feature.

Remember that the low-flow channel may abruptly shift from one side of the stream to the other. The rod person needs to be acutely aware of the location of the low flow channel especially in abraded channels where it may be difficult to determine which of the several channels is actually the lowest. Sometimes the occurrence of algal mats or changes in bed material will help establish the location of the active low flow channel.

Profile Leveling - Wild Creek
Thalweg profile

| STA | BS (+) | HI | FS (-) | ELEV (Feet) |
|---|---|---|---|---|
| BM 1 | 6.25 | 106.25 | | 100.00 |
| | | | 9.20 | |
| 0+00 | | | | 97.05 |
| | | | 9.29 | |
| 0+15 | | | | 96.96 |
| | | | 8.84 | |
| 0+35 | | | | 97.41 |
| | | | 10.34 | |
| 0+75 | | | | 95.91 |
| | | | 7.82 | |
| TP 1 | 3.04 | 101.47 | | 98.43 |
| | | | 5.87 | |
| 1+00 | | | | 95.60 |
| | | | 7.54 | |
| 1+50 | | | | 93.93 |
| | | | 8.27 | |
| TP 2 | 9.73 | 102.93 | | 93.20 |
| | | | 8.93 | |
| 2+25 | | | | 94.00 |
| | | | 2.93 | |
| BM 1 | | | | 100.00 |

*Figure 9. Profile leveling data*

# APPENDIX D.

# SELECTED PROTOCOLS

## 5. POOL FILLING BY FINE SEDIMENTS - V*

United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Research Station**

P.O. Box 245
Berkeley
California 94701

Research Note
PSW–RN-414
July 1993

# Measuring the Fraction of Pool Volume Filled with Fine Sediment

**Sue Hilton** **Thomas E. Lisle**

Hilton, Sue; Lisle, Thomas E. 1993. *Measuring the fraction of pool volume filled with fine sediment.* Res. Note PSW-RN-414. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 11 p.

The fraction of pool volume filled with fine sediment (usually fine sand to medium gravel) can be a useful index of the sediment supply and suitable habitat of gravel-bed channels. It can be used to evaluate and monitor channel condition and to detect and evaluate sediment sources. This fraction (V*) is the ratio of fine-sediment volume to pool water volume plus fine-sediment volume. These volumes are computed for the residual portion of the pool that lies below the elevation of the downstream riffle crest. Fine-sediment thickness is measured by driving a graduated metal probe into a fine-grained deposit until the underlying coarser substrate is felt. Water depth and fine-sediment thickness are measured across transects, and volumes are computed by summing products of cross-sectional areas and distances between transects. Replicate measurements of V* were made in 20 pools, and the variability of $V^*_w$, the weighted mean value of V* for a reach, was analyzed in 12 reaches. The largest source of variability in V* was the measurement of fine sediment volume. Topographic irregularities in pools and on riffle crests and effects of variation in discharge on measurement of riffle crest elevation also affected V*. Ten to 20 pools are needed to estimate $V^*_w$ in a reach, depending on acceptable error and variability between pools.

*Retrieval Terms*: fine sediment, pools, monitoring, sedimentation, fish habitat

Experienced hydrologists and geomorphologists can estimate the relative mobility of a streambed by looking at indicators of bedload transport, such as the freshness of bed-surface material. Another such indicator is the amount of fine sediment in pools. Pools in gravel-bed streams commonly contain deposits of fine sediment (mostly sand and gravel) that overlie a coarser substrate of coarse gravel, cobbles, or boulders. In such channels, the fraction of pool volume filled with fine sediment can be used as an index of the supply of mobile sediment. This fraction (V*) is the ratio of fine-sediment volume to pool water volume plus fine-sediment volume. In a previous paper, we investigated the relationship of $V^*_w$, the weighted mean value of V* for a reach, to qualitative evaluations of sediment yield in eight tributary basins of the Trinity River in northwestern California.[1] This study suggested that $V^*_w$ could be used to evaluate sediment supply in gravel-bed channels without directly measuring sediment transport or sediment delivery from hillslopes. In one channel, V* increased abruptly downstream of a sediment source, suggesting that V* could be used to identify significant sediment sources.

We are conducting ongoing research on the relationship between $V^*_w$, sediment supply, and basin characteristics and are attempting to link V* to habitat suitability for aquatic organisms. If this is successful, V* could be used to simultaneously evaluate sediment supply and its effects on aquatic ecosystems. These relationships could then provide a needed link between watershed condition and fish habitat.

This paper describes a method to measure V* and discusses factors affecting the accuracy of estimates of V* and $V^*_w$.

## APPLICATIONS AND LIMITATIONS

V* can be used to evaluate and monitor channel condition and to identify and quantify effects of discrete sediment sources. There are, however, limits to the types of channels where it can be used, and care must be taken in interpreting differences in V* between channels.

The usefulness of V* is limited to channels in which significant volumes of fine sediment can be deposited in pools. To date, we have found that V* can be accurately measured and results consistently interpreted in channels that have:

- a wide range in particle size between armor layers and fine sediment in pools. Sediment supply needs to include at least moderate proportions of sand and fine gravel. We have found V* to be very low and insensitive to sediment supply in basins that are formed in basalt or competent, fine-grained metamorphic or sedimentary rocks, for example.
- stable banks of densely rooted alluvium, bedrock, or armored colluvium.
- a single thread. In braided channels, the volume and proportion of fine sediment can vary widely between anabranches and thus create wide variations in V*.
- gradients less than about 5 percent. We

are uncertain about how V* varies inherently between step pools, which are associated with steep slopes, and bar pools, which are commonly associated with gentle slopes.

Care should be taken in interpreting differences in $V^*_w$ between different stream channels. Knowledge of variations of V* between streams with different geologies and stream types is needed to interpret variations in V* with respect to sediment supply. For example, a value of $V^*_w$ of 0.15 would be expected to represent high sediment supplies in basins underlain by competent metamorphic rocks, but would be considered low for basins in weathered granite. V* values can be expected to be associated with substrate conditions important to aquatic organisms, such as embeddedness or infiltration, but specific responses will depend on the community present, which will in turn depend on the natural range and variability of substrate conditions in the channel.

These problems are not encountered when monitoring changes in $V^*_w$ over time or in using V* to evaluate sediment sources. Volumes of sediment from landslides, for example, can be easily measured from air photos or in the field, but evaluating the intensity, extent, and duration of their impacts on channels has been problematical. $V^*_w$ measurements upstream and downstream of such sources can potentially be used to evaluate and monitor their mobile sediment inputs.

Measuring V* in large rivers has practical limitations, although pools can be sounded and fine sediments probed from tethered rafts. We have measured V* in pools as wide as 30 m and 2000 $m^3$ in volume. Small pools create no logistical problems, but measurement precision may need to be increased in very small pools (<1 $m^3$ in volume). We have measured V* in second- through fifth-order channels.

## METHODS

$V^*_w$ is estimated in a section of a stream channel by measuring the water and fine sediment volume in the residual pool in all of the pools in a study reach and then calculating the weighted average value of V* for the reach.

### Time and Equipment

Two or three experienced people can measure a wadable pool in half an hour to an hour, but accurate measurement of large pools requires a raft, which takes more people and more time. The minimum equipment required is two tapes, chaining pins, and a graduated rod. The rod must be long enough to measure water depth plus fines depth in the deepest part of the pool. A rod made of one-half inch diameter stainless steel probes fine sediment deposits well without bending. Systematic sampling also requires a calculator with a random number generator or a random number table. We use a palmtop computer with a spreadsheet to choose transect locations, enter the data, and calculate V*. This reduces data processing time and provides an opportunity to catch and correct errors in the field.

### Choosing a Study Reach and Identifying Pools

The general location of a study reach is set by the purpose of the study. Reaches may be located upstream and downstream of a sediment source or downstream of a watershed rehabilitation project, for example. The specific location is chosen to avoid complicating factors which might affect V* within the reach, such as intra-reach sediment inputs, braided sections, or tributaries. A reach should include enough pools to provide an accurate estimate of $V^*_w$ for the stream segment. The number of pools needed depends on the variability of V* between pools and on the desired accuracy of the estimate of $V^*_w$. In channels where V* does not vary greatly between pools, 10 to 15 pools are often sufficient (see Discussion).

After a study reach has been selected, the length of the reach is surveyed to identify pools to measure and determine what constitutes fine sediment in this channel. For our purposes, a measurable pool is an area of channel which (1) has a significant residual depth[2,3] (the deepest part of the pool must be at least twice as deep as the water flowing out of the pool at the downstream end); (2) has an essentially flat water surface during low flow (water surface slope <0.05 percent); and (3) includes most of the channel (it must include the thalweg and occupy at least half of the width of the low-flow channel). The specific criteria can vary, as long as they are repeatable and consistent across all reaches compared. We allow for possible variation in depositional patterns between different types of pools by measuring all pools in a reach, regardless of origin, but pool type could be a selection factor if enough pools are available. One should avoid measuring potential pools with unclear boundaries, such as long glides containing small deep areas or small deep areas in rocky channels, because it is difficult to measure such pools consistently.

What constitutes fine sediment in a channel is determined by the distribution of particle sizes and patterns of fine-sediment deposition in the channel. Fine sediment is defined as the material forming the matrix among the gravel framework of the bed material.[4] This material is commonly winnowed from areas of high shear stress, such as riffles, and deposited in pools.[1] Fine sediment in a reach is defined as material which (1) is distinctly finer than the bed surface (median particle size ($D_{50}$) of fine sediment approximately one tenth or less of the $D_{50}$ of the bed surface) and (2) can be distinguished from underlying coarser sediment by probing with the rod. Deposits of fine sediment that are armored (covered by a layer of larger sediment) or densely occupied by roots of riparian plants are not considered available for transport and are not measured. In most channels, fine sediment is defined for working purposes as deposits with a $D_{50}$ of 11 mm or less, but deposits with a $D_{50}$ of 16 mm (medium gravel) can be measured in channels with large surface particle sizes and high transport energy.

### Measuring Riffle-Crest Depth and Defining Pool Boundaries

Calculation of V* requires measuring the volume of water and fine sediment in the "residual" pool. The residual pool is defined as the portion of the pool that is deeper than the riffle crest forming the downstream lip of the pool, that is, the pool that would remain if there were negligible surface flow *(figure 1A)*.[3] The riffle crest is a high point on a longitudinal profile and usually the shallowest place at the downstream end of a pool. During low flows, when the water surface in pools is nearly flat, the riffle crest can be identified by the beginning of the riffled, more sloping water surface.

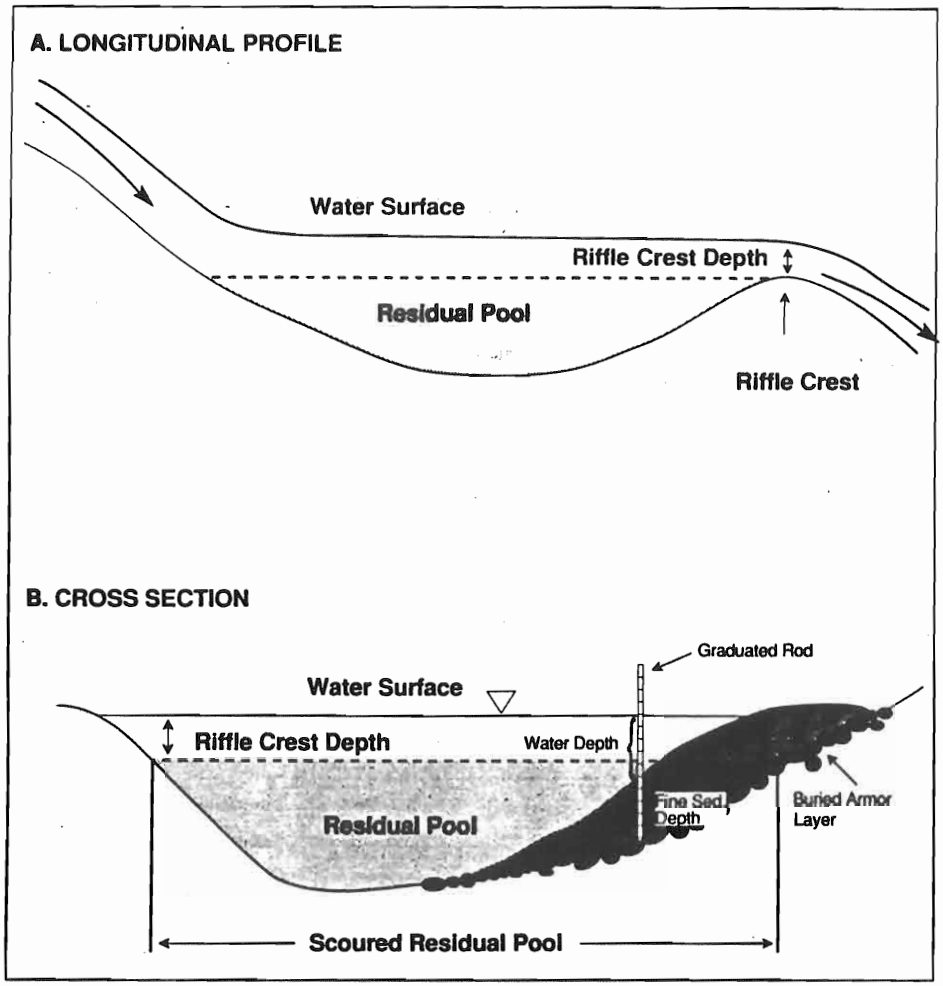


**Figure 1**—(A) Longitudinal profile of a pool, showing the riffle crest and the area included in the residual pool volume. (B) Cross section of a pool, showing measurement of water and fine sediment depth and volume of water and fine sediment in the scoured residual pool.

The first step in calculating V* is to measure the riffle-crest depth and define the pool boundaries. Water depth at the riffle crest is measured by taking the median of several depth measurements taken across the thalweg at the riffle crest *(figure 2)*. Because the riffle-crest depth defines the residual pool, it is important to measure it consistently. Near the riffle crest, the water surface may break in several places, discontinuously, or gradually over a distance. The riffle crest is identified as the shallowest continuous line (usually not straight) across the channel close to where the water surface becomes continuously riffled. Depths are measured across the deepest part of the flow at 5-20 evenly spaced locations along this line, depending on the width and irregularity of the measured section. To consistently measure the same section of the riffle crest, measurements are taken where we expect water to flow at minimum discharge. Thus the measured section occupies a smaller proportion of the total wetted width at high flows than at low flows. Defining and measuring the riffle crest can be confusing. Survey teams should discuss measurement locations and periodically take duplicate measurements to maintain consistency.

Water depths and fine-sediment depths are measured within the "scoured residual pool," which is the residual pool that would result if all of the fine sediment in the pool were removed. If the water surface over the pool is essentially horizontal, the boundary of the scoured residual pool is where water depth plus fine-sediment depth equals riffle-crest depth *(figure 1B)*. Where the water surface is not completely horizontal, as at the upstream ends of many pools, the boundary is where a plane at the elevation of the riffle crest would intersect the streambed with fine sediment removed (see *figure 1A*). In a few situations, we exclude sections of stream channel which would be included in this definition. For example, a long glide extending into a pool may be excluded, even if the glide is deeper than the riffle-crest depth. Similarly, if the upstream end of the pool is a riffle that is deeper than the riffle crest, the upstream boundary of the pool is defined as where the nearly horizontal water surface would begin at a minimum flow.

## Measuring Water and Fine Sediment Volume

Volumes of water and fine sediment in the residual pool are calculated from measurements of water and fine-sediment depth along a series of cross sections in the pool. The basic technique is essentially a systematic sample, with cross sections spaced evenly along the length of the pool. Zero-area cross sections are assumed at the ends of the pool. Depth-measurement points are spaced evenly across each cross section and at either end. The locations of both the cross sections and the depth-measurement points are determined from a random start. The basic system is modified in some cases to improve the accuracy of the estimate. The basic systematic sample will be described first, followed by examples of modifications for specific situations.

*Basic systematic sample (figure 2).*

1. Stretch a tape along the length of the pool, from the upstream end to the furthest point on the riffle crest or along the longest dimension of the pool. This tape must be straight, since bends will distort the volume calculations. If the pool is so irregular that a bend cannot be avoided, divide the pool into sections and measure each separately *(figure 3)*.

2. Draw a sketch map of the pool, showing locations of the upstream end of the pool, riffle crest, areas of fine-sediment deposition, and major features of the pool, such as logs and outcrops.

3. Decide on the number of cross sections and the distance between depth-measurement points. The appropriate sampling intensity depends on the complexity of the pool and on the accuracy required. We take from 4 to 10 cross sections in each pool and

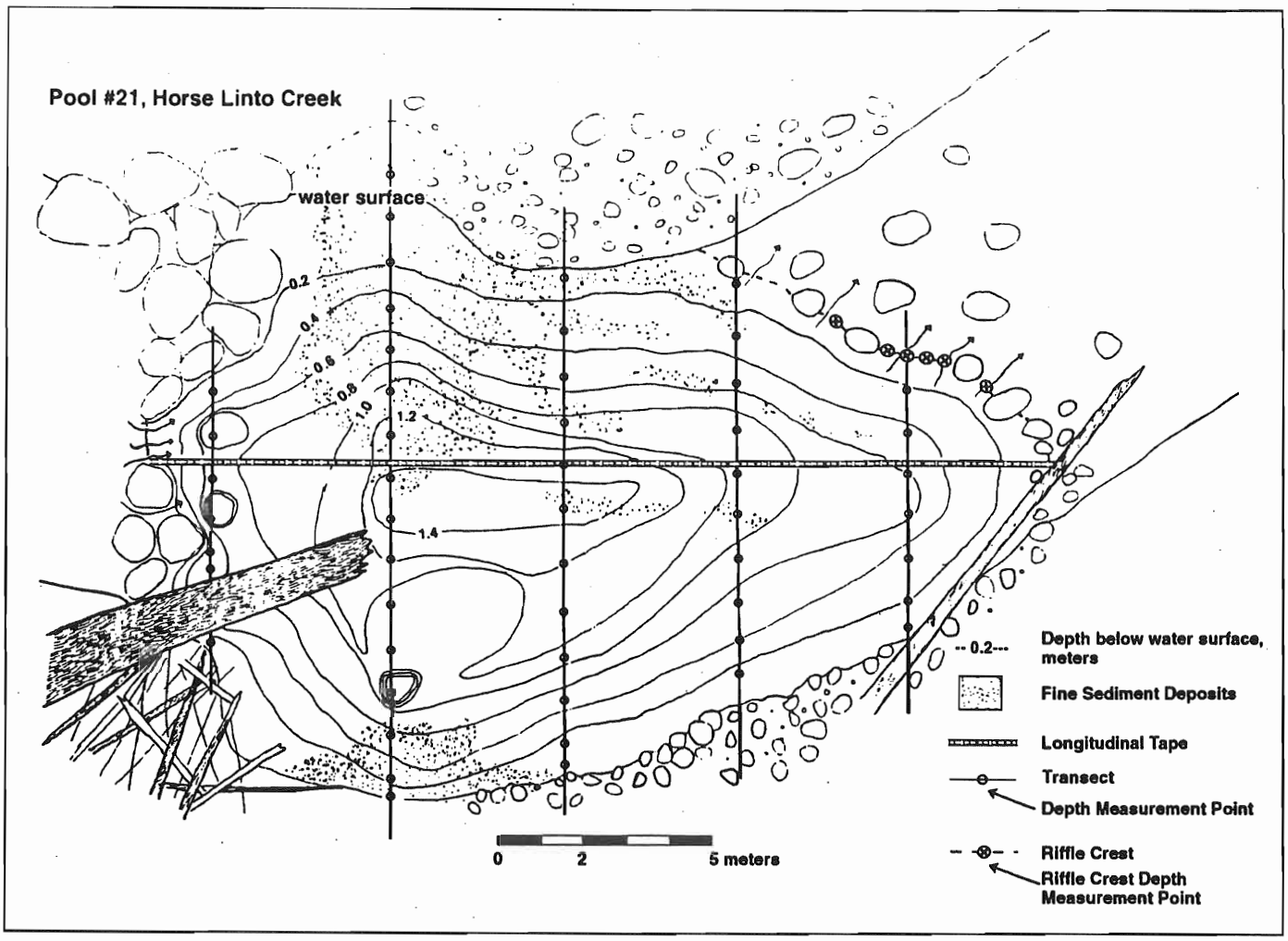


**Figure 2**—Pool #21, Horse Linto Creek, showing location of the longitudinal tape, transects, measurement points for water and fine sediment depth, the riffle crest, and measurement points for riffle crest depth.

set the distance between depth locations to provide 7 to 16 points across the widest cross section.

4. Determine the locations of cross sections and depth-measurement points. Divide the total length of the pool by the number of cross sections to find the distance between sections. Choose a random number between zero and this distance to locate the first cross section, and add the chosen spacing to locate the remaining sections. Choose random numbers between zero and the distance between depth-measurement points to locate the first point in from the edge of each cross section.

5. Run a tape perpendicular to the lengthwise tape at each cross-section location. Measure water depth and the thickness of any fine sediment present at each measurement point with a graduated rod. Fine-sediment depth is determined by probing with the rod until a change in resistance is felt as it strikes coarser material *(figure 1B)*. A small sledge may be useful for probing deep deposits. The cross section begins at the edge of the scoured residual pool, where water depth plus fines depth becomes greater than riffle-crest depth *(figure 1B)*. Record total water depth and fines depth at both edges of the pool, and at regular intervals across the pool as determined in step 4. If a fines deposit deep enough to be included in the scoured pool extends above the water surface, record height above the water surface as a negative water depth.

*Modifications.* The advantage of the basic systematic sample is that it is simple, repeatable, and statistically unbiased. The main disadvantage is that it does not use information about the pool (such as the location of fines deposits) that is available to the people taking the measurements. The basic sample can be modified in a variety of ways, from decreasing the distance between cross sections or depth-measurement points at some locations to dropping the systematic sample entirely and deliberately choosing cross-section or depth-measurement locations or both. Because deliberately chosen locations introduce potential bias, locations are chosen only when it will clearly improve the accuracy of the estimate. These are some common situations in which modifications can improve accuracy:

- In most pools, fines occupy less than one-half of the substrate area. To measure fines volume more accurately, the distance between depth measurement points is usually reduced over fines deposits, and points are added at their edges. Also, cross sections are often added to measure an area of fines more intensely or to define its upstream or downstream limits.

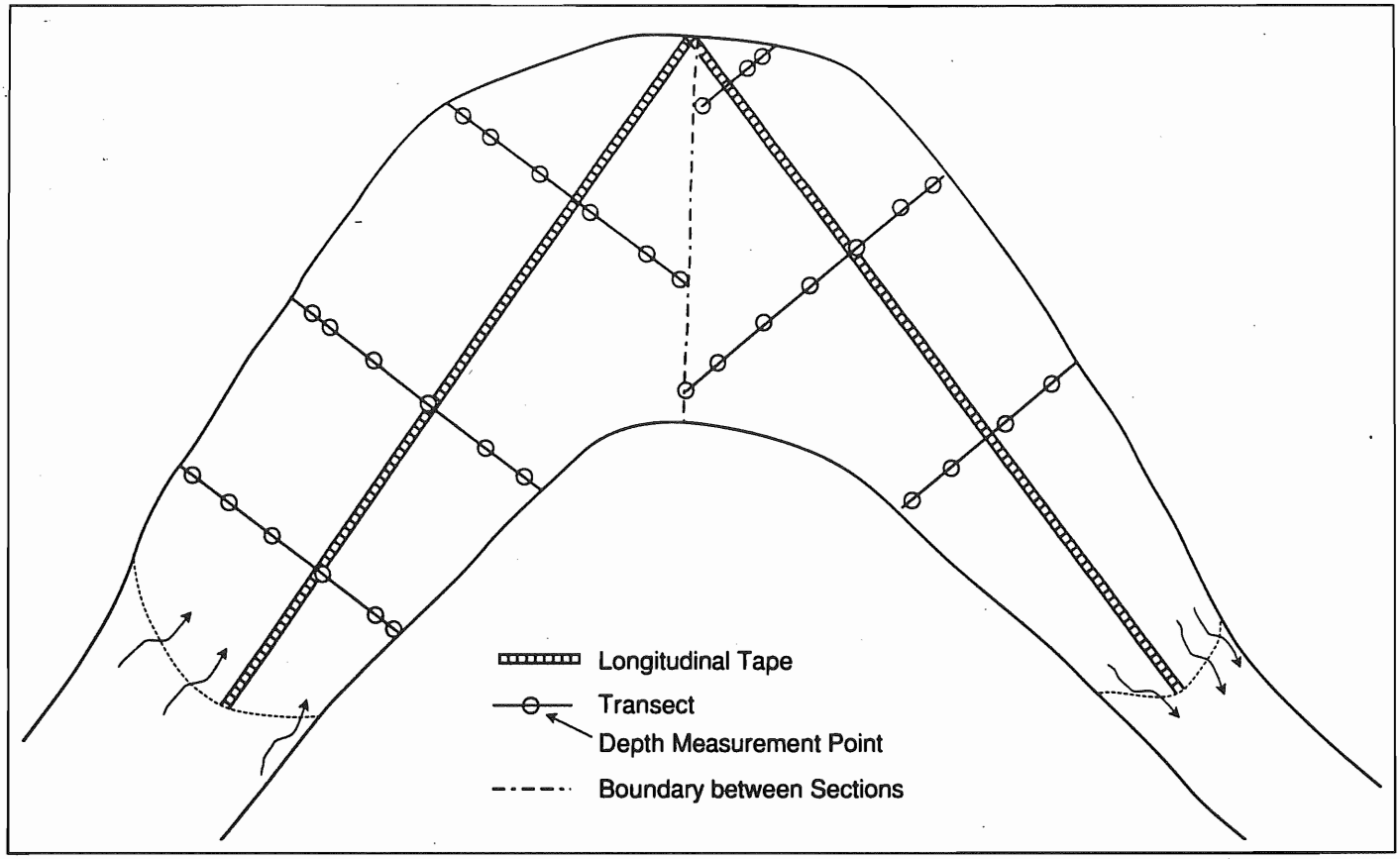


**Figure 3**—Measuring a pool with a bend. The longitudinal tape is strung in two straight segments, transects are located systematically along the tape, and a zero-area cross section is recorded at the location of the bend in the tape.

• If a pool has a deep, complex segment and another segment that is fairly long, simple, and shallow, the pool may be divided into two segments and the more complex segment sampled more intensely. A cross section at the boundary between segments makes the volume estimates for each more accurate.

• Cross sections or depth-measurement points or both may be added to adjust for irregularities in pool shape, such as large rocks, holes, or shoals.

• If most or all of the fines in a pool are in a few discrete deposits, their volume can be measured separately. The pool volume is measured using the basic systematic technique, as though fines in the discrete deposits were absent (fines depth measurements in the deposits are recorded as zero). The residual-pool volume of fine sediment in the deposits is then measured more intensively, and the volumes of the discrete deposits are added to the fine sediment volume measured in the rest of the pool.

**Calculating V* and $V^*_w$**

V* is calculated as follows:

1. Calculate the residual cross-sectional area (the area deeper than the depth at the riffle crest) of fines and water in each cross section.
2. Set a zero-area cross section at the upstream and downstream ends of the pool.
3. Calculate the average residual cross-sectional area of fines and water between each pair of adjacent cross sections.
4. Multiply the average cross-sectional area for each pair by the distance between them.
5. Add the volumes of the water and fine sediment in all the segments to find the totals for the pool.
6. Calculate V* for the pool:

$$V^* = \frac{\text{residual fines volume}}{\text{scoured residual pool volume}}$$

where scoured residual pool volume = residual fines volume + residual water volume.

A sample data set with detailed instructions and examples of the calculations is shown in *appendix A*. Worksheets are available to do these calculations in Lotus 1-2-3 and in SQL*Calc.

$V^*_w$ is the average of the V*'s for all the pools in a reach weighted by the scoured pool volume of each pool. Because V* is the ratio of fines volume to scoured pool volume, the weighted mean for the reach can be simply calculated as:

$$V^*_w = \frac{\Sigma\,(\text{residual fines volume})}{\Sigma\,(\text{scoured residual pool volume})}$$

The variance of the estimated residual water volume, fines volume, and V* for individual pools may be assessed by remeasuring a sample of the pools and treating each measurement as a random sample of all possible measurements of that pool. The variability of $V^*_w$ for the reach can also be estimated, but since V* is a ratio of two estimates (fines volume and water volume), calculating the variability of the weighted

mean is complex. A formula for estimating the variability of $V^*_w$ is in *appendix B*, along with a process for testing for significant differences in $V^*_w$ between reaches.

## ACCURACY OF THE ESTIMATES

The accuracy of the estimated value of $V^*_w$ for a reach depends on the accuracy of the estimates of V* for each pool and on the variability of V* between pools in the reach. To find out how precise our individual pool volume measurements were, we measured variability due to sampling and measurement error by repeating measurements of several pools. We also investigated how discharge at the time of measurement affected the measured surface elevation of the residual pool and consequent values of V*. To find out how variability between pools affected $V^*_w$, we studied the relationship between the estimated value of $V^*_w$ and the variability of the estimate of $V^*_w$ in 12 reaches, eight in the Trinity River watershed and four others in northern California.

### Individual Pool Estimates

Nine pools in Trinity River tributaries were measured three times each in 1990, and six of these were remeasured two or three times each in 1991. For these duplicate measurements, we kept riffle-crest depth and pool length constant and varied the starting point for the systematic sample. The standard deviation of V* ranged from 0.00 to 0.08, and increased slightly with V*. Coefficients of variation ranged from 0 to 170 percent, with the higher values concentrated at very low values of V* *(figure 4)*. The coefficient of variation of V* in a pool was highly correlated to that of the fine sediment volume in that pool (r = 0.995). *Figure 4* also includes the coefficients of variation for five pools in the Salmon River, California, which were measured three times each in 1991. These measurements were taken a week apart, by different people, and riffle-crest depth and pool length varied somewhat between measurements. The standard deviations and coefficients of variation of those pools were similar to those of the other replicate measurements.

### Effect of Discharge on V*

Because we measure only within residual pools, the measured water and fine-sediment volumes (and thus V*) should not vary with discharge. If the riffle crest is always measured in the same place, the riffle-crest depth will increase exactly as much as the water surface of the pool rises, the elevation of the surface of the residual pool (riffle-crest elevation) will be constant, and the same volume will be measured at any discharge. However, because locating the riffle crest and selecting the section to measure are somewhat subjective, there is some potential for error. Systematic errors could occur if the measured riffle-crest elevation is consistently affected by discharge and if V* is consistently affected by riffle-crest elevation. To determine whether discharge affects riffle-crest elevation, we measured riffle-crest elevation (water-surface elevation minus the measured riffle-crest depth) at three pools in Jacoby Creek at four different flow levels. Elevations were measured at extremely low base flows, normal summer base flows, and flows significantly above summer base flows. To find out whether riffle-crest elevation affects V*, V*'s calculated at different riffle-crest depths were compared for sample pools from five creeks in northern California.

Measured riffle-crest elevations in Jacoby Creek tended to be higher at low flows than at high flows, possibly because the width of the minimum flow channel was underestimated at high flows. Riffle-crest elevations did change less than water-surface elevations, however. Maximum changes in water-surface elevation ranged from 0.10 to 0.20 m, whereas changes in riffle-crest elevation ranged from 0.01 to 0.07 m. Maximum changes in residual elevation were equivalent to 10 percent, 25 percent, and 70 percent of the riffle-crest depth of the respective pools at moderately low flows.

To evaluate the effect of an error of this magnitude in riffle-crest elevation on V*, we calculated V* using a riffle-crest depth equivalent to 150 percent of the original value (measured at moderately low flows) in 19 pools. Original values of V* ranged from 0.01 to 0.62. The deeper riffle-crest depths resulted in smaller residual pools, which had higher V* values in 18 of the 19 cases. The mean percent change in V* was 13 percent (16 percent if the negative change was omitted), which corresponded to a mean absolute change in V* of 0.05.

### Variability in $V^*_w$

We calculated the standard error of the estimate of $V^*_w$ for all of the reaches we measured using the formula in *appendix B*. We then modified the formula to predict the number of samples (pools) required to

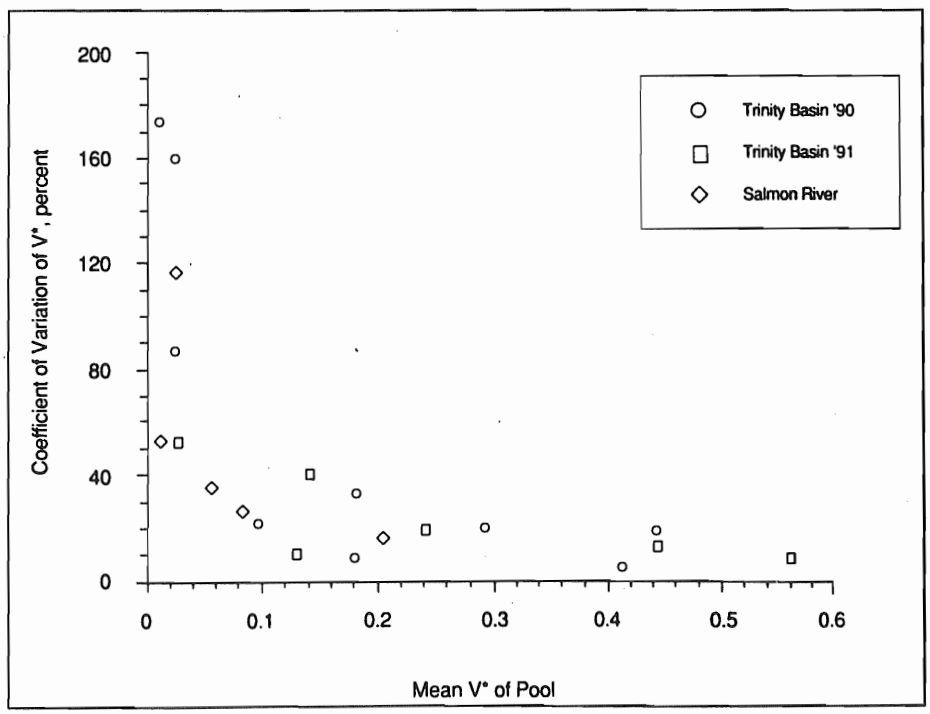


**Figure 4**—Variability of the estimate of V*, from multiple measurements of V* on pools in Trinity River tributaries in 1990 and 1991 and in the South Fork Salmon River in 1991. The coefficient of variation is the percentage ratio of the standard error of the mean to the mean value of V* for each set of measurements.

achieve a standard error of 20 percent of $V^*_w$ for each reach. The standard errors of our reaches, each of which included 10 to 20 pools, ranged from 0.01 to 0.06 and averaged 17 percent of the value of $V^*_w$. The calculated sample size necessary to obtain a 20 percent error in $V^*_w$ ranged from 4 to 26 pools and generally decreased as $V^*_w$ increased. Exceptions were reaches in Grouse Creek, which had extremely irregular pools due to the presence of very large boulders, and in North Fork Caspar Creek, which had irregular pools caused by large woody debris. These two reaches had high standard errors and required higher sample sizes.

## DISCUSSION

The main factor affecting the variability of the estimate of V* for a pool seems to be the amount of fines in the pool. In pools with moderate to high values of V* (V* >0.10), most (80 percent) of the standard deviations were less than 20 percent of the mean V* for the pool. In pools with lower V* values, the standard deviations ranged up to 170 percent of V*. Although it is not practical to expect the same percent errors in these pools as in those with higher V* values (because a small percent of a small number is a very small number), it may still be important to measure V* in these pools more precisely than in pools with a higher proportion of fine sediment. Error in V* was strongly correlated with error in fines-volume measurement, and fine sediment does tend to be measured less intensively when it occupies a small proportion of the area of the pool. Therefore, we strongly recommend increasing sampling intensity in areas of fines or measuring fine-sediment deposits separately, or both, particularly where fine-sediment deposits occupy a small proportion of the surface area of the pool or when it is important to measure low values of V* accurately.

Estimates of the maximum possible error in V* due to variations in discharge (13-16 percent of V* measured at moderately low flow) were slightly less than the 18 percent average measurement error for replicate measurements at a constant discharge. However, measurement error from systematic samples with a random start is random, whereas errors due to changes in water depth appear to be consistent and thus have the potential to bias $V^*_w$. We recommend measuring at moderately low flows. Riffle-crest depths can be difficult to measure accurately at very low flows when the pattern of the flow is affected by surface rocks. At moderately high flows the water surface over a pool is likely to slope appreciably and affect pool volume measurements. For monitoring over time, comparisons will be more accurate if $V^*_w$ is measured at a consistent stage or discharge. Similarly, comparisons between reaches will be more reliable if all reaches are measured at nearly the same relative flow. If this is not possible, allowance should be made for the possibility that values of $V^*_w$ measured at high base flow could be elevated relative to those measured at low flow.

Our estimates of the variability of $V^*_w$ include the effects of measurement errors in V* but do not include any possible bias due to variations in discharge, since all pools in a reach were measured at approximately the same discharge. The desired standard error of $V^*_w$ depends on the precision required to detect changes in a reach, deviations from a reference value, or differences between reaches. We found that the standard errors from measuring 10-20 pools per reach enabled us to distinguish fairly well between reaches, and the sample size calculations indicated that fewer pools would probably have been enough in most reaches. The calculated sample size (*figure 5*) is not necessarily the number of pools that should be measured in each reach, since the percent error in $V^*_w$ needed to distinguish between reaches will depend on both the value of $V^*_w$ (a 20 percent error is a large range of $V^*_w$ values when $V^*_w$ is high and a small range when $V^*_w$ is small) and on the closeness of the values being compared. The sample size calculation does, however, indicate the relative sampling intensity required to be able to measure reaches with high standard errors at the same precision as reaches with lower variability between pools. We recommend evaluating the irregularity of the pools and the variation in V* before and during data collection in a reach. If all of the pools in a reach have similar values of V*, then differences between the estimates of V* caused by measurement error could have a significant effect on the variance of the estimate of $V^*_w$, and $V^*_w$ can be best estimated by measuring a few (6-10) pools accurately. For most reaches we recommend measuring 10-15 pools, and if the value of V* varies widely between pools, the best strategy might be to measure as many pools as possible (20 or more), perhaps with less sampling intensity on each. If V* is highly variable but the number of pools available

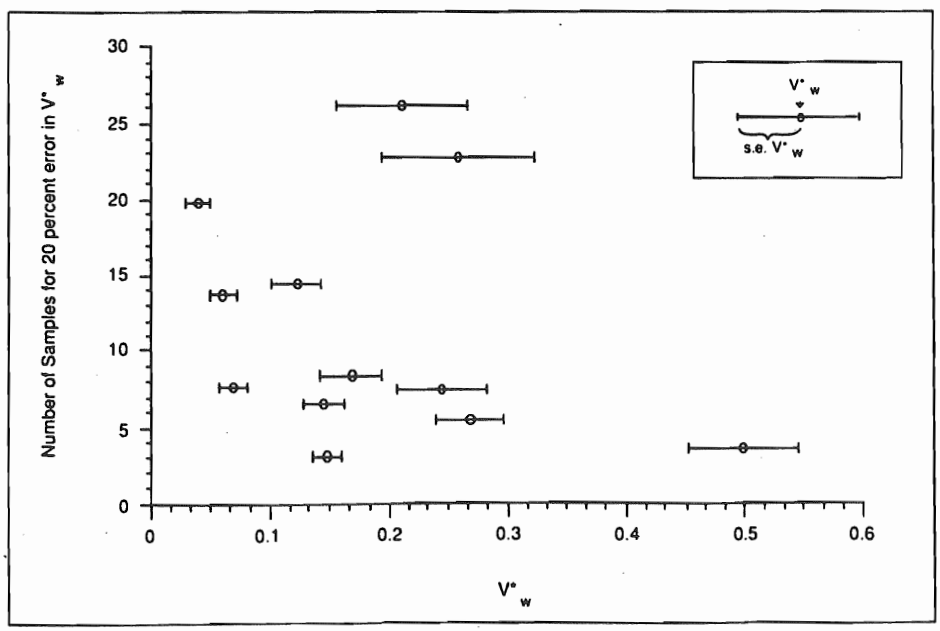


**Figure 5**—Predicted sample sizes necessary to limit the error in $V^*_w$ to 20 percent of the value of $V^*_w$ for that reach, calculated for 12 reaches. Our estimate of $V^*_w$ for each reach is shown with our standard error of the estimate for that reach, which was based on 10-20 pools.

in the reach is limited (by sediment sources, changes in slope, etc.), putting more effort into sampling each pool will at least reduce the measurement-error component of the total variability. If the objective is to monitor a reach over time, and if the structure of the pools in a reach is fairly stable, accurate measurements of a few major pools at approximately the same discharge each year may give the best information.

## SUMMARY OF RECOMMENDATIONS

To minimize variability of the estimates and eliminate potential bias, we make the following recommendations:

### Fine Sediment Measurements

- When fine-sediment deposits occupy a third or less of the pool substrate area, increase measurement intensity in fine-sediment deposits, either by decreasing the distance between depth-measurement points or by making separate measurements of deposits.

### Discharge Levels

- Measure all pools at moderately low flows.
- If a reach is being monitored over time, measure at approximately the same discharge each year.
- If reaches are being compared, measure all reaches at approximately the same relative flow.

### Sample Size

- If all pools in a reach have similar values of V*, measure 6-10 pools relatively intensively.
- If V* varies somewhat (V* for all pools is within 20-30 percent of the mean), measure 10-15 pools.
- If V* is highly variable (some V*'s of 0.4 or more and others 0.1 or less), measure as many pools as possible, up to 20 or so.
- If the objective is to monitor changes over time in a single reach, and if the pools in the reach are structurally stable, intensive measurement of a few pools (4-5 minimum) may minimize variability and provide additional information about changes in individual pools.

## APPENDIX A

### Calculating Residual Pool Water Volume, Fine-Sediment Volume, and V*

Follow these basic steps to compute residual-water and fine-sediment volumes for a pool:

1. Calculate cross-sectional areas of the water and fine sediment in the residual pool at each cross section.
2. Assume a zero-area cross section at the beginning and end of the pool. Calculate water and sediment volumes in cells between each pair of adjacent cross sections, including the zero-area cross sections at the endpoints.
3. Sum residual-water and fine-sediment volumes for all of the cells to compute total volumes.

The following example of the calculations uses the data from a very small pool. In this example, $d$ = water depth, $d_{rc}$ = riffle-crest depth, and $y_f$ = fine-sediment thickness. These are the data:

riffle-crest depth ($d_{rc}$) = 0.10 m; total length of pool = 12.0 m

cross section #1 at 2.4 m

| | | | | | |
|---|---|---|---|---|---|
| distance (m) | 0 | 0.5 | 1.5 | 2.5 | 2.7 |
| $d$ (m) | 0.10 | 0.50 | 0.88 | 0.40 | 0.10 |
| $y_f$ (m) | 0 | 0 | 0.02 | 0.02 | 0 |

cross section #2 at 6.4 m

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| distance (m) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6.2 |
| $d$ (m) | 0.06 | 0.62 | 0.74 | 1.12 | 0.96 | 0.70 | 0.56 | 0.10 |
| $y_f$ (m) | 0.04 | 0.10 | 0.02 | 0.01 | 0 | 0 | 0 | 0 |

cross section #3 at 10.4 m

| | | | | | | |
|---|---|---|---|---|---|---|
| distance (m) | 0 | 0.8 | 1.8 | 2.8 | 3.8 | 4.6 |
| $d$ (m) | -0.02 | 0.08 | 1.08 | 1.14 | 0.94 | 0.10 |
| $y_f$ (m) | 0.12 | 0.10 | 0.14 | 0.06 | 0.04 | 0 |

The first step is to compute depths of the water and fines in the residual pool. The residual water depth, $d_r$, is the water depth minus the riffle crest depth. The residual fine-sediment thickness, $y_{rf}$, is the thickness of the fine sediment below the riffle crest *(figure 1)*. If the water depth at any location is less than the riffle crest depth, the fines thickness at that location is reduced by a corresponding amount. That is, $d_r = d - d_{rc}$ and IF $d < d_{rc}$, THEN $y_{rf} = y_f - (d_{rc} - d)$, ELSE $y_{rf} = y_f$. After these calculations, the data look like this:

cross section #1

| | | | | | |
|---|---|---|---|---|---|
| distance (m) | 0 | 0.5 | 1.5 | 2.5 | 2.7 |
| $d_r$ (m) | 0 | 0.40 | 0.78 | 0.30 | 0 |
| $y_{rf}$ (m) | 0 | 0 | 0.02 | 0.02 | 0 |

cross section #2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| distance (m) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6.2 |
| $d_r$ (m) | -0.04 | 0.52 | 0.64 | 1.02 | 0.86 | 0.60 | 0.46 | 0 |
| $y_{rf}$ (m) | 0 | 0.10 | 0.02 | 0.01 | 0 | 0 | 0 | 0 |

cross section #3

| | | | | | | |
|---|---|---|---|---|---|---|
| distance (m) | 0 | 0.8 | 1.8 | 2.8 | 3.8 | 4.6 |
| $d_r$ (m) | -0.12 | -0.02 | 0.98 | 1.04 | 0.84 | 0 |
| $y_{rf}$ (m) | 0 | 0.08 | 0.14 | 0.06 | 0.04 | 0 |

The next step is to compute cross-sectional areas of water and fine sediment. We start by calculating the width $w_i$, average residual depth $(d_r)_i$, and average fine-sediment thickness $(y_{rf})_i$ of each segment of the cross section (between two adjacent measurement points).

cross section #1

| | | | | |
|---|---|---|---|---|
| segment number | 1 | 2 | 3 | 4 |
| $w_i$ (m) | 0.5 | 1 | 1 | 0.2 |
| $(d_r)_i$ (m) | 0.20 | 0.59 | 0.54 | 0.15 |
| $(y_{rf})_i$ (m) | 0 | 0.01 | 0.02 | 0.01 |

cross section #2

| segment number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $w_i$ (m) | 1 | 1 | 1 | 1 | 1 | 1 | 0.2 |
| $(d_r)_i$ (m) | 0.24 | 0.58 | 0.83 | 0.94 | 0.73 | 0.53 | 0.23 |
| $(y_{rf})_i$ (m) | 0.05 | 0.06 | 0.015 | 0.005 | 0 | 0 | 0 |

cross section #3

| segment number | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $w_i$ (m) | -0.8 | 1 | 1 | 1 | 0.8 |
| $(d_r)_i$ (m) | -0.07 | 0.48 | 1.01 | 0.94 | 0.42 |
| $(y_{rf})_i$ (m) | 0.04 | 0.11 | 0.10 | 0.05 | 0.02 |

In each segment, the cross-sectional area of residual water $(a_r)_i$ equals $(d_r)_i \times w_i$, and cross-sectional area of fine sediment $(a_{rf})_i$ equals $(y_{rf})_i \times w_i$. Negative average water depths are set equal to zero. This gives us:

cross section #1

| segment number | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $(a_r)_i$ (m$^2$) | 0.10 | 0.59 | 0.54 | 0.03 |
| $(a_{rf})_i$ (m$^2$) | 0 | 0.01 | 0.02 | 0.002 |

cross section #2

| segment number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $(a_r)_i$ (m$^2$) | 0.24 | 0.58 | 0.83 | 0.94 | 0.73 | 0.53 | 0.046 |
| $(a_{rf})_i$ (m$^2$) | 0.05 | 0.06 | 0.015 | 0.005 | 0 | 0 | 0 |

cross section #3

| segment number | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $(a_r)_i$ (m$^2$) | 0 | 0.48 | 1.01 | 0.94 | 0.336 |
| $(a_{rf})_i$ (m$^2$) | 0.032 | 0.11 | 0.10 | 0.05 | 0.016 |

The total cross-sectional area of residual water, $A_r$, and fine sediment, $A_{rf}$, of each cross section equals the sum of the corresponding segment areas. Cross sections are added to upstream and downstream ends of the pool and given areas of zero.

| cross-section # | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| location (m downstream) | 0 | 2.4 | 6.4 | 10.4 | 12 |
| $A_r$ (m$^2$) | 0 | 1.26 | 3.90 | 2.77 | 0 |
| $A_{rf}$ (m$^2$) | 0 | 0.032 | 0.130 | 0.308 | 0 |

To compute the water and fine sediment volume in each cell of the pool, between each two adjacent cross sections, we calculate the average cross-sectional areas of residual water $(A_r)_j$ and fine sediment $(A_{rf})_j$ and the length $(l_j)$ for each cell. The cell in the upstream end of the pool, for example, has an average residual area equal to one-half of the area of the first cross section downstream.

| cell number | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $l_j$ (m) | 2.4 | 4.0 | 4.0 | 1.6 |
| $(A_r)_j$ (m$^2$) | 0.63 | 2.58 | 3.33 | 1.38 |
| $(A_{rf})_j$ (m$^2$) | 0.016 | 0.081 | 0.219 | 0.154 |

The volumes for each cell, $(V_r)_j$ and $(V_{rf})_j$, are the average areas times the length, and the total for the pool is the sum of the volumes of all the cells.

| cell number | 1 | 2 | 3 | 4 | total |
|---|---|---|---|---|---|
| $(V_r)_j$ (m$^3$) | 1.5 | 10.3 | 13.3 | 2.2 | 27.4 |
| $(V_{rf})_j$ (m$^3$) | 0.04 | 0.32 | 0.88 | 0.25 | 1.48 |

Finally we calculate V* as: $\dfrac{\text{total fines volume}}{(\text{total fines} + \text{total residual pool volume})} = 0.051$

and we're done!

## APPENDIX B

### Estimating the Variance of the Estimate of $V^*_w$

The formula we used for estimating the variance of $V^*_w$ was developed using the Delta method[5] for estimating the variance of a variable that is a function of other variables. The variance of $V^*_w$ for a reach is calculated as:

$$\widehat{Var}\left(V_w^*\right) \cong n\left(\sum_{i=1}^{n} f_i + \sum_{i=1}^{n} w_i\right)^{-4}\left[\left(\left(\sum_{i=1}^{n} f_i\right)^2 \sigma_w^2 + \left(\sum_{i=1}^{n} w_i\right)^2 \sigma_f^2\right) - 2\sum_{i=1}^{n} f_i \sum_{i=1}^{n} w_i \left(\operatorname{cov}(f,w)\right)\right]$$

where $f_i$ is the fines volume and $w_i$ is the residual pool water volume of the $i$th pool in the reach, and $\widehat{cov}\,(f,w)$ is the covariance of the fines volume and the water volume in the reach. The covariance is calculated as:

$$\widehat{cov}\,(f,w) = \frac{\sum_{i=1}^{n}\left(f_i - \bar{f}\right)\left(w_i - \bar{w}\right)}{n-1}$$

The covariance can be obtained from many statistical programs by printing a variance-covariance matrix.

The calculated variance can be used to test for significant differences in $V^*_w$ between two reaches by assuming that the test statistic,

$$\frac{V_{w1}^* - V_{w2}^*}{\sqrt{\widehat{Var}\left(V_{w1}^*\right) + \widehat{Var}\left(V_{w2}^*\right)}},$$

has a standard normal distribution.


## ACKNOWLEDGMENTS

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# APPENDIX D.

# SELECTED PROTOCOLS

## 6. CANOPY MEASURES

# SOLAR PATHFINDER

## Introduction

The Solar Pathfinder is used for solar site analysis. Any trees and/or buildings that would cast shadows on a collector or photovoltaic panel are reflected in the plastic dome, clearly showing shading patterns at the site for the entire year. A wax pencil can be used to trace around the reflected shadows on a sunpath diagram, providing a permanent record of each reading. A compass and a level are built into each Pathfinder, making it easy to keep the instrument level and facing in the right direction. The legs on the optional tripod are adjustable, allowing a person to use the Pathfinder anywhere, including a sloping roof.

## Instrument Set-up

The Solar Pathfinder is made up of three parts: the dome assembly, the diagram platform (the part with the compass on it), and the base. To avoid accidently dropping the dome assembly, it should be set aside until the tripod, base, and diagram platform are securely assembled. Save the plastic bag for storing the Pathfinder when it's not in use.

Step 1: Separate the three tripod legs and insert each rounded end into one of the rubber grommets on the base. Pull on the rubber leg end to slide out the inside section (the height of the instrument usually only needs to be 2-3 feet high, as you will want to lean over the dome and have your eyes about 15 inches above the dome). Adjust the legs to get the base approximately level. The base doesn't need to be precisely level, as the diagram platform and dome assembly both pivot on the base to finish adjusting the leveling and the directional orientation of the Pathfinder.

Step 2: Set the diagram platform onto the base.

Step 3: Put a sunpath diagram over the center pivot of the diagram platform.

Step 4: Solar gain is usually increased by facing the collector to "true" south, not "magnetic" (or compass-seeking) south. In order to find "true south, it's necessary to adjust for the difference ("declination") between "true" south and "magnetic" south. Follow the directions below to make this adjustment.

A. Look on the magnetic declination map on pages 12 and 13 to find the declination for your area. Magnetic declination changes slowly over time, and also has local abnormalities. These local abnormalities are of the greatest concern, and usually exist where there are large iron deposits nearby. If you think there are iron deposits in your area, you will want to check with a local surveyor to make sure you have the correct magnetic declination.

Of lesser concern is the slow change in the general magnetic field over time. One theory says that the change is due to the movement of the earth's molten liquid core relative to the earth's crust. At the current rate of movement, the greatest change would only be a degree or two over a dozen years. If you would like to get an updated map in the future at no charge as they become available, contact us.

B. Rotate the sunpath diagram on the central pivot counterclockwise for declinations to the east, or clockwise for declinations to the west, until the small white dot on the rim of the base is opposite the appropriate "Magnetic Declination East (or West)." These declination figures are marked on the outside edge of the sunpath diagram.

C. Put the dome in place on top of the diagram platform.

Step 5: To level the Pathfinder: use the tripod legs to get the Pathfinder as level as possible. Then using the bubble level, slide the instrument portion around on the cupped base until it is level. If you can't get the instrument level this way, readjust the tripod legs and try again.

Step 6: Rotate the base until the south end of the compass needle is directly above the "S" on the compass. Make sure the base is still level.

## Pathfinder Viewing

The Solar Pathfinder is designed to be viewed from between twelve and eighteen inches above the dome, and within ten to fifteen degrees of the vertical centerline on the sunpath diagram. Site readings are best taken on cloudy or overcast days to avoid glare from the sun. On a sunny day, shade the dome with your free hand. CAUTION: DO NOT STARE AT THE REFLECTED IMAGE OF THE SUN ON THE PATHFINDER DOME.

## Diagram Selection

There are two types of sunpath diagrams used with the Solar Pathfinder: the monthly sunpath diagrams, and the angle measurement grid.

The monthly sunpath diagram shows the percentage of solar energy that is potentially available at your site each month of the year. There are two different monthly sunpath diagrams: Horizontal and Southfacing. (Northfacing diagrams are available for use in the southern hemisphere.) The horizontal diagrams are used for nearly horizonal surfaces or collectors (those tilted at 10 degrees or less). Several agencies use these for gauging and monitoring tree canopy conditions relative to the biological activity under the canopy. The southfacing diagrams are used for tilted collectors, and are usually used in solar applications.

The angle measurement grid is used to measure the azimuth (degrees east or west of true south or north) and the elevation (degrees above the horizon) of any object reflected in the Pathfinder's dome. The clear angle grid is used as an aid in siting collectors. (See the section on Siting Collectors.)

## Site Tracing

The Solar Pathfinder is supplied with white pencils to make it easy to write directly on the sunpath diagrams. To record a site reading, trace around the objects reflected in the dome directly onto the sunpath diagram.

To avoid breaking the pencil lead, make a light tracing under the dome, and then remove the dome to darken it. If the tracing is to be analyzed later, make note of any deciduous trees so that adjustments can be made as suggested in the section on "Seasonal Variations in Foliage and Ground Cover."

Note: Clouds should not be counted as shade. See the section on "Sizing Collector Systems" for a discussion of climatic factors.

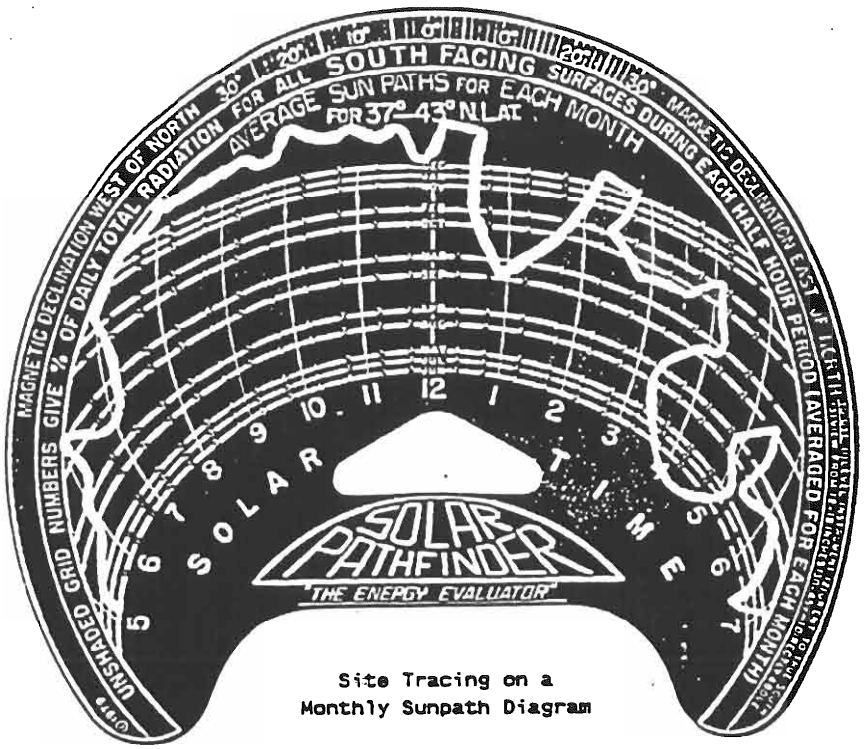
## Monthly Sunpath Diagram

The monthly sunpath diagram contains 12 horizontal arcs, one for each month, as well as vertical lines for solar time. Each arc shows the sun's path across the sky for that month. The sunpath arc for December is farthest from the center of the Pathfinder, showing the lowest winter sunpath through the sky. The sunpath arc for June is closest to the center, showing the highest summer sunpath.

The sunpath diagram is set up for solar time, with sunrise on the left (east) and sunset on the right (west) when the Pathfinder is facing south. A solid white line shows each half-hour division. Solar time is approximately standard time at the center of each time zone. Generally, the farther you are from the center of your time zone, the greater the difference will be between solar time as shown on the Pathfinder and the time shown on your wristwatch. Daylight savings time is not taken into consideration on the Pathfinder diagram. (See "Converting Solar Time to Standard Time" for more information.)

The small white numbers inside the half-hour divisions are values that have been calculated to account for the relative energy in each half-hour. This is necessary because a half hour near noon can provide a lot more energy then a half hour early or late in the day. The numbers along each sunpath arc add up to one hundred percent.

Monthly Sunpath Example




Site Tracing on a
Monthly Sunpath Diagram

To find the site percent, add the numbers in the unshaded part of the sunpath arc. The site tracing shown above has 64% solar availability for January, found by adding 2 + 3 + 4 + 5 + 6 + 7 + 7 + 8 + 8 + 8 + 6 =

## Spherical Densiometer

The spherical densiometer can be used as a hand held instrument to estimate relative vegetative canopy closure or canopy density caused by vegetation. Vegetation canopy closure is the area of the sky over the selected stream channel that is bracketed by vegetation (regardless of density). Canopy density is the amount of the sky blocked within the closure by vegetation. Canopy closure can be constant throughout the season if fast growing vegetation is not dominant, but density can change drastically if canopy vegetation is deciduous.

Spherical densiometers are produced with either convex or concave reflecting surfaces. These instructions are for a convex (Model A) spherical densiometer. The mirror surface of the densiometer has 37 grid intersections forming 24 squares. At a probability level of 95 percent, tests show the average measurements of the same overstory area can be excepted to be within $\pm 2.4$ percent of the mean. Because the instrument has a curved (convex or concave) reflecting surface resulting in a field the includes lateral as well as overhead positions, an overlap of side readings occurs when readings are taken from the same point. To account for this bias, the modifications developed by Strichler (1959) are used and modified to more accurately measure canopy closure and density. Strichler uses only 17 of the line intersects as observation points by taping a right angle on the mirror surface (Figure 1).

**For Stream Orders 1 Through 4** - Stand in the middle of the habitat type area and in the center of the stream facing downstream. The densiometer is held in the hand, in front of the body at about waist level, with the arm from the hand to the elbow parallel to the water surface. The convex densiometer is held away from the observer's body with the apex of the V pointed toward the observer. The observer's eye reflection should seen along the margin of the original grid (Figure 1). Level the densiometer using the bubble indicator and maintain the level and standard eye positions while recording. The grid between the V formed by the tape encloses 17 observation points. Each point has a value of 1.5 percent when four different recordings are made. The number of points (line grid intersects) that are covered by vegetation are counted when measuring canopy density. The number of points surrounded by vegetation are counted when measuring canopy closure. Measurements are taken in the four quadrants while standing on the same point (facing downstream, right bank, upstream, left bank).

The points counted for each reading are totaled and multiplied by 1.5 to obtain the percentage of canopy density or closure.

If all possible observation points are counted the total value will be 102 percent (68 x 1.5 = 102). Although this error is small and not considered important for comparisons of relative values, the following correction factor can be applied to determine the correct percentile:

| Calculated value | Subtract from Calculated value |
|---|---|
| less than 30 | 0 |
| 30 to 60 | -1 |
| over 60 | -2 |

Example: (8+11+7+12)(1.5) = 57% subtract 1% = 56% density

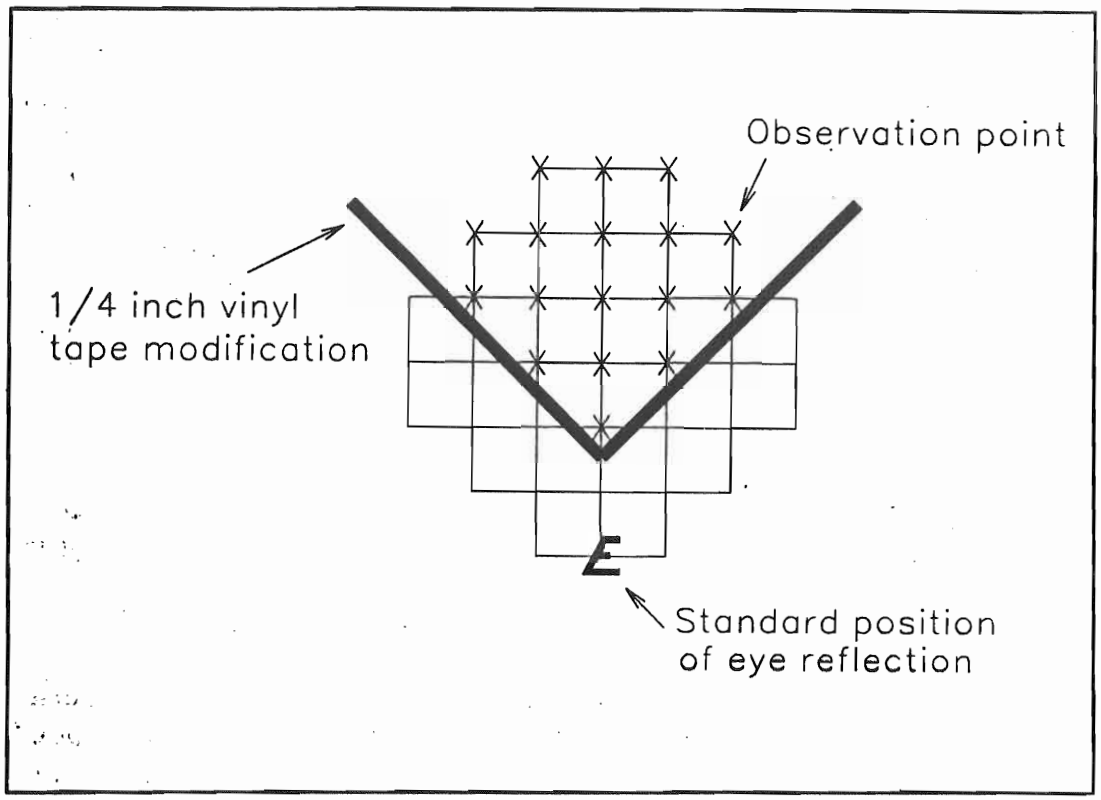



Figure 1. Modified grid of convex spherical densiometer showing the 17 observations points (X's) and the position of the observer's eye reflection.

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Platts, W. S., D. Amour, G.D. Booth, M. Gryant, J.L. Bufford, P. Culpin, S. Jensen, G.W. Lienkaemper, G.W. Minshall, S.B. Monsen, R.L. Nelson, J.R. Sedell, and J.S. Tuhy. 1987. Methods for Evaluating Riparian Habitats with Applications to Management. US Dept of Agriculture, Forest Service, Intermountain Research Station, General Technical Report INT-221.

Strichler, G.S. 1959. Use of the densiometer to estimate density of forest canopy on permanent sample plots. Research Note INT-180. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 5p.

# *APPENDIX D.*

# *SELECTED PROTOCOLS*

# *7. LARGE WOODY DEBRIS*

# LARGE WOODY DEBRIS SURVEY MODULE

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# LARGE WOODY DEBRIS SURVEY MODULE

## Introduction

Large woody debris (LWD) is an important component of stream channels in the Pacific Northwest. It plays an integral role in the formation of channel morphology and fish habitat. Logs and rootwads enter stream channels due to bank cutting, blowdown, and mass wasting. Once in the channel, the effect of LWD is related to the size, stability and longevity of the individual pieces, and to the tendency of wood to collect in large accumulations known as debris jams (Figure 1).

Figure 1. CSS Field Tech. Joe Apfel surrounded by a large debris jam on West Fork Taneum Creek.

Large woody debris influences channel morphology in several ways. Pools often form in association with LWD, due to adjacent scouring or impoundment of water behind channel-spanning pieces. Large woody debris often traps and stores sediment, having a moderating affect on sediment transport rates. In steeper, smaller channels, it often forms distinct steps that capture sediment on the upstream side and dissipate energy as the flow drops over the step.

Large woody debris plays an important biological role in Pacific Northwest streams, creating and enhancing fish habitat in streams of all sizes (Bisson et al., 1987). Pools formed in association with LWD often provide deep, low velocity habitat with cover. This habitat is beneficial for a variety of salmonid species and life history stages, particularly those that over-winter in stream channels. Large woody debris also functions to retain spawning gravel in high energy channels and provides thermal and physical cover.

The nature and abundance of large woody debris in a stream channel reflects past and present recruitment rates. This is largely determined by the age and composition of past and present adjacent riparian stands. Activities that disturb riparian vegetation, including timber removal in riparian areas, can reduce LWD recruitment. In addition, current conditions also reflect the past history of both natural and management-related channel disturbances, such as flood events, debris flows, splash damming, and stream cleanout.

Our understanding of the function of large woody debris in stream channels is still developing. To help increase the state of knowledge regarding LWD distribution and characteristics in Washington streams, Peterson et al. (1992) recommend expanding the type and amount of information collected in LWD monitoring and inventory surveys.

## Purpose of the Large Woody Debris Survey Module

The purpose of the large woody debris survey module is to:

1. Provide a means of accurately documenting the current abundance and characteristics of large woody debris in stream channels.

2. To provide a repeatable methodology that can be used to monitor changes in the status of large woody debris over time.

3. To provide information on the abundance, size and function of large woody debris that is suitable for use in the Watershed Analysis cumulative effects assessment procedure.

4. To improve our knowledge of the distribution and characteristics of large woody debris in Pacific Northwest streams.

## Large Woody Debris Survey Methodology

This method is designed to be used in conjunction with the Stream Segment Identification and Reference Point Survey modules. Please refer to these modules if you have not completed them.

This section describes procedures for identifying and measuring large woody debris and large debris jams. Two options are provided for collecting information on logs and rootwads. The Level 1 method is least intensive and does not require measurement of individual pieces of wood. It is designed to collect a minimal amount of information on LWD rather rapidly and generate information on the abundance and size class of LWD suitable for Watershed Analysis Level 1. The more intensive Level 2 method involves taking measurements on individual pieces of wood. This method is more time consuming, however it provides detailed information on attributes such as diameter, length, volume, channel location, wood type and stability that is suitable for Watershed Analysis Level 2. Please record all measurements in metric units to reduce confusion and streamline data processing.

## Information and Equipment Needed

In order to complete the Ambient Monitoring large woody debris survey, it is necessary to have previously identified a survey segment (see stream segment identification module). It is also desirable to have established reference points (see the reference point survey module) so that large woody debris and debris jams can be associated with permanent reference locations.
You will need the following equipment:

*Fiberglass tape (metric)
*Stadia rod (metric)
*Calipers, Biltmore Stick, Logger's tape (metric)
*Electronic or Optical rangefinders (metric)
Large Woody Debris survey Form 4.1 or 4.2
Large Debris Jam survey Form 5
Number 2 pencils
Clip board or form holder
Field notebook
Field guide to tree identification (to help distinguish coniferous and deciduous species)
Hip boots or waders
First aid supplies
(* calibration required)

### Calibration

Calibration of field measurement equipment is the first task before the start of the survey season, and for some types of equipment at the start of each survey day. Calibration information should be recorded and a copy incorporated with your project files.

All linear measurement equipment is calibrated against a designated 50 meter fiberglass tape (a 30 meter tape will work if it the longest or best you have). To designate your calibration standard tape, choose the newest equipment that does not have any breaks or splices for its entire length. The accuracy of the calibration standard is determined by comparing it to other tapes that are not spliced or broken. Once you have designated a fiberglass tape, identify it as such by writing "Calibration Standard" in permanent marker on the housing and include the date.

To calibrate other equipment to your standard, find an open area and roll out the tape in a straight line with the zero end anchored. The Large Woody Debris Survey Module has several pieces of equipment which need to be calibrated at least once per year as follows:

**Fiberglass Tape:** Anchor the zero ends at the same point as the calibration standard and run the tape out completely. Return to the zero end. While holding both tapes taught, proceed along the tapes and compare markings at each 0.1 meter for two meters and at each meter mark for the rest of the length. Note any damage such as breaks or splices and repair or replace them if necessary. Using a permanent marker, write "Calibrated" on the housing of the equipment and include the date.

**Stadia Rod**: Place the stadia rod parallel to the calibration standard with the zero ends at the same point. Check the accuracy of the markings to the 0.01 meter level for the first 2 meters and the rest at the 0.1 meter level. Check the rod for damaged and illegible markings. Locking buttons are often replaceable if they no longer function properly. Illegible markings can be fixed by permanent marker if not too severe. Avoid using any correction factors for damaged equipment.

**Log Calipers, Biltmore Sticks, Logger's tape (metric):** Log calipers are checked against the calibration standard tape at the centimeter level. Also, inspect the equipment for damage or misaligned blades. Biltmore sticks and logger's tapes must be checked with similar equipment and cross-checked with the log caliper readings.

**Electronic and Optical rangefinders (metric):** Electronic rangefinders must be calibrated daily and optical rangefinders must be calibrated at least twice daily and more if needed. Use your calibration standard tape and check the accuracy of your instruments at 5, 15, and 30 meter intervals. Adjust instruments according to manufacturer guidelines and stated accuracy ranges.

## Identifying Large Woody Debris

For the purposes of the large woody debris survey module, there are three types of LWD; logs, rootwads and large debris jams. Somewhat different information is collected for each type, so the first step is to identify the type of piece being observed.

### How to Identify a Log

To qualify as a log, a piece of wood must (Figure 2a):

1. be dead (or imminently dying with no chance of survival);
2. have a root system that is wholly or partially detached and is no longer capable of supporting the log's weight;
3. have a diameter of at least 10 cm for at least 2 meters of its length, and;
4. intrude into the bankfull channel.

This criteria is based on the definition of LWD used by Bilby and Ward (1989; 1991), and is compatible with the Watershed Analysis LWD assessment procedure. Pieces that meet the minimum length and diameter criteria above are classified as logs regardless of whether or not they have roots attached.

Individual stems that have grown in a cluster and meet at the base may be counted as separate pieces if they meet the minimum length and diameter criteria. Branches that are attached to the trunk of the tree should not be counted regardless of their size. Trees or logs which have been broken into smaller pieces are counted as separate if they meet minimum criteria. Use the "pick-up" technique to help determine if they are separate. To do this, imagine a crane picking-up one of the broken pieces; if the other piece did not remain attached, it would be counted separately. This technique can also be used to determine the length of an extensively rotted log or rootwad.

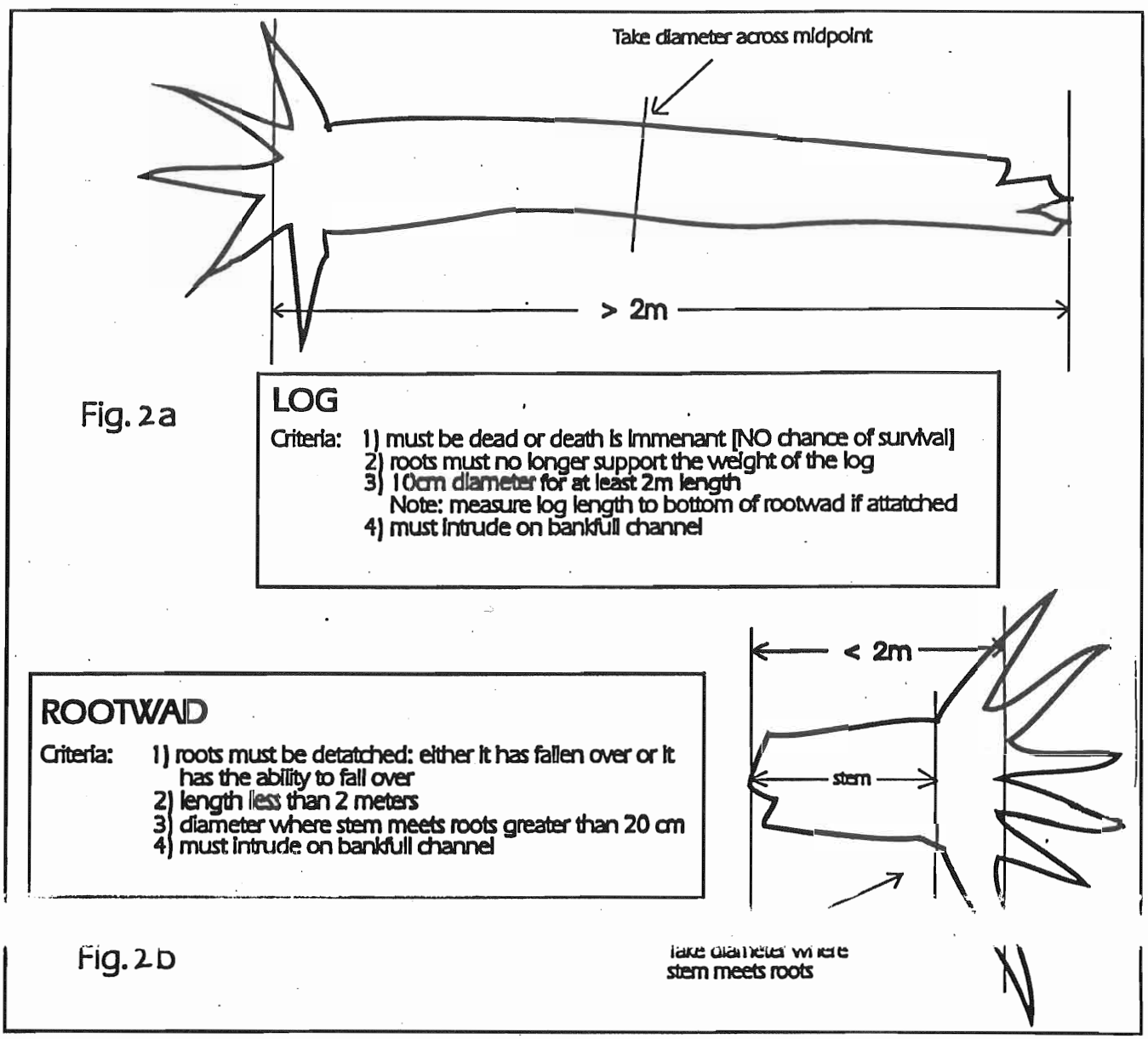


**Figure 2. Criteria for large woody debris.**

<u>How to Identify a Rootwad</u>

Rootwads are pieces of wood with a root system that do not meet the minimum length criteria for a log. To qualify as a rootwad, a piece (Figure 2b);

1. must be less than 2 meters long (except for old-growth stumps) and have a root system attached;
2. must be at least 20 cm diameter at the base of the stem where it meets the roots;
3. must have roots that are detached from their original position on the floodplain or terrace; and/or the rootwad has the ability to fall over; and
4. must intrude into the bankfull channel.

Old stumps are often found along the banks of stream channels running through areas that were harvested in the past. Often the stream has cut into the bank, exposing the roots of these standing stumps. The exposed roots are within the bankfull channel, and may have an influence on channel morphology. However, to maintain consistency with Bilby and Ward (1989; 1991), stumps with root systems that are still anchored in their original position on the floodplain or terrace are not counted as rootwads. This factor can be difficult to determine especially if the piece is still in an upright position and the root system is buried. If this is the case, you must determine if the piece was originally anchored at a higher level but was undercut by the stream action and eventually recruited into the bankfull channel. If you are unsure that the stump is in its original position, don't count it. If the stem (above the roots) has fallen into the bankfull channel, the root system has obviously become detached and the piece is counted.

How to Identify a Large Debris Jam

Large debris jams are defined as accumulations of 10 or more qualifying logs or rootwads that are in contact with one another (Figure 3). Each qualifying piece must meet the minimum size criteria (defined above) and must intrude into Zone 1, 2 or 3. While smaller accumulations may sometimes function as debris jams, for our purposes they are not counted as "large debris jams". Only limited information is collected on individual pieces of wood in large debris jams (see section on large debris jams, below).

**Figure 3. Lyman Bullchild on top of a large debris jam in the headwaters of Charley Creek, 1991**

## The Level 1 Large Woody Debris Method

The following information is collected on qualifying logs and rootwads during the Level 1 survey. This type of information is not collected for logs or rootwads that occur in accumulations of 10 or more pieces; they are treated separately as large debris jams (see the "Large Woody Debris Jams" section).

Piece Identification

Begin the survey at the downstream start of the stream segment and walk the channel, counting the number of qualifying pieces encountered. In the Level 1 LWD survey, qualifying pieces are assigned to one of the following four categories:

| | |
|---|---|
| ***Rootwad**: | 20 cm or greater at base of stem |
| ***Small Log**: | 10-20 cm diameter at midpoint |
| ***Medium Log**: | 20-50 cm diameter at midpoint |
| ***Large Log**: | greater than 50 cm diameter at midpoint |

Zone Identification

Next, determine the lowest zone to which the piece intrudes into the channel. Assign the piece to either channel location zone 1 or 2 (optional zone 3). If a portion of the piece intrudes into the water at low flow, it is assigned to Zone 1. If it does not intrude into the water at low flow but would be partially submerged at bankfull flow, it would be assigned to Zone 2. See the section on length and channel location in the Level 2 LWD method (below) for a detailed discussion of the channel location zones.

Once the size category and channel location have been determined, tally the piece in the appropriate column (size category) and row (channel location zone) in the matrix on the Level 1 Form 4.1. Each piece should only be tallied once. It may be helpful to use a piece of street or logger's chalk to mark those pieces tallied to prevent missing or duplication in complex areas. At the end of the survey add up all the tally marks in each cell of the matrix and record the total at the bottom of each cell. The sum of the totals for all cells equals the count of individual pieces in the segment. Add this number to the total number of pieces counted in large debris jams to calculate the total number of LWD pieces surveyed.

## The Level 2 Large Woody Debris Method

The following information is collected on qualifying logs and rootwads during the Level 2 survey. This type of information is not collected for logs or rootwads that occur in accumulations of 10 or more pieces; they are treated separately as large debris jams (see the "Large Woody Debris Jams" section below).

Piece Identification

Follow the procedures for identifying a log and rootwad as noted above.

Association with Reference Points

Each log or rootwad should be assigned to a 100 meter reach delineated by established reference points (see Reference Point Survey module). Locate the mid-point along the log or rootwad, and record the number of the nearest **downstream** reference point (Figure 4).

Diameter

Diameter information is useful in determining the relative size and volume of individual logs. Diameter (to the nearest centimeter) is measured at the mid-point along the length of each log with a caliper, Biltmore stick, or logger's tape. A log caliper is the most versatile instrument of the three. If a log cannot be measured, for example if the water is too deep or part of the log is suspended above the channel, estimate the diameter and note it as such in your field notes. If the log is divided into several large branches at the mid-point, measure the diameter immediately below the point where

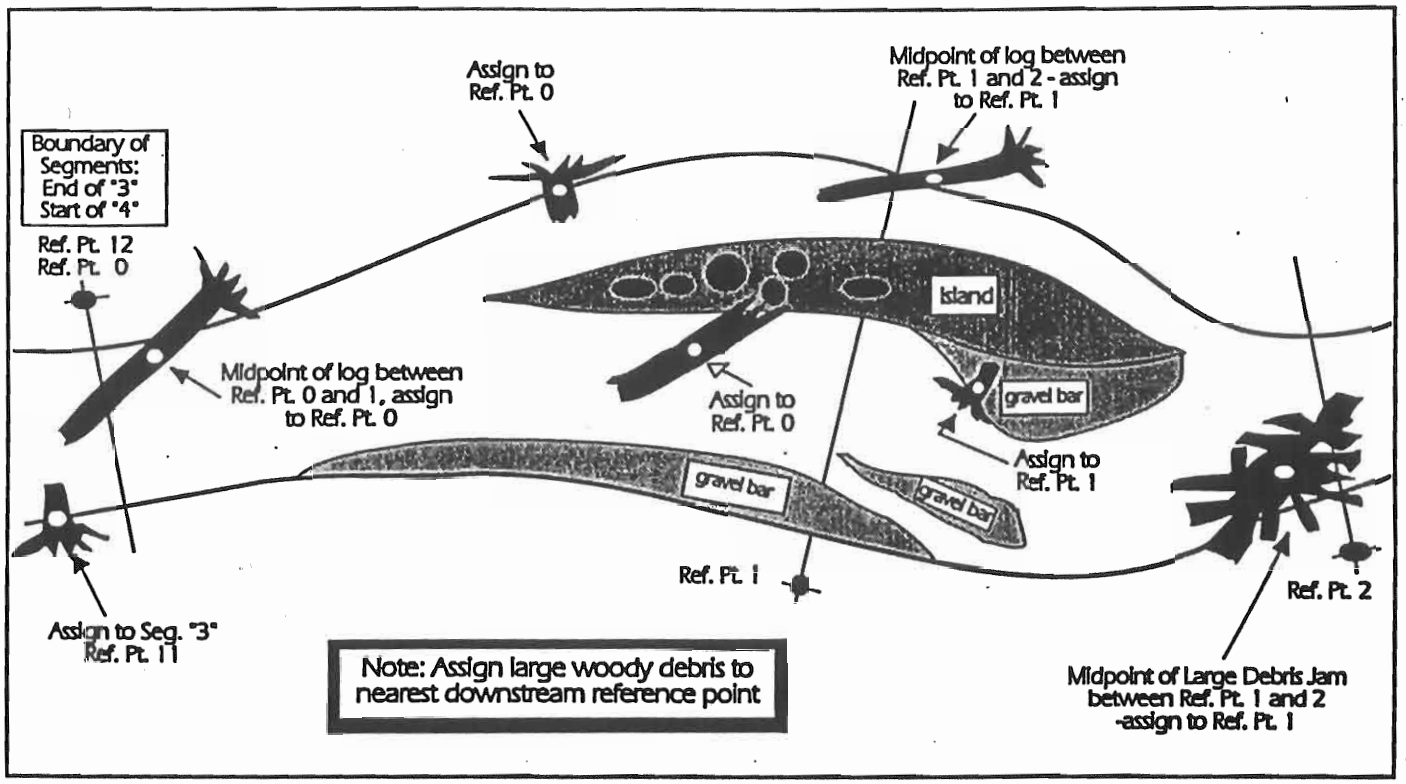


**Figure 4. Assigning large woody debris to reference points.**

the branches fork. The diameter of rootwads is measured on the stem just above where the roots begin.

If the piece is round, measure the diameter with the spline of the caliper parallel to the channel substrate or water surface. If the piece of wood is irregular in shape (non-circular), take a measurement at the widest and narrowest point, sum the measurements and divide by two to calculate the average diameter.

## Channel Location

Information on the length of logs and rootwads is useful in determining their relative size and volume. In conjunction with the length measurement, information on the channel location of the piece is collected. The system used to describe channel location (based on Robison and Beschta, 1991) consists of four location zones or categories (Figure 5).

**Zone 1** is the wetted low flow channel, defined as the area under water at the time of the survey.

**Zone 2** is the area within the influence of the bankfull flow. This zone is within the perimeter of the bankfull channel and below the elevation of the water at bankfull flow (excluding areas defined as Zone 1). Zone 2 includes areas such as gravel bars that are exposed at low flow.

**Zone 3** is the area directly above the bankfull channel - from the bankfull flow waterline upwards indefinitely. This zone includes pieces that extend out over the channel but are suspended above the elevation of the water at bankfull flow;

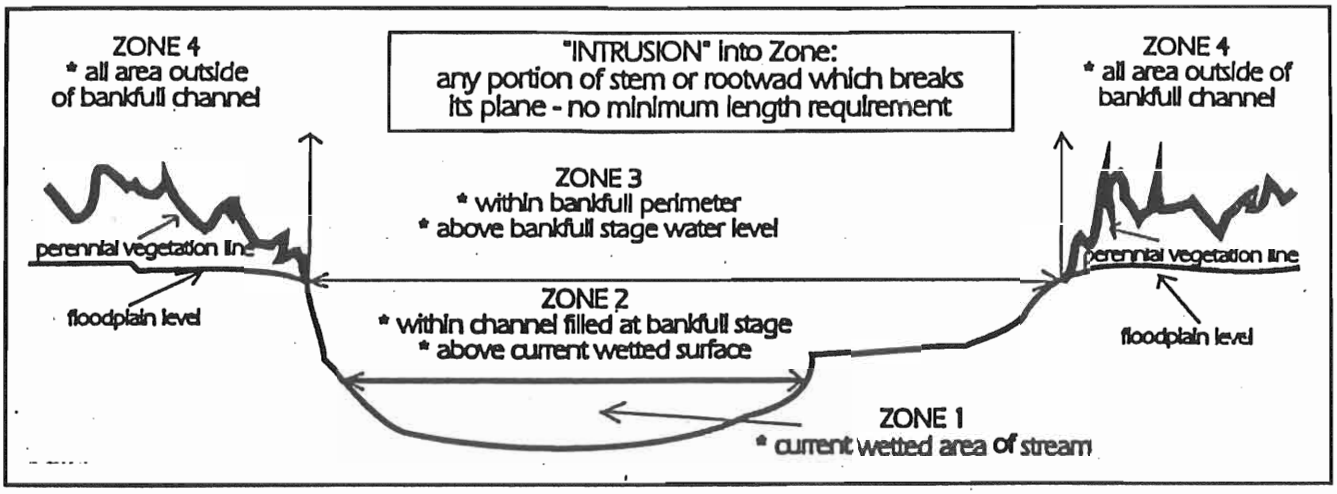


**Figure 5.** Description of LWD zones in stream channel.

**Zone 4** is the area outside of the bankfull channel perimeter. This zone includes the upper banks and riparian areas not directly influenced by bankfull flows.

Collecting information on LWD pieces in Zone 1 and 2 is important because they interact with the stream during bankfull (channel-forming) flows. These pieces can play an important role in formation of pool habitat and creation of habitat diversity during these events. They also play an important role in regulating sediment transport, routing and storage and can control the abundance and distribution of spawning gravels in some stream segments. Pieces or portion of pieces in Zone 1 also provide critical cover for salmonids during summer low flows. Pieces (especially accumulations) in both Zone 1 and 2 provide critical winter refuge habitat for juvenile coho salmon during freshets.

Collecting information on portions of LWD pieces in Zone 3, although they do not affect a stream hydraulically, can provide information on cover quality, LWD recruitment resources to the channel, and identify key pieces which are causing debris accumulations or jams. Collecting information on portions of LWD pieces in Zone 4 is important because their size or placement often act as anchors for the portions within the bankfull channel as well as provide potential recruitment into the channel.

## Measuring Lengths by Channel Location

To measure length and channel location, first determine which zones the log or rootwad passes through. A variety of methods have been used by geomorphologists to establish the outer boundaries of the bankfull channel, however many require discharge records or surveying techniques. For ambient monitoring purposes, use bank form and vegetation indicators to identify the perimeter of the bankfull channel. See the Reference Point Survey module (pages 8-9) for a detailed discussion on determining bankfull channel dimensions. Often, it is useful to identify all the zone boundaries on the piece before taking the length measurements. A piece of chalk is useful to help mark and remember boundary locations.

To locate the boundaries of Zone 1, first identify where the end of the piece is. In situations where this boundary of the piece is buried or extends into deep water, use your stadia rod to quickly probe for this end. Next, locate the upper boundary where Zone 1 meets Zone 2. The boundary line

between two zones generally passes through the log at an angle and the point you are looking for is located at the furthest extent that the log influences Zone 1. Often, this point is found where the waterline last touches the bottom of the log. At this point, use your chalk to place a 90° mark on the piece to that boundary point.

The lower boundary of Zone 2 is now established and the outer boundary needs to be located. To find this point, it is necessary to determine the point on each bank that represents the high water mark at bankfull flow. Extend this line across the channel to locate where it intersects the piece you are measuring. It is helpful to use an extend stadia rod for this purpose by placing one end at the bankfull width and having your partner step back to determine when it is level. Use this to sight along to determine the furthest extent that the piece influences Zone 2. Often, this point is found where a bankfull waterline would last touch the bottom of the piece. At this point, use your chalk to place a 90° mark on the piece to that boundary point.

The lower boundary of Zone 3 is now established and the outer boundary needs to be located. To find this point, use the bankfull width point used for establishing Zone 2 and imagine a boundary line from that point straight up. Again, it is helpful to use your stadia rod to represent this line and determine where the upper Zone 3 boundary intersects the piece. Locate the furthest extent that the piece influences Zone 3 and this is often found along the top of the piece. At this point, use your chalk to place a 90° mark on the piece to that boundary point.

The lower boundary of Zone 4 is now established and the outer boundary needs to be located. This boundary is the end of the piece located on or above the floodplain/terrace. Often, locating the end of a piece in Zone 4 is difficult, too time-consuming, or too dangerous to accurately determine. In these situations, estimate the boundary and note on Form 4.2 the accuracy of the estimate (+/- .5, 1.0, 5.0 meter).

Once the zones have been determined, measure the length of the log (Figure 6) or rootwad (Figure 7) along its main stem in each of the four zones and note estimated zone lengths as needed. If part of a piece that is within Zone 1 or 2 also extends into Zone 3 or 4, measure and record the length in Zone 3 and/or 4. It is not required to count or measure pieces which intrude only into Zone 3, however, this information can be collected if desired (see below). Pieces which lay only in Zone 4 are not counted in the survey.

Extend the length measurement from the base of the attached roots, if present, to the furthest end of the log, even if the end is less than the minimum diameter. If a portion of a log is buried and the entire length cannot be determined, measure only the exposed portion of the log. When a piece of wood forks into numerous small branches, such as the branches at the top of a tree, measure to the point where the main stem is no longer distinctly larger than the branches forking off of it.

Cooperators may also want to count and measure pieces of debris that are suspended or bridged over the channel in Zone 3. To do this, also enter data for qualifying pieces that intrude into Zone 3 but do not enter Zone 1 or 2. These pieces will not be included in the regular wood count but will be reported in a separate category. The decision on whether to count pieces in Zone 3 within a segment is made by the project leader prior to initiating the survey.

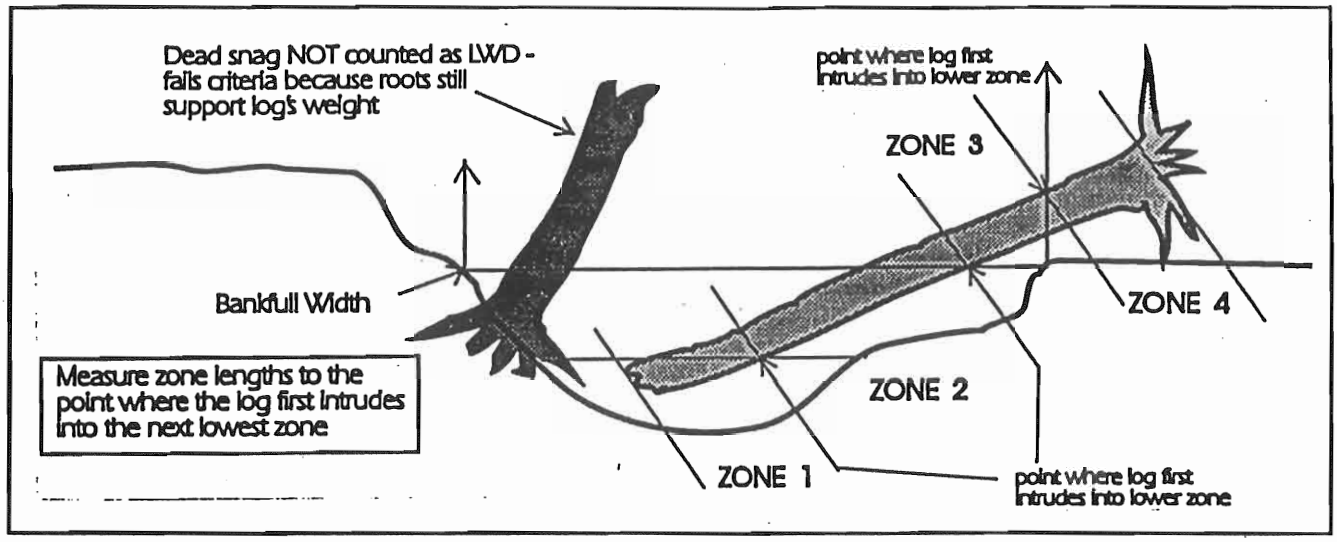


Figure 6. Assigning portions of logs to stream channel zones.

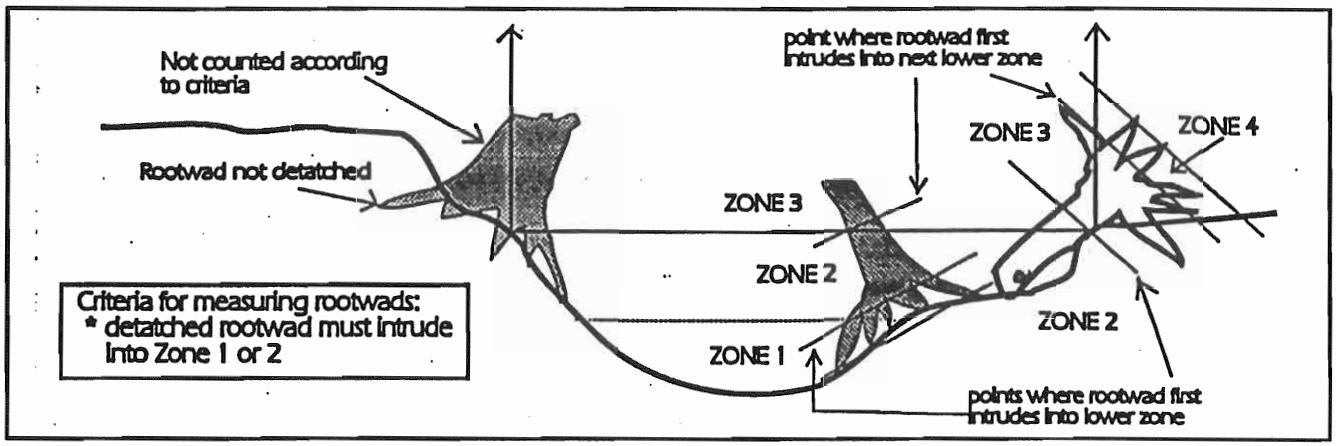


Figure 7. Assigning portions of rootwads to stream channel zones.

## Wood Type

Logs are classified in one of three categories based on the species of tree. The three categories are Coniferous (C), Deciduous (D) or Unknown (U). This provides information on the type of material that is entering the channel and its potential longevity, since conifers resist rot and persist longer than deciduous pieces. Characteristics of the bark, wood fiber, and branching pattern can often be used to identify the type of wood. A tree identification guide may be useful to help identify various species. If unsure about the type of wood, enter Unknown.

## Stabilizing Factors

Note if the piece has a Root system (R), is partially Buried (B), is Pinned (P), or is unstable (U). A root system is defined as having increased stability at bankfull flow due to the presence of roots or a rootball. Buried is defined as having increased stability at bankfull flow due to complete burial of either end or lateral burial of 50% or more of the piece. Pinned is defined as having increased stability at bankfull flows due to having another qualifying LWD piece on top of it, or due to being pegged between other logs, standing trees or bedrock. A piece can have all three factors noted if present. If none of the above stability factors are present, then the piece is considered unstable.

Pool Forming Function

Note if the log or rootwad is associated with pool formation - contributing to channel scour and the impoundment of water. Use the Habitat Unit Survey module pool criteria based on a segment's average bankfull channel width for minimum surface area and residual pool depth to help determine qualifying pools for this category (Appendix A). This includes Zone 2 pieces outside of the summer low-flow wetted perimeter that you determine contribute to pool formation at bankfull flows.

Orientation and Decay Class

Collection of this information is optional. The classification systems listed below are not currently being trained or part of the quality assurance testing.

For Orientation, see Robison and Beschta (1990) for a more detailed description of this method. The orientation method used ("$0^0$ - $180^0$"; or "$0^0$, $90^0$, $180^0$") must accompany any data entered into the TFW Ambient Monitoring database.

There are two Decay classification systems recommended by the TFW Ambient Monitoring Program. These are a five-class system by Robison and a seven-class system by Grette (Appendix B). Other classification systems are acceptable. The classification method or a concise definition of the method used must accompany any data entered into the TFW Ambient Monitoring database.

## Large Woody Debris Jams

Large woody debris jams consist of accumulations of ten or more qualifying pieces (either logs or rootwads) that are touching. Pieces must be wholly or partially within Zones 1 or 2 (Zone 3 optional) to be counted in LWD jams. This information is used in both Level 1 and Level 2 LWD surveys.

The following information is collected on logs and rootwads that are found in LWD jams. Walking on top of LWD jams can be difficult and dangerous, so this information is intended to be collected while walking around the outside of the jam and does not necessitate actual measurement of individual pieces of wood.

Associating Large Debris Jams with Reference Points

Each debris jam should be associated with a 100 meter reach delineated by established reference points (see the Reference Point Survey Module). Locate the mid-point along the length of the debris jam, and record the number of the nearest **downstream** reference point (see Figure 5).

Number and Size of Visible Pieces

Walk around the debris jam and count the visible pieces that meet the minimum size criteria for logs and rootwads. Because it is often not possible to see both ends of logs that go through the middle of large jams, it may be difficult to know if you are counting the same piece twice. Using chalk to

mark pieces tallied is helpful to prevent missing or duplicate counting of pieces. Assign each piece that you count to one of four categories, based on a visual estimate of the diameter. Note: estimation of log diameter sizes requires experience with a log caliper to calibrate your eye. The categories are:

| | |
|---|---|
| ***Rootwad**: | 20 cm or greater at base of stem |
| ***Small Log:** | 10-20 cm diameter at midpoint |
| ***Medium Log:** | 20-50 cm diameter at midpoint |
| ***Large Log:** | greater than 50 cm diameter at midpoint |

Channel Location

Note the lowest channel zone into which the LWD jam intrudes. Use the system of channel location zones described in the section on collecting information on logs (above).

Pool Forming Function

Note if the debris jam is associated with pool formation - contributing to channel scour and the impoundment of water. Use the Habitat Unit Survey module pool criteria based on a segment's average bankfull channel width for minimum surface area and residual pool depth to help determine qualifying pools for this category (see Appendix A). This includes Zone 2 jams outside of the summer low-flow wetted perimeter that you determine contribute to pool formation at bankfull flows.

# Filling Out Large Woody Debris Survey Forms

The information gathered for the Large Woody Debris Survey is recorded on forms provided by the TFW Ambient Monitoring Program. Copies of these forms are located in the Appendixes section of this module or can be requested at the program office. Once a survey has been completed, the data on the forms is entered into the program's statewide relational database. The following section provides a detailed step-by-step procedure for completing data categories on Level 1, Level 2, and LWD Jam survey forms. Header information is consistent throughout all TFW Ambient Monitoring modules and this will be covered first.

## Header Information

All header information must be completed fully for each sheet of each type form for the entire segment. Start each day with a new form and number the pages sequentially for the entire segment. This level of documentation is required for continuity of data quality for short and long-term purposes.

**W.R.I.A.** (Water Resource Inventory Areas) - This six to seven number code is found in the Wash-

ington Department of Fisheries Stream catalog. Refer to the Stream Segment Identification module (page 9) for determining an unlisted number.

**Segment #** (Segment Number) - Record the segment number of the stream reach you are conducting the LWD survey on.

**Survey Start Date** - Record the date of the first day you begin this survey. This date does not change from form to form.

**Survey End Date** - Record the date of the last day of this survey. This date reflects all field gathering and error-checking activities up to entering the data into the database.

**Stream Name** - Record the official stream name (W.R.I.A. designated) and any local names (in Notes section).

**Basin Name** - Record the basin name as stated in the W.R.I.A. catalog. If your stream is in W.R.I.A. 25 or greater, or you cannot find the official basin name, leave blank and the database will fill it in for you.

**Rivermile from __ to __** - Record the segment's beginning (downstream) and ending (upstream) boundary rivermile location according to the W.R.I.A. catalog.

**Ref. Pt. from __ to __** (Reference Point number) - Record the segment's beginning (usually "0") and ending reference point numbers. Use your segment's completed Reference Point Survey Form 2 for this information.

**Crew Lead/Recorder/Affiliation** - Record the full names of the survey crew and each person's Tribal, agency, or other work affiliation. This information is important when there are questions regarding past data that only a survey crew member might be able to answer.

**Survey Date** - Record the actual day that this form is being used. Each new day requires starting with a new form.

**Discharge __._CMS (cubic** meters per second)**/Discharge Date** - Record your most recent discharge measurment in cubic meters per second and the month/day/year taken from your Form 7 (see Habitat Unit Survey module).

## LWD Level 1 Form 4.1

The TFW Ambient Monitoring Program provides field forms for recording monitoring data. For the Level 1 LWD survey, use Form 4.1 (Appendix C). There are no scan-able forms available for this level of survey. All data must be entered by hand into the database. The following section describes how to record data on this form.

**Category and Zone Tally** - Assign one tally-mark for each qualifying LWD piece to one of eight (8) Category/Zone combinations (12 combinations if you are collecting Zone 3 information).

Add the tally marks together at the end of the segment survey and record the number in the small "Total" box located in the lower-center portion of the tally boxes.

## LWD Level 2 Form 4.2

Two options are available for recording information collected on large debris jams. Use the regular Large Woody Debris Survey Form 4.2 (Appendix D) if you plan on entering data by hand into the database. Use the scan-able version Form 4 (Appendix E) if you want to scan the data directly into the database by NWIFC. Scan-able forms are available from NWIFC. The following section describes how to record data on the hand-entry Form 4.2.

**Piece #** (Piece number) - Assign each qualifying LWD piece a unique piece number, beginning with 001 and continuing sequentially to the last piece in the stream segment. Fill-out one row on the Form 4.2 for each qualifying piece of wood (except those in LWD jams).

**Dwn Ref Pt #** (Downstream reference point number) - Record the number of the nearest down-stream reference point using the mid-point of the log or rootwad.

**Piece Type L-R** - Record (L) for Log or (R) for Rootwad in the piece type column.

**Piece Dia cm** (Piece Diameter in centimeters) - Record the diameter measurement (to the nearest centimeter) in the diameter column. Document estimated measurements due to buried or obstructed pieces in the Notes section.

**Length** - The form has separate columns for each of the channel location zones. Record the length of the portion of the log or rootwad assigned to each zone in the appropriate column. If there is no length in one or more of the zones, place a diagonal mark across that box documenting that you did not simply forget a length. Lengths are measured to the nearest 0.1 meter unless estimated and documented in the Notes section. Total lengths and volumes are computed during data processing.

**Wood type** - Record the type of wood in this column using (C) for Conifer, (D) for Deciduous or (U) for Unknown.

**Stability** - Use this column to record all of the applicable stability factors for the piece using (R) for Root system, (B) for Buried, (P) for Pinned, and (U) for Unstable.

**PFF** (Pool Forming Function) - After determining if the log or rootwad is associated with a pool, use this column to record (Y) for Yes and (N) for No.

**Orientation** - Optional. Use this column to record the angle of orientation of the piece in the bank-full channel ($0^0$ - $180^0$; or $0^0$, $90^0$, or $180^0$). Document in Notes section which method is being used on the first form of the survey.

**Decay** - Optional. Use this column to record the number or letter code relating to the method used. Document in Notes section which method is being used on the first form of the survey.

### LWD Jams Level 1 & 2 Form 5

Two options are available for recording information collected on large debris jams. Use the regular Large Woody Debris Jam Survey Form 5 (Appendix F) if you plan on entering data by hand into the database. Use the scan-able version Form 5 (Appendix G) if you want to scan the data directly into the database by NWIFC. Scan-able forms are available from NWIFC. The following section describes how to record data on this form.

**Jam #** (LWD jam number) - Assign each LWD jam in the segment a unique number beginning with 001 and sequentially numbering each jam to the end of the segment. Fill-out one row of Form 5 for each qualifying LWD jam (10 or more interconnected qualifying pieces of wood).

**Dwn Ref Pt #** (Downstream reference point number) - Record the number of the nearest downstream reference point using the mid-point along the length of the LWD jam.

**Visible pieces** - Tally the total number of visible pieces in each of the size categories in the appropriate column, add the tally marks together at the end of the survey and record the number in the small box located in the lower-right-hand corner of the tally boxes.

**Zone** (Jam channel location zone) - Record the zone number (**1, 2,** or optional **3**) documenting the lowest zone the LWD jam intrudes into the bankfull channel.

**PFF** (Pool Forming Function) - After determining if the jam is associated with a pool, use this column to record (**Y**) for Yes or (**N**) for No.

## Data Processing and Analysis

After data has been hand entered (by the cooperator) or scanned into the database, it is error checked. Then, an in-channel Large Woody Debris summary report is generated (Appendix H). This report provides information on LWD for the segment including: the frequency, average diameter, length and volume by channel location zone of logs and rootwads; frequency and volume by species type; and the size and composition of debris jams. This information is suitable for use in Watershed Analysis or for assessment and monitoring purposes. In addition, cooperators will receive a copy of the database on floppy disk for their use. Data is stored in a statewide database at NWIFC for future TFW-related use.

## Training, Field Assistance and Quality Control

This manual is intended as a reference for those collecting information using the TFW Ambient Monitoring Program Large Woody Debris Survey Module. Because of the difficulty in relying solely on a manual to learn and implement monitoring methodologies, the TFW Ambient Monitoring Program offers formal training sessions and informal field assistance visits to help cooperators learn and implement the methodologies.

In addition, the Ambient Monitoring Program also provides a quality control service that uses an experienced crew to perform replicate surveys for cooperators. The purpose of these replicate surveys is to identify and correct inconsistencies in application of the methods and to provide documentation that data is being collected in a replicable and consistent manner throughout the state. The quality assurance service entails both pre- and mid-season QA surveys. The pre-season QA survey documents that your crews are collecting high quality data from day one. The mid-season QA survey documents crew consistency and whether training or corrections applied to problems during the first QA survey were effective. For more information on quality assurance protocols, refer to the Quality Assurance Module.

We encourage cooperators to utilize these services. Please contact the Northwest Indian Fisheries Commission (1-206-438-1181 ext. 332) for more information concerning the TFW Ambient Monitoring Program.

## References


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# *APPENDIX D.*

# *SELECTED PROTOCOLS*

# *8. RECRUITMENT TREES*

# Part 1. Large Woody Debris Recruitment

## Introduction

Harvesting trees within riparian areas can have a significant effect on stream resources by altering the number of large trees available for recruitment to the channel. In-channel debris dissipates stream energy, influences sediment storage, and provides habitat and cover for fish both directly and through changes in channel morphology.

Current forest practice rules and regulations are designed to supply Large Woody Debris (LWD) to fish-bearing (Type 1-3) streams over the long term. Stands logged prior to current rules where trees were cut to the water's edge, will take a substantial amount of time to recover and supply LWD to the stream. In addition, current riparian management rules allow for continued harvest of large trees is RMZs, which in some instances may further delay recovery.

The purpose of this portion of the Riparian Function module is to evaluate the riparian zones for their ability to provide a continuous supply of LWD to the stream for maintenance of desired channel features. Methods for the remote assessment and field validation of existing riparian function are provided. Guidelines for additional field assessments and appraisal of the long-term recruitment potential are also given.

The standard procedure evaluates the current conditions for LWD recruitment into stream channels by examining, with remote means, the age, density, and type of riparian overstory vegetation. In-channel LWD levels obtained from the fish and channel assessment teams are used to classify the wood recruitment condition. Additional information can be gathered to expand the in-channel LWD data. In addition, data can be gathered about understory conditions to project future LWD recruitment outcomes under different management scenarios.

In non fish-bearing streams (Type 4, 5) LWD functions to dissipate energy and helps store sediment. This is especially true in steeper tributaries crossing unstable terrain or in inner gorge areas. For the purposes of this analy-

sis, LWD recruitment potential is assumed to be approximately equal for all bank slopes, channel gradients, and valley confinements.

# Critical Question

***What is the condition of the riparian zone relative to its ability to supply large woody debris to the stream in the near-term?***

# Assumptions

- The majority (95%) of in-channel LWD is recruited from within 66 feet (20 m) of the stream (Murphy and Koski 1989).
- All trees 12" DBH and larger within 66 feet of a stream are candidates for LWD.
- West side riparian stands with an average age of 40 years and older are assumed to have average DBH of at least 12 inches.
- Riparian stands with an average tree size of 12 inches and larger must be well-stocked to provide adequate LWD supplies.
- Older, conifer-dominated, well-stocked stands will provide adequate and sustainable supplies of LWD.
- A Red Alder dominated stand may not be capable of supplying sufficient long-term LWD inputs.
- For this analysis we divide the state into two geographic regions (east side and west side) for consideration of differences in riparian stand characteristics (species, density, size, etc.).
- For east side riparian areas, stands 40 years and older may not have trees of DBH over 12". Due to this, age isn't a reliable indicator of size. Sizes must be verified.

# General Approach and Products

The riparian analyst uses aerial photographs and ground-truthing to evaluate and describe the current condition of the riparian zone for fish-bearing (Type 1-3) streams and selected non-fish-bearing streams (Type 4,5). The first product generated is the working basemap (map D-1) that contains the type, age/size, and density of trees in the riparian areas. This is based on

details visible on 1:12,000 photos. This encompasses all fish-bearing (Types 1-3) waters.

The next step is to use the stream channel segment map to partition the data (worksheet D-1) and prepare it for classifying according to situation category. Riparian data can be combined with information on in-channel LWD counts gathered by the fish or channel teams to describe LWD recruitment either by segment (map D-2), by indicator area (several segments combined; summary text), or for the entire watershed (summary text). Where no in-channel LWD data is available, use a default matrix to classify segments according to their ability to supply LWD (map D-2 and summary text). Selected non-fish-bearing streams (Type 4,5) may be evaluated for their wood recruitment potential as deemed necessary by the other assessment teams.

The products from the standard assessment describe the current LWD recruitment condition. If needed, additional assessments can examine characteristics of the riparian understory. From this, a realistic long-term LWD recruitment prognosis can be developed. Considerably more field work is needed because, from aerial photos, it is difficult to determine the species of conifer in the overstory and impossible to determine the understory. Both are needed to develop projections of future riparian stands. Sampling methods to obtain the most useful data will vary depending on the conditions in the watershed. Products of this portion are descriptions of how riparian areas are expected to develop over time, starting from the common situations identified in the standard assessment. Silvicultural treatment options will affect future LWD recruitment. This information can be supplied to the prescription team.

# Confidence in the Work Products

The watershed analyses completed to date have shown that an experienced photo interpreter can accurately determine the current condition of the riparian overstory using good recent stereo photography. Ground-truthing is needed, however, to calibrate the analyst's eye with regard to estimating tree size. Overall, the confidence level for evaluating the riparian status for near-term LWD recruitment is high. Identifying the LWD recruitment situations using in-channel wood counts is straightforward and the confidence in this assessment is similarly high. The only limitation is the number of segments that can be surveyed for LWD during the standard assessment. Confidence in evaluations of the riparian zone's future (long-term) LWD recruitment potential is dependent on the experience of the analyst and the quality and extent of available data on conifer species composition in the overstory and the understory. Foresters and silviculturists do not ordinarily address riparian areas separately from adjacent uplands. Skill in predicting future LWD recruitment and riparian stand development will grow with experience.

# Qualifications and Skills

## Skills for assessment of near-term recruitment status

- Ability to interpret tree species, size/age, and density from aerial photographs
- Timber cruising
- Ability to use a map wheel

## Education and Training

- Associate's degree in forestry or related field, or equivalent experience

## Experience

- At least two years experience in aerial photo interpretation and field forestry in the region where the watershed is located (western or eastern Washington).

## Additional skills for assessment of long-term recruitment status

- An understanding of the processes of natural succession within riparian tree communities under a variety of existing conditions and how silvicultural practices can alter the course of that succession.

## Education and Training

- Experience at least 2 years of field sampling, including identification of tree species, sizes, and stocking densities using both plot and visual methods.

# Startup Materials

## Maps

- Water-type maps and revisions from DNR regional offices or local landowners. This information is also available on DNR's GIS.

- Official WAU base map (1:24,000 scale).
- Stream channel segment map from channel assessment team.

## Photographs

- Most recent aerial photographs (stereo pairs). 1:12,000 black and white is the minimum sufficient resolution. Higher resolution photographs are preferable, if available.

## Other

- From landowners or DNR GIS-Landsat, obtain stand information for uplands adjacent to riparian zones, or from riparian zones specifically, if they have it. Note that timber stand data usually applies to the timber units and may not be representative of the riparian zone.
- Results of in-channel LWD counts from surveys conducted by the fish and channel teams.
- Riparian serial stage and vegetation type inventory data may be available from TFW Ambient Monitoring Program. Contact Northwest Indian Fish Commission (206) 438-1180.
- Aerial video of stream and riparian zone may be available. Check with landowner, WDF, WDW, and USFS.

# Analysis Procedure

## Current LWD Status

The following guidelines are designed to assist the analyst in evaluating the current status of the riparian zone relative to providing recruitable wood to the stream in the near-term:

### Define Assessment Area

- Prepare an overlay map (mylar or other material) that encompasses all fish bearing streams. Label this map: D-1 Riparian Timber Condition Map. This is your working map.
- Determine the dominant tree type (deciduous or conifer, Table D-1), age/size (Table D-2 or D-3), and density (table D-4), for the riparian zone on each side of the stream separately according to the categories defined

below. Record the riparian information on the overlay map (e.g., Figure D-1).

The riparian conditions are recorded on the map using the following coding method:

(CMD), where

C = Tree Species Type (Table D-1)

M= Tree Size (West Side use Table D-2, East Side use Table D-3)

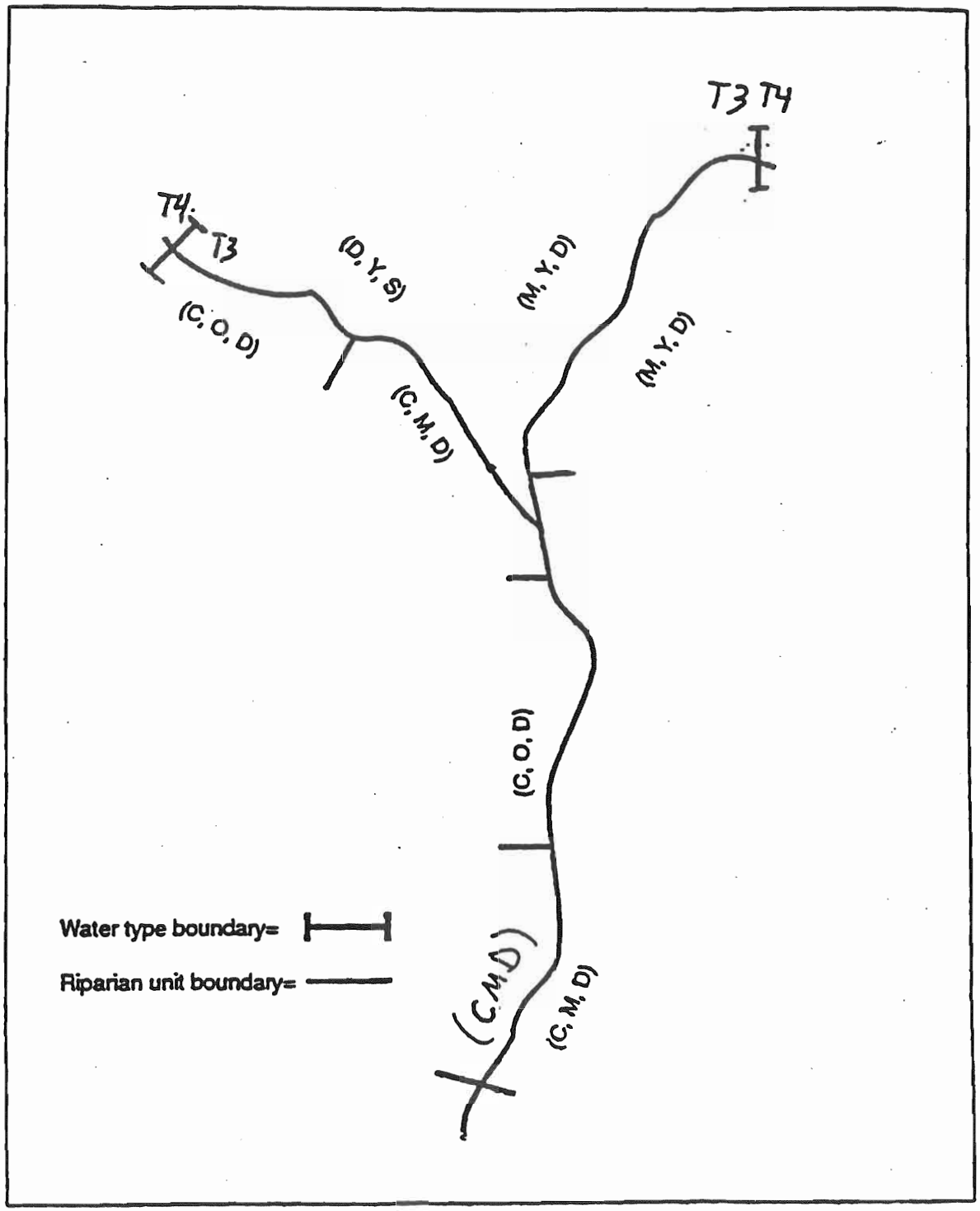
D = Stand Density (Table D-4)

For example, a length of riparian zone dominated by conifers, of mature age/ size, and dense spacing would be coded as CMD (Figure D-1). The riparian condition codes should be placed off to the side of the unit. The length of each riparian condition unit should be a minimum of 2000 ft. long (equals 1 inch on 1:24,000 scale overlay map), unless the conditions of smaller areas can be discerned and are warranted (e.g., where the first 1000' = old growth, and the next 1000' = a ten year-old clearcut). The boundaries of discreet combinations of type, size, and density are delineated by short lines drawn perpendicular to the stream (see Figure D-1).

The accuracy of this method is dependent on ground-truthing of photograph interpretations and review of any supplemental information that may be available. Preliminary estimates of riparian conditions are made in the office using the photographs and supplemental information. These estimates are coded on mylar attached to representative photographs of the WAU. Then one or more days are spent on field surveys (depending on WAU area) to check the accuracy of estimates for the representative riparian conditions. The analyst should attempt to verify the estimates for each combination of tree type, age/size, and density. Keep a record of where ground-truthing was performed for later evaluation of your confidence.

Note: Don't hesitate to ask members of the fish, channel, and perhaps other assessment teams to help gather field data for your ground-truthing (riparian tree type, size, density, and canopy closure). They will be spending considerable time in the field and can greatly expand your field checks, if they have time. You can facilitate this by providing each team with a reasonably-sized (field) version of your riparian condition map or a marked photocopy of an aerial photo. They can carry these to the field and make corrections directly on them.

**Figure D-1: Example of Riparian Conditions Map D-1.**



- Classify the dominant tree types along both sides of the stream defined below:

**Table D-1: Dominant Tree Species Definitions**

| | |
|---|---|
| ≥ 70% Coniferous Species | Conifer Dominated |
| ≥ 70% Deciduous Species | Deciduous Dominated |
| All Other Cases | Mixed |

- Classify the average age/size of the dominant tree species using the age and size class guidelines listed in Tables D-2 and D-3. For west side watersheds (see WAC 222-30-020 for boundary), age can often be estimated by reviewing historic aerial photographs to determine when the riparian vegetation was last harvested. The average size of dominant riparian tree types must be estimated for eastern Washington, since age is not a reliable indicator of size.

- Estimates of tree size should be verified during the ground-truthing reconnaissance survey.

**Table D-2: Average Riparian Tree Size Classification Based on Age and Vegetation Class (western Washington)**

| Vegetation Class | Age Class (years) | | |
|---|---|---|---|
| | Young | Mature | Old |
| Conifer[1] | <40 | 40–120 | >120 |
| Mixed | <40 | 40–80 | >80 |
| Deciduous[2] | <40 | 40–80 | >80 |

[1]Based on growth characteristics of Douglas fir in western Washington.
[2]Based on growth characteristics of red alder in western Washington.

**Table D-3: Average Riparian Tree Size Classification Based On Average DBH and Vegetation Class (eastern Washington)**

| Vegetation Class | Size Class (inches dbh) | | |
|---|---|---|---|
| | Young | Mature | Old |
| Conifer | <12 | ≥12 and <20 | ≥20 |
| Mixed | <12 | ≥12 and <20 | ≥20 |
| Deciduous[1] | <12 | ≥12 and <20 | ≥20 |

[1] East side deciduous species are predominantly cottonwood and aspen

- Characterize the density of the existing riparian stand along each response reach by identifying the amount of open ground between trees.

**Table D-4. Riparian Stand Density Criteria.**

| | |
|---|---|
| **West Side:** | Density is sparse if more than 1/3 of the ground is exposed. Otherwise, it is dense. |
| **East Side:** | Density is sparse if more than 1/2 of the ground is exposed. Otherwise, it is dense. |

## Tally information by stream segment

Once the riparian condition basemap has been constructed, you are ready to begin summarizing and interpreting the information. By now, the channel assessment team has developed the stream channel segment map (preliminary or field-verified final). Obtain a copy of this, and transfer the segment boundaries to your basemap or to another overlay. Occasionally, the segment boundaries will extend upstream of the Type 3 fish-bearing network. When this happens, simply work with the portion of the segment covered by your basemap.

With a map wheel, measure the lengths of each type of riparian condition found within a given segment (both sides of the stream), and record this information on worksheet D-1. The map wheel measurements will be in centimeters or inches, depending on the type of instrument. This is your raw data, and at this point it is not necessary to convert the unit lengths into km or mi. Sum the lengths recorded for each segment (column) to obtain a total length by segment. This number should actually be twice the channel length for this segment because you have measured the riparian zones on both sides of the stream. Continue until you have filled out the worksheet for all segments within the fish-bearing network.

This summary provides a picture of the current ability of the riparian zone to supply LWD to the channel, on a segment-by segment basis. This information can be used to develop summary situations by indicator area (identified during synthesis) or by a WAU in its entirety. The information can now be evaluated using the relative rating system for current LWD recruitment potential (Table D-6). Before doing this, however, a more detailed picture can be developed for those areas where the fish or channel teams have gathered in-channel LWD data.

## Incorporate in-channel LWD information.

Upstream LDW conditions may influence downstream segments by supplying some LWD. Field observations from the fish and channel teams can supply you with this information where they have counted LWD. The four situa-

tions described in Figure D-2 occur commonly. At one extreme, the stream contains ample large, functional wood, and the riparian zone contains adequate amounts of trees suitable for recruitment (situation RF1). At the other extreme, there is little LWD in the channel, and nothing available in the riparian zone for near-term recruitment (situation RF4). Situations RF2 and RF3 are intermediate. For segments where you have counts of in-channel LWD and an on- or off-target rating from the fish and channel teams (see methods in fish module), record this information on worksheet D-2. In addition, use the LWD situation description guidelines in Figure D-2 to identify which situation fits, then record this on worksheet D-2.

## Identify general status of LWD recruitment potential

When you do not have in-channel LWD counts, refer to the default evaluation Table D-5 to identify areas with low, moderate, and high current recruitment potential. Areas with low recruitment potential are rated as high. (See Figure D-2 next page)

**Table D-5. Riparian LWD Recruitment Impact Calls on Vegetation Class and Age/Size Class (Western and Eastern Washington)**

| Dominant Tree Type | Age\Size Class and Density | | | | | |
|---|---|---|---|---|---|---|
| | Young | | Mature | | Old | |
| | Sparse | Dense | Sparse | Dense | Sparse | Dense |
| Conifer | H | M | M | L | M | L |
| Mixed | H | H | H | L | M | L |
| Deciduous | H | H | H | M | H | M |

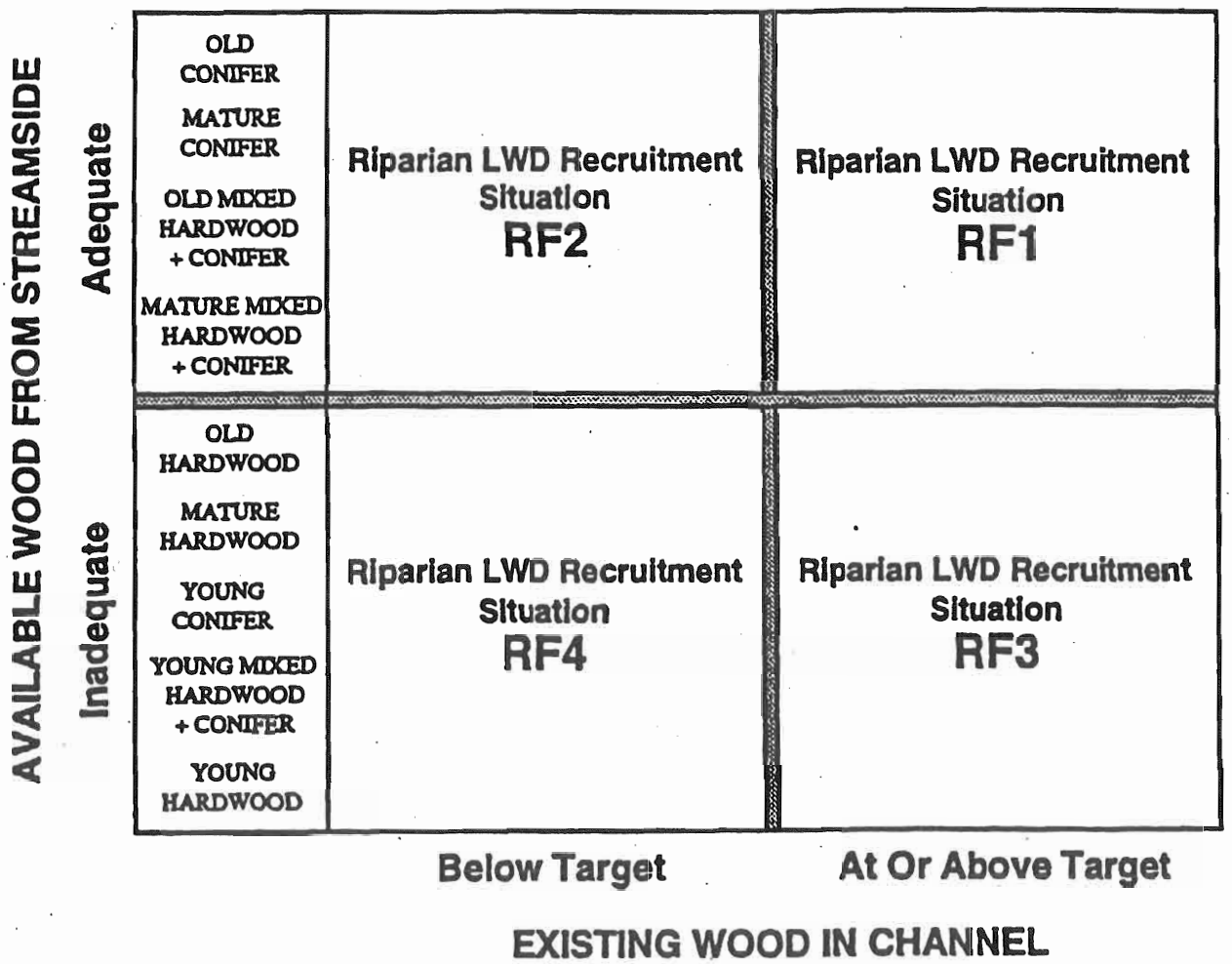
**Table D-6. Map labeling guidelines for near-term LWD recruitment potential**

| | |
|---|---|
| Solid red line | Poor LWD recruitment potential |
| Solid blue line | Fair LWD recruitment potential |
| No line | Good LWD recruitment potential |
| Dotted black line | Areas naturally deficient in LWD |
| Dashed blue line | Indeterminate LWD recruitment potential |
| Variable (analyst's descretion) | Situations RF1-RF4 |

- *Assign low, moderate, and high LWD recruitment impact calls* to the riparian condition on each side of the stream, using colored line codes. (See Table D-6)

- *Identify areas with naturally low LWD recruitment potential.* You will probably encounter some situations where natural watershed features have limited the ability of large trees to grow along the stream. These include talus slopes, cliffs, extreme wet areas (especially beaver ponds), or areas that routinely undergo disturbance (e.g., flooding). To distinguish these areas from those caused by forest management, use historical aerial photos or other records to document baseline conditions. Other situations not related to forest management include road or power line right-of-ways where trees are regularly cleared. These should be noted on Worksheet D-2, and should be identified on the situation map with appropriate coding (dotted black line).

**Figure D-2. Descriptions of common near-term LWD recruitment situations.**



# Assessment of Long-Term LWD recruitment

At this stage of the riparian assessment, the analyst should have a reasonable understanding of the current situation for the watershed. You will have a knowledge of whether the current riparian conditions are of immediate concern, or whether fresh inputs of LWD will occur before the in-channel material rots and is swept away. This is all that is required for the standard analysis. The analyst may wish to continue the riparian evaluation for two reasons: (1) to address any indeterminate segments identified during the standard assessment, and (2) to estimate the long-term LWD recruitment situations for the basin. Knowledge of the age, species composition, and stocking density of the riparian overstory and understory should provide sufficient information to predict long-term LWD recruitment.

Rather than using aerial photographs, further analysis substitutes field measurements of stand age, size, density and type. A field crew visits areas where confidence was low using the remote assessment methods in the standard analysis. To evaluate the long-term recruitment capabilities for the basin, the analyst will expand the data collections to identify tree species and stocking densities for both overstory and understory trees.

## Riparian type, age/size, and density.

For each segment sub-sampled, the field crew would:

**Measure or visually estimate the diameter at breast height** (dbh) of one-half (i.e., every other tree) of the trees along a randomly selected acre of riparian zone (622 ft-long X 70 ft. wide). Record the overstory and understory components separately.

a. If evaluating an indeterminate from the standard assessment, use this information to determine stand age class as defined in Table D-3.
b. For long-term recruitment evaluations, use this information to estimate the successional pathway the stand is likely to take if left alone.

**Record the species composition of the riparian timber stand.**

a. If evaluating an indeterminate from the standard assessment, use this information to assign a timber type (i.e., coniferous, deciduous or mixed) as described in the standard analysis procedure, above.
b. For long-term recruitment evaluations record overstory and understory conditions separately.

**Measure or estimate stocking density.**

a. If evaluating an indeterminate from the standard assessment, use this information to assign stand density. If fully stocked for a similar site in the area, record as "dense". If not, record as "sparse".

b. For long-term recruitment evaluations, use this information to estimate the successional pathway the stand is likely to take if left alone.

### Rate LWD Recruitment Impact

Use the information gathered in step 1 to answer the critical questions for all areas where certainty was low using the standard assessment.

Work products from these additional assessments will vary depending on the methods chosen by the analysts and the character of the watershed. No standard worksheets are provided, and the guidance is limited to the requirements that the critical question be answered, and that a map must be produced that displays the long-term recruitment situations identified in the watershed.

## Riparian LWD Recruitment Assessment Report

The report is intended to convey your results to the others on the assessment team, to the prescription team, and to others who may be interested in a concise, written description of your work. A brief written account of the information should be used to describe the results of your analysis and any conclusions reached relative to the critical questions. The map products should be self-explanatory. You should address the following topics.

- List the date and resolution of the aerial photos used for your assessment. Record the photo series (flightline photo number, etc.) and where these photos are stored.

- Summarize the current LWD recruitment situations for the basin, using percentage data from worksheets D-1 and D-2, and referencing maps D-1 and D-2. This includes any special situations you found in your watershed.

- If you used historical aerial photos or other information to identify areas that were naturally limited for current or long-term LWD recruitment, describe these and attach the sources (when feasible).

- Summarize your prognosis of the long-term LWD recruitment potential for the watershed, using data from worksheet D-3.

- Describe where Type 4 waters were analyzed, if any, and why. Discuss the results of your T4 analysis.

# Assessment of Long-Term LWD recruitment

At this stage of the riparian assessment, the analyst should have a reasonable understanding of the current situation for the watershed. You will have a knowledge of whether the current riparian conditions are of immediate concern, or whether fresh inputs of LWD will occur before the in-channel material rots and is swept away. This is all that is required for the standard analysis. The analyst may wish to continue the riparian evaluation for two reasons: (1) to address any indeterminate segments identified during the standard assessment, and (2) to estimate the long-term LWD recruitment situations for the basin. Knowledge of the age, species composition, and stocking density of the riparian overstory and understory should provide sufficient information to predict long-term LWD recruitment.

Rather than using aerial photographs, further analysis substitutes field measurements of stand age, size, density and type. A field crew visits areas where confidence was low using the remote assessment methods in the standard analysis. To evaluate the long-term recruitment capabilities for the basin, the analyst will expand the data collections to identify tree species and stocking densities for both overstory and understory trees.

## Riparian type, age/size, and density.

For each segment sub-sampled, the field crew would:

**Measure or visually estimate the diameter at breast height** (dbh) of one-half (i.e., every other tree) of the trees along a randomly selected acre of riparian zone (622 ft-long X 70 ft. wide). Record the overstory and understory components separately.

a. If evaluating an indeterminate from the standard assessment, use this information to determine stand age class as defined in Table D-3.
b. For long-term recruitment evaluations, use this information to estimate the successional pathway the stand is likely to take if left alone.

**Record the species composition of the riparian timber stand.**

a. If evaluating an indeterminate from the standard assessment, use this information to assign a timber type (i.e., coniferous, deciduous or mixed) as described in the standard analysis procedure, above.
b. For long-term recruitment evaluations record overstory and understory conditions separately.

**Measure or estimate stocking density.**

a. If evaluating an indeterminate from the standard assessment, use this information to assign stand density. If fully stocked for a similar site in the area, record as "dense". If not, record as "sparse".

b. For long-term recruitment evaluations, use this information to estimate the successional pathway the stand is likely to take if left alone.

### Rate LWD Recruitment Impact

Use the information gathered in step 1 to answer the critical questions for all areas where certainty was low using the standard assessment.

Work products from these additional assessments will vary depending on the methods chosen by the analysts and the character of the watershed. No standard worksheets are provided, and the guidance is limited to the requirements that the critical question be answered, and that a map must be produced that displays the long-term recruitment situations identified in the watershed.

# Riparian LWD Recruitment Assessment Report

The report is intended to convey your results to the others on the assessment team, to the prescription team, and to others who may be interested in a concise, written description of your work. A brief written account of the information should be used to describe the results of your analysis and any conclusions reached relative to the critical questions. The map products should be self-explanatory. You should address the following topics.

- List the date and resolution of the aerial photos used for your assessment. Record the photo series (flightline photo number, etc.) and where these photos are stored.

- Summarize the current LWD recruitment situations for the basin, using percentage data from worksheets D-1 and D-2, and referencing maps D-1 and D-2. This includes any special situations you found in your watershed.

- If you used historical aerial photos or other information to identify areas that were naturally limited for current or long-term LWD recruitment, describe these and attach the sources (when feasible).

- Summarize your prognosis of the long-term LWD recruitment potential for the watershed, using data from worksheet D-3.

- Describe where Type 4 waters were analyzed, if any, and why. Discuss the results of your T4 analysis.

- Provide a description of any deviations from the standard methods and why the changes were necessary.
- If additional assessments were performed, describe methods used, including assumptions and reference material.
- Describe your confidence in the work products.
- Make suggestions on how this portion of the module could be improved in the next revision. Please be specific and provide examples.

## Maps

- D-1, D-1 Riparian Timber Condition and Water Type Map
- D-2, near-term LWD recruitment situations.
- D-3, long-term LWD recruitment situations (if additional assessments performed).

## Summary Data

- Worksheets D-1, D-2, and D-3 plus additional worksheets (as needed to complete additional assessments).

**An important reminder:** The steps outlined in this module are meant to provide guidance to the analyst and aid in answering the critical questions as thoroughly and efficiently as possible. The evidence obtained through these steps should lead to and satisfactorily support answers to the critical questions. However, each watershed will present its own interpretive challenges and the analyst is encouraged to do what is necessary to focus on the questions, not merely the step-by-step instructions. Where deviations from these methods are made, the analyst is expected to supply supporting documentation.

# *APPENDIX D.*

# *SELECTED PROTOCOLS*

## *9. GRAVEL SAMPLING*

Timber-Fish-Wildlife
Ambient Monitoring Program

# SALMONID SPAWNING GRAVEL COMPOSITION MODULE

**August 1994**

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Northwest Indian Fisheries Commission

# SALMONID SPAWNING GRAVEL COMPOSITION MODULE

## Introduction

The development of salmonid eggs and alevin typically occurs in the gravel substrate of freshwater rivers and streams. Mature females choose sites where substrate and flow conditions are favorable and deposit their eggs in nests (redds) they excavate in the substrate. After the eggs hatch, the alevins continue to reside within the streambed gravel, subsisting on nutrients from an external yolk-sac. When the yolk-sac has been absorbed they emerge from the gravel and begin active feeding.

The eggs and alevin require a stable streambed and an adequate supply of water while developing to prevent dehydration, supply oxygen and carry away metabolic waste. Mortality during intra-gravel development is highly variable, depending on hydrologic, geomorphic and biotic conditions. Mortality has been attributed to a variety of causes including disease, predation, suffocation, dehydration, mechanical disturbance and freezing (McNeil, 1969).

### How Fine Sediments Affect the Incubation Environment

Salmonid eggs require an abundant supply of dissolved oxygen to ensure survival to emergence and proper development (Alderdice et al., 1958). Oxygen reaches the eggs through a three-step process involving dissolution of oxygen from the atmosphere into stream water, transport of oxygenated water to the stream bottom, and interchange of oxygenated water from the stream to the pores between gravel in the egg pocket (Vaux, 1962). Fine sediment (fine sand, silt or clay) that lodges in the interstitial spaces between gravel particles reduces permeability and slows the rate of flow through the gravel substrate (McNeil and Ahnell, 1964; Johnson, 1980). Numerous studies (Chapman, 1988, Everest et al., 1987; Iwamoto et al. 1978) have associated high levels of fine sediments with elevated mortality rates and reduced fitness of surviving fish (Koski, 1975). These effects are due to increased stress and mortality associated with oxygen deprivation (Alderdice et al., 1958), the accumulation of toxic metabolic by-products (Bams and Lam, 1983), and entombment of emerging fry (Chapman, 1988).

### Natural and Management-Related Sources of Fine Sediments

Concentrations of fine sediments in stream channels vary in space and time (Adams and Beschta, 1980). The amount of fine sediments present at a particular location depends on the nature and magnitude of erosional processes that produce fine sediments and introduce them to the stream channel, as well as the geomorphic factors that control the transport and storage of sediments, such as stream gradient and hydrology. In addition, spawning salmonids tend to remove fine sediments from the substrate during redd construction, however the persistence of this effect is not well understood (Everest et al. 1987). During the incubation period, fine sediments moving through the stream channel may intrude into the redd. The severity and significance of fine sediment intrusion is

related to the size and amounts of transported sediment, and the depth of intrusion (Lisle, 1989). Fine sediment levels are higher in watersheds where the geology, soils, precipitation or topography create conditions favorable for erosional processes that produce fine sediments (Duncan and Ward, 1985). Fine sediments are typically more abundant where land-use activities such as road-building or land-clearing expose soil to erosion and increase mass wasting (Cederholm et al., 1981; Swanson et al., 1987; Hicks et al., 1991).

## Purpose of the Spawning Gravel Composition Module

The purpose of this module is to provide a standard method of sampling potential salmonid spawning habitat to characterize gravel composition and fine sediment levels on a stream segment scale in streams where there is no prior data available on variation in gravel composition to guide sample design. (For streams with existing data, it may be preferable to develop custom sampling strategies based on segment-specific variation). The intent is to ensure replicable data that allows comparisons to be made through time and between stream segments. The information generated on the condition of potential spawning habitat is suitable for use as a management indicator. The module does not attempt to document or predict actual survival to emergence, because that objective would require research of an intensity impractical for management purposes. Nor is it oriented towards the requirements of any particular salmonid species, as species may vary within and between stream segments around the state.

The information generated using this methodology is suitable for:

* evaluating the composition and characteristics of spawning gravel;
* estimating the percentage of fine sediments less than 0.85 mm for Watershed Analysis;
* comparing spawning gravel composition among stream segments, watersheds and eco-regions;
* monitoring trends in spawning gravel composition over time.

## The Spawning Gravel Sampling Methodology

This section will cover what information and equipment is needed, site selection, determining a sampling strategy, inventory of sampling sites, and collection of samples from the stream.

### Information and Equipment Needed

Map delineating stream segments
*McNeil sampler with plunger
*Fiberglass tape (30, 50 or 100 meter, depending upon channel width)
Plastic buckets (5 gallon) with lids- one per sample
Backpack carrier for buckets (optional)
Squirt bottles (2)
Hip boots or chest waders
Rain gear
(* Calibration required)

Form 6.0
Form 6.1
Field notebook
Pencils
Permanent markers
Flagging
Bucket labels

Field Note: (1) The plastic buckets and lids should be sequentially numbered with a permanent marker prior to taking them out in the field. (2) The equipment needed for processing samples depends upon the method used. The equipment requirements of each processing method are discussed separately in the sections on "volumetric processing" and "gravimetric processing".

### Calibration

Check the McNeil sampler for damage. There should be no broken welds, holes, or dents sufficient to cause changes in volume of sample taken. Measure the coring cylinder length from the top of the stop ring to the base of the collection basin. The standard length should be 23 cm. Next, measure the inside diameter of the coring cylinder. The standard diameter should be 15 cm. If your coring cylinder has different dimensions, make a note of it. Check the plunger for damage. Tighten any loose fittings and replace defective washer/seals and flap valves.

Calibrate your fiberglass tapes using the methods outlined in the Reference Point Survey Module calibration section. Record all information in your QA plan.

## Site Selection

Prior to inventorying sampling sites and collecting samples, it is necessary to determine which segments are best suited to gravel sampling and then identifying the logistically feasible sampling reaches within it.

### Appropriate Times to Collect Samples

Spawning gravel composition (particularly fine sediment levels) in a stream reach can vary over the course of the year. In western Oregon streams, substrate composition was relatively stable from early summer to early fall, and was most variable during the winter storm season when peak flows mobilized the substrate and the processes of fine sediment infiltration were most active (Adams and Beschta, 1980). In order to provide a management indicator of substrate composition that can be used to compare stream reaches and determine trends over time, sampling should be conducted during moderate to low flow conditions outside of the winter-spring high runoff period. The actual timing of the high runoff period will vary depending on the hydrologic regime of the system. If you are unfamiliar with the system to be sampled, consult with people familiar with the system or refer to USGS stream flow records to determine an appropriate sampling period.

Collecting spawning gravel samples during extremely low flow conditions is also to be avoided, because only a small portion of the potentially available spawning habitat will be wetted. This may introduce bias into site selection. We do not recommend sampling areas that do not have water flowing over them such as dry, exposed bars because the potential effect this may have on the sampling process or the composition of the sample is unknown.

It is usually ideal to sample in the late summer/early fall low flow period when conditions are similar to those encountered by salmonids when they begin to spawn. Avoid working in the channel

during spawning or when there are eggs in the gravel, to prevent unnecessary disturbance and mortality to salmonid populations.

## Identifying Sampling Segments

Delineation of stream segments is the first step in selecting a sampling reach. This methodology characterizes spawning gravel composition at the stream segment scale. Stream segments, reaches distinguished from one another by changes in gradient, valley confinement or tributary confluences, are the fundamental unit of analysis. This step may already have been done during Watershed Analysis or previous Ambient Monitoring surveys. If so, use the segment maps generated and skip this step. If not, partition the river system into stream segments using the TFW Ambient Monitoring Stream Segment Identification Module.

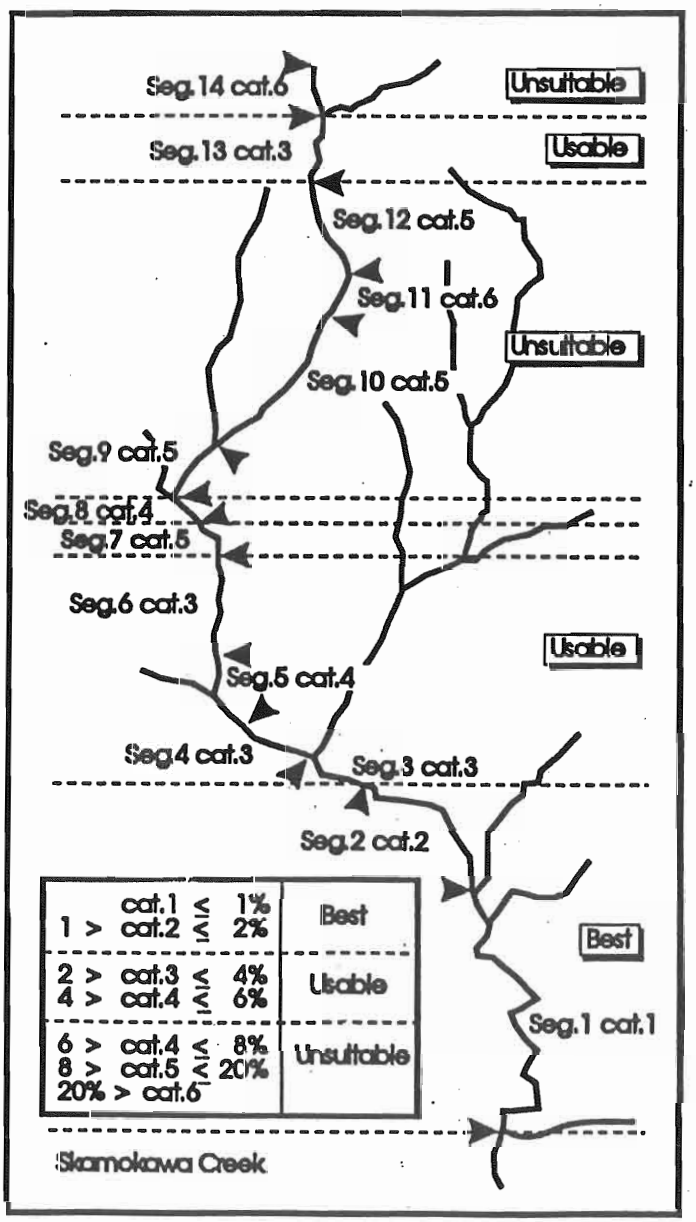


Figure 1. Suitability of gravel sampling by segment and gradient.

## Choosing Appropriate Segments to Sample

Once the river system has been divided into segments, the criteria used to select appropriate monitoring segments should include salmonid use (current, historic, or future potential), appropriate gradient, and substrate size. The McNeil sampler does not work well in substrates with particles greater than ten cm (four inches) in diameter.

This methodology is best suited for segments consisting of pool-riffle sequences (typically gradients less than two percent). It can sometimes be applied (with modifications) on segments in the two-to-six percent range where spawning gravels typically occur in patches, but is usually unsuitable for segments with gradients over six percent (Figure 1). For segments with a category 4 gradient (4 - 8%), it is necessary to know the average map gradient based on USGS 7.5 minute topographic maps in order to select those segments with 4 - 6% gradient.

## Logistically Feasible Sampling Areas

Once a segment has been chosen for sampling, the next step is to identify portions of the segment suitable for sampling and to eliminate portions where sampling is logistically im-

practical. Ideally, sampling sites should be distributed throughout the entire segment. However, this is not always practical due to the size and weight of the sampler and the gravel samples, proximity to vehicle access, and stream channel features. Alternative transport systems such as helicopters or boats may provide better access.

Examine the segment and identify potential access roads and trails, and terrain features that impede access. Then determine how far it is feasible to transport equipment and samples to the access points. This will depend on the terrain and the physical strength and endurance of those transporting the samples. Transporting samples for distances greater than 0.75 - 1.0 kilometer is probably not practical in most cases (Figure 2).

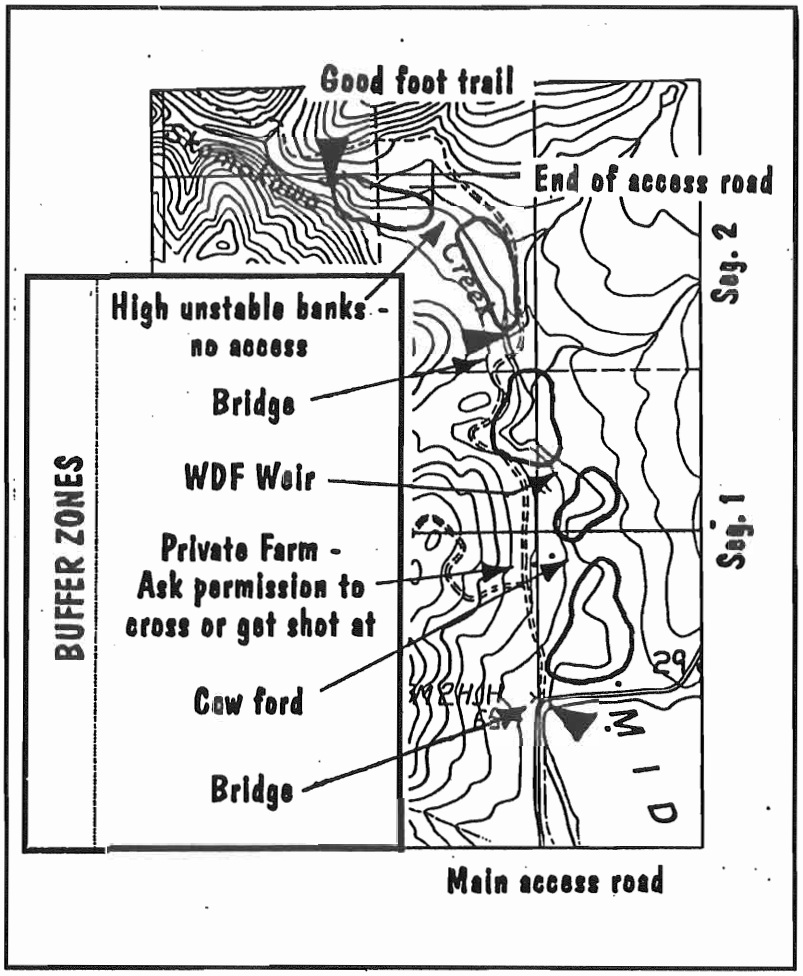


Figure 2. Determining and finalizing potential sampling areas in segment reaches 1 and 2 based on topographic map and local knowledge. The circular areas are the finalized areas for sampling.

## Eliminating Areas in the Vicinity of Instream Structures

Human structures and disturbance in the stream channel such as bridges, culverts, weirs, dams, bank protection, fords, etc., locally alter hydraulic conditions in stream channels, affecting sediment deposition patterns. Samples taken in the vicinity of these structures or disturbances reflect the local effects of the structure and mask the overall effect of watershed conditions on the stream channel. Avoid sampling within the immediate influence of these features. The length of affected stream channel will vary, however as a general guideline do not collect samples within 50 meters of instream structures.

## Finalizing the Sampling Reach

Once areas that are logistically impractical to sample or are in the immediate vicinity of instream structures have been eliminated, the remainder of the segment is available for sampling and is referred to as the sampling reach.

## Determining a Sampling Method

The next step is to determine a sampling strategy. Two options are available: (1) the riffle crest sampling method or (2) the gravel patch sampling method. The choice of sampling strategy should be based on an evaluation of potential sampling sites within the sampling reach to determine if there are an adequate number of riffle crests to use the riffle crest sampling method. For both methods, a minimum of 12 samples is required.

### Riffle Crest Sampling Method

The riffle crest sampling method is the preferred strategy, because it allows consistent and reproducible sampling at a specific geomorphic feature, the riffle crest, as in Tripp and Poulin (1986). This method is best used in low gradient segments (< 2%) where substrate size and pool/riffle characteristics are optimal for using a McNeil gravel sampler.

Riffle crests are located at the upstream end of riffles, typically forming the boundary between pool tailouts on the upstream side and the riffle on the downstream side (Lisle, 1987.) Riffle crests were chosen as sampling sites for the following reasons:

1) Riffle crests are distinct geomorphic features that can be identified and located by different observers in a wide variety of streams. This reduces observer bias in site selection and increases our ability to replicate and compare data on a statewide basis.

2) Riffle crests are located at the transition between the two areas most heavily utilized for spawning by salmonids, pool tailouts and riffles. The riffle crest is utilized by nearly all salmonids for spawning, and is often the first area in the stream selected by salmonids for spawning.

3) Sampling riffle crests avoids the confusion associated with using species-specific criteria to identify sites (particularly in areas used by multiple species), and eliminates potential bias associated with the effect of run-size when using actual spawning sites selected by salmonids.

*How to Identify a Riffle Crest*

The term "riffle crest" refers to a specific feature of the streambed. The riffle crest (RC) is located at the high point of the bar that typically occurs below many pools. Viewed in longitudinal profile, the channel bottom slopes down in both an upstream and downstream direction at the RC (Figure 3). RCs typically act as hydraulic control structures that impound water in the upstream pool. They can be located by finding the boundary between the smooth, laminar flow of water leaving the pool and the surface turbulence of the riffle associated with increased velocity and decreased depth as water flows over the downstream slope of the bar. See Habitat Unit Survey Module for a more detailed description.

### Gravel Patch Sampling Method

When a project leader identifies stream segments greater than 2% in gradient or where it is unknown

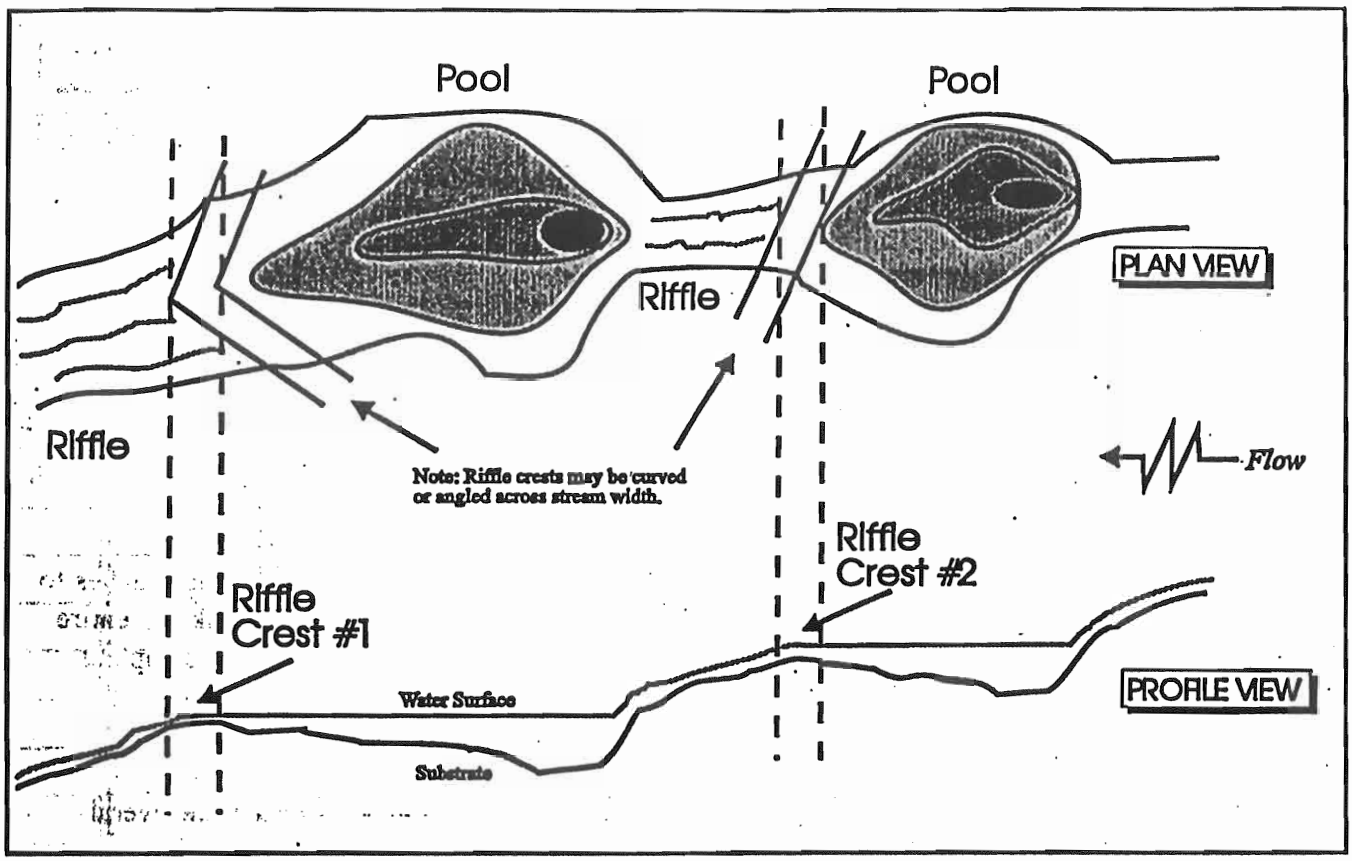


**Figure 3. Plan and profile views of a stream reach identifying the location of riffle crests.**

if there are enough RCs to produce 12 samples, it is recommended that you inventory both RCs and patches to determine which method to use. The gravel patch method is recommended when there are not enough riffle crests or when the riffle crests are too heavily armored with large particles to collect an adequate number of samples with the McNeil sampler. This method is useful in steeper streams where the pool-riffle sequences typically are less well defined and the riffle crests contain larger particles. In these situations, spawning gravels typically occur in patches associated with obstructions or the tailouts of large pools. The patch method has a minimum guideline of 12 samples per segment.

### *How to Identify a Gravel Patch*

The definition of a gravel patch covers a broad range of potential spawning gravel situations. Basically, a patch is one contiguous formation of suitable spawning gravel covered by water under summer low-flow conditions. The guideline for the minimum size of a patch is two square meters, but this may vary depending upon local conditions or redd size characteristics required of the species which utilizes (or potentially utilizes) that segment of stream. The minimum size is also a consideration of equipment limitations in regards to the potential for a successful sample collection. Patches are most often located on the downstream side of an obstruction such as a log or boulder, in the tailout of a pool, along the submerged edge of a gravel point bar; and sometimes as a portion of a riffle unit. Riffle crests are treated as patches when there are too few to meet the minimum number necessary to use the riffle crest sampling method.

## Inventory of Sampling Reaches

At this point, you should have completed your segmenting and defined your sampling reaches within the segment. For this section, you will need a map of the stream segment showing reaches, access points or local conditions to be aware of, several blank copies of Form 6.0 (Appendix A), flagging and permanent markers, hipboots and other appropriate field gear.

The first task is to determine which sampling method to employ. To do this, use the suitability index (Figure 1) as a guideline. If the segment gradient is less than 2%, a systematic riffle crest inventory strategy is generally the most suitable and usually only riffle crests would be inventoried. If the segment is greater than 2%, then both riffle crests and patches are inventoried unless local knowledge indicates that there are enough suitable riffle crests.

Once the sampling method is decided, the next step is to inventory the segment's sampling reaches to determine the total sampling population using Form 6.0. For the riffle crest method, walk the entire length of each sampling reach and inventory all riffle crests (RCs) with 2 or 3 estimated sampling sites. For the patch method, walk the entire length of each sampling reach and inventory all riffle crests *and* patches with 1, 2, or 3 estimated samples.

The evaluation of a sampling site to estimate the number of potential samples is based on several factors. First, determine the spawning gravel area in regards to substrate size and obstructions. Second, estimate the number of samples possible considering the diameter of the equipment, the area of equipment disturbance created by attempting a core, and the area of human disturbance caused when trying to provide stable footing. As a guideline, samples should be taken a minimum of 1 meter apart. Third, record the number of undisturbed samples physically possible (minimum-1/ maximum-3 per site). Be sure to eliminate sites that have been disturbed by human activities as described above.

During the inventory, riffle crest and/or patch sites that appear suitable for sampling (1-3 potential samples) are assigned unique riffle crest (RC #) or patch (P #) numbers. Begin at the downstream end of the segment and assign the RC and P numbers sequentially by type throughout the sampling reaches. Using Form 6.0, record the number assigned to each suitable RC or P and note its location relative to a reference point or landmark. Marking the location on aerial photographs provides another level of documentation. In the stream, mark each suitable RC or P site with flagging showing the RC or P number. The complete set of suitable riffle crest and/or patch sites identified within the segment's sampling reaches constitutes the pool of *potential* sampling sites from which the systematic inventory strategy is applied to determine a final sampling population.

### *Systematic Riffle Crest Inventory Strategy*

In low gradient stream segments where you have high confidence that there are enough riffle crests to provide a minimum of 12 samples, inventory only riffle crests with 2 or 3 estimated samples. For example, Figure 4 shows the inventory strategy for riffle crests using Form 6.0. The riffle crests are numbered sequentially (RC #), the estimated number of undisturbed samples possible from the RC are noted, and the sampling site location is established by assigning distances from the nearest reference point (RP #) or other landmarks as necessary.

## SPAWNING GRAVEL COMPOSITION

Fill out all information on every form. Full names required on first form for each day - Initials can be used on secondary pages

**FORM 6.0**
**INVENTORY**

W.R.I.A. 14.0012 ___
Segment # 6 ○LB ○RB
Inventory Date 9/15/94
to 9/15/94

Stream Name KENNEDY CREEK
Basin Name SHELTON
Rivermile from 4.0 to 4.5
Ref. Pt. from Q to 8
Segment Gradient 2.5%

Inventory Lead ALLEN PLEUS — Affiliation NWIFC
Recorder DAVE SCHUETT-HAMES — NWIFC

| SP# | Riffle Crest RC # | Patch P # | Samples Est. # | Landmark RP # | Distance | Up or Dn | Field Notes |
|---|---|---|---|---|---|---|---|
| | 1 | | 3 | Q | 20 m | UP | GOOD SITE - No obstructions |
| | 2 | | 2 | Q | 70 m | UP | Large log blocking 1/3 RC on LB |
| | 3 | | 3 | 1 | 5 m | UP | GOOD SITE |
| | 4 | | 2 | 1 | 35 m | | SMALL RC on 2ndry Pool unit |
| | 5 | | 2 | 1 | 40 m | | LARGE COBBLE PRESENT |
| | 6 | | 2 | 2 | 55 m | | " " " |
| | 7 | | 3 | 3 | 25 m | | GOOD SITE - Avoid LB eddy |
| | 8 | | 3 | 6 | 60 m | | GOOD SITE |
| | 9 | | 2 | 7 | 15 m | | BEDROCK INTRUDES RB |
| | 10 | | 2 | 7 | 30 m | | BEDROCK INTRUDES RB & LB |
| | 11 | | 2 | 7 | 60 m | | LARGE COBBLE RB |
| | 12 | | 3 | 8 | 45 m | ↓ | GOOD SITE - CAUTION! HORNET NEST LB |
| | | | | | | | |

**Figure 4. Form 6.0 showing the riffle crest inventory strategy**

After inventorying the sampling reaches of your segment on Form 6.0, count the number of estimated samples for all RCs.

**a.)** If the total estimated number of samples falls between 12-18, the result constitutes your total sampling population from which 100% of the RCs must be sampled for the segment. Skip the rest of this section and go to the "Identifying Sampling Points at Riffle Crest and Patch Sites" section (pg. 15).

**b.)** If the number is greater than 18, the result constitutes your sampling population from which a random sub-sample is taken (Figure 5). Skip the rest of this section and go to the "Sample Population: Systematic Random Sampling Strategy" section (pg.13).

**c.)** If the total estimated number of samples is below 12, you will need to re-inventory the segment using the systematic patch inventory strategy below.

**Riffle Crest Method**

| RC | # RC | # Samples |
|---|---|---|
| w/3 | 5 | 15 |
| w/2 | 7 | 14 |

**Figure 5. Number of RCs and Samples.**

*Systematic Patch Inventory Strategy*

This strategy is useful in higher gradient stream segment situations (>2%) where you do not know if there are enough riffle crests to provide the minimum 12 samples. In this strategy, walk the stream starting from the downstream end and identify/inventory all riffle crests and patches sequentially on Form 6.0 (Figure 6). At the end of the segment, assess the number of samples possible from using only RCs with 2 or 3 estimated samples. If the estimated sample number is greater than 12, (and this characterizes the segment for your purposes) use the systematic riffle crest inventory strategy outlined above and eliminate all patches and riffle crests with only 1 estimated sample. If the number is less than 12, lump the riffle crests and patches together into the systematic patch inventory strategy.

| SP # | Riffle Crest RC # | Patch P # | Samples Est. # |
|---|---|---|---|
| | ~~1~~ | | 1 |
| 1 | | 1 | 2 |
| 2 | 2 | | 2 |
| 3 | | 2 | 3 |
| | | ~~3~~ | 1 |
| 4 | 3 | | 2 |
| | ~~4~~ | | 1 |
| 5 | | 4 | 2 |
| 6 | | 5 | 2 |
| | | ~~6~~ | 1 |
| 7 | 5 | | 2 |
| 8 | | 7 | 2 |
| | ~~6~~ | | 1 |
| 9 | | 8 | 2 |
| 10 | | 9 | 3 |
| | | | |

Figure 6. Detail of Form 6.0 showing the systematic patch inventory strategy

The systematic patch inventory strategy follows the same format as the riffle crest inventory strategy except that both riffle crests and patches are now part of the same total sample population. After inventorying the sampling reaches of your segment on Form 6.0, count the number of estimated samples for all riffle crests and patches with 2 or 3 estimated samples.

a.) If the total estimated number of samples falls between 12-18, the result constitutes your total sampling population from which 100% of the RC/Ps must be sampled for the segment. Eliminate all sampling sites with only 1 estimated sample and adjust your sampling population number (SP #) on Form 6.0 to reflect the proper sequence. Skip the rest of this section and go to the "Identifying Sampling Points at Riffle Crest and Patch Sites" section (pg. 15).

b.) If the number is greater than 18, the result constitutes your sampling population from which a random sub-sample is taken. Eliminate all sampling sites with only 1 estimated sample and adjust your sampling population number (SP #) on Form 6.0 to reflect the proper sequence (Figure 7). Skip the rest of this section and go to the "Sample Population: Systematic Random Sampling Strategy section" (pg.13).

**Patch Method**

| RC | # RC | # Samples |
|---|---|---|
| w/3 | ~~0~~ | ~~0~~ |
| w/2 | 3 | 6 |
| w/1 | 3 | 3 |

| P | # P | # Samples |
|---|---|---|
| w/3 | 2 | 6 |
| w/2 | 5 | 10 |
| w/1 | 2 | 2 |

| RC/P | # RC/P | # Samples |
|---|---|---|
| w/3 | 2 | 6 |
| w/2 | 8 | 16 |
| w/1 | 5 | 5 |

Figure 7. Patch method: enumeration of riffle crests and patches - lumping into combined sampling sites (RC/P).

c.) If the total estimated number of samples is below 12, include all riffle crest and patch sites with 1 estimated sample. Repeat the strategy listed above, but ignore the section on elimination.

Note: There may be times when a complete inventory of a segment produces a sample population with less than the guideline of 12 estimated samples. A low sample population could be the result of many factors such as stream and segment size, substrate armoring, or access. Ultimately, it is up to the cooperator to determine whether such a low sample population adequately characterizes their segment.

## Sample Population: Systematic Random Sampling Strategy

At this point, you should have a completed Form 6.0 from which identifies your sampling population. The following systematic sampling strategy was developed by examining four existing large data sets from Washington State to determine variation within and among riffles. It uses a two-stage sample design with riffle crests as the primary sample units and samples within riffle crests as the secondary sample units. Systematic sampling of riffle crests (with a random starting point) is recommended to avoid potential clustering, because fine sediment may systematically increase in a downstream direction if gradient decreases. Based on the existing data we examined, a coefficient of variation of less than 20% can be achieved by collecting a minimum of three samples per riffle crest and sampling as many riffle crests as possible, but no fewer than 10% of the total riffle crests in each segment. The following recommendations for sampling are based on the number of riffle crest and/or patch sites inventoried in the stream segment. The objective is to maximize the distribution of sampling sites, but within the logistical constraint of keeping the total number of samples per segment under 20.

To determine the number of riffle crest and/or patch sites to sample, refer to your inventory Form 6.0. In the left hand column of Table 1, locate the appropriate row corresponding with the segment riffle crest and/or patch inventory total. The second column on that row will state the percentage of sites to be sampled. For example, if 17 riffle crests were inventoried, then the third row (13 - 18) would be selected so 33% of the riffle crests should be sampled.

Table 1. Recommendations for sampling riffle crest (RC) and patch (P) sites.

| Total No. RCs and Ps | Percent of sites sampled | Choose random number between | Total Samples |
|---|---|---|---|
| 4 - 6 | 100% | - | 12 - 18 |
| 7 - 12 | 50% | 1-2 | 12 - 18 |
| 13 - 18 | 33% | 1-3 | 12 - 18 |
| 19 - 24 | 25% | 1-4 | 12 - 18 |
| 25 - 30 | 20% | 1-5 | 12 - 18 |
| > 30 | 12.5% | 1-8 | 12 + |

Next, select a random starting number using a random number generator, die, or a random number table (provided in Appendix B). Use the third column in Table 1 to determine the appropriate range of random numbers to select from. Then find the appropriate box in Table 2 to determine the sequence of riffle crests and/or patches to sample. Circle the corresponding numbers in the SP # column of Form 6.0 to identify those which will be sampled in the field.

Table 2. Selection of systematic sampling SITE (RC/P) sequences.

| Random No. | 50% | 33% | 25% | 20% | 12.5% |
|---|---|---|---|---|---|
| 1 | 1,3,5,7 9,11 | 1,4,7,10,13,16 | 1,5,9,13,17,21 | 1,6,11,16,21,26 | 1,9,17,25,33, 41 etc. |
| 2 | 2,4,6,8,10,12 | 2,5,8,11,14,17 | 2,6,10,14,18,22 | 2,7,12,17,22,27 | 2,10,18,26,34, 42 etc. |
| 3 | | 3,6,9,12,15,18 | 3,7,11,15,19,23 | 3,8,13,18,23,28 | 3,11,19,27,35, 43 etc. |
| 4 | | | 4,8,12,16,20,24 | 4,9,14,19,24,29 | 4,12,20,28,36, 44 etc. |
| 5 | | | | 5,10,15,20,25,30 | 5,13,21,29,37, 45 etc. |
| 6 | | | | | 6,14,22,30,38, 46 etc. |
| 7 | | | | | 7,15,23,31,39, 47 etc. |
| 8 | | | | | 8,16,24,32,40, 48 etc. |

*Selecting Additional Random Sampling sites*

There may be instances where the random sequence does not provide enough sites to collect 12 samples. In these cases, randomly select additional sampling sites as needed from the unselected sample population and circle the SP # on Form 6.0.

## Collection of Samples

At this point, the cooperator should be ready to collect actual gravel samples. For this section, you will need your completed Form 6.0, several blank copies of Form 6.1 (Appendix C), and all field equipment outlined in the "Information and Equipment Needed" section.

Start by locating on the stream your first sampling site as listed on Form 6.0 (SP #1). The next step is to determine the specific points on the riffle crest or patch to sample. The most important part to remember is that this method is for an analysis of *salmonid spawning gravel*. This means that any given length of riffle crest or size of patch may not constitute 100% gravel suitable for spawning. There are three common characteristics of spawning gravel used to determine the dimensions of the spawning gravel section of a riffle crest or patch: (1) must be covered by flowing water - gravel under eddies or stagnant water are not included; (2) avoid depositional areas where sand/silt are dominant - usually along wetted edges; and (3) factors limiting the use of the sampling equipment - the gravel composition is dominated by substrate more than 10 cm diameter, gravel under/near logs, boulders, or jams.

Identifying Sampling Points in Riffle Crest and Patch Sites

At each riffle crest selected for sampling, samples are taken on a line extending across the spawning gravel section along the top of the riffle crest. If the riffle crest extends diagonally across the channel, the line should follow the riffle crest.

Begin by extending a fiberglass tape across the wetted portion of the spawning gravel of the riffle crest. Three samples should be taken at each riffle crest site. The first sampling point is the mid-point of the line across the spawning gravel of the riffle crest. Place a marker (flagged weight) at this point. Next, measure two-thirds of the way between the mid-point of the cross-section and the wetted gravel perimeter towards the left bank and mark this location. Last, measure two-thirds of the way from the mid-point to the wetted gravel perimeter towards the right bank and mark this location. If the spot selected is on a small dry bar, too close to a log or boulder, or in still water, go to the nearest suitable location along the line. If a sampling point is lightly covered with organic debris such as leaves or twigs, gently remove them without disturbing the gravel underneath. The resulting three markers are the sampling points for the riffle crest (Figure 8).

On many stream systems, it is necessary to make several coring attempts with the McNeil gravel sampler before a successful sample is taken. This commonly occurs when the buried substrate is too large for the coring cylinder. If you are unsuccessful taking a sample at a selected location because of this or other reasons, try sampling laterally along the transect, remaining as close to the original point as possible but beyond any gravel disturbance caused by the cylinder or footholds. In situations where you are unsuccessful in collecting any samples from a riffle crest, randomly select either the upstream or downstream adjacent riffle crest (flip a coin) and collect the samples at this location. Be sure to note this change on your Form 6.0 or in your field notebook.

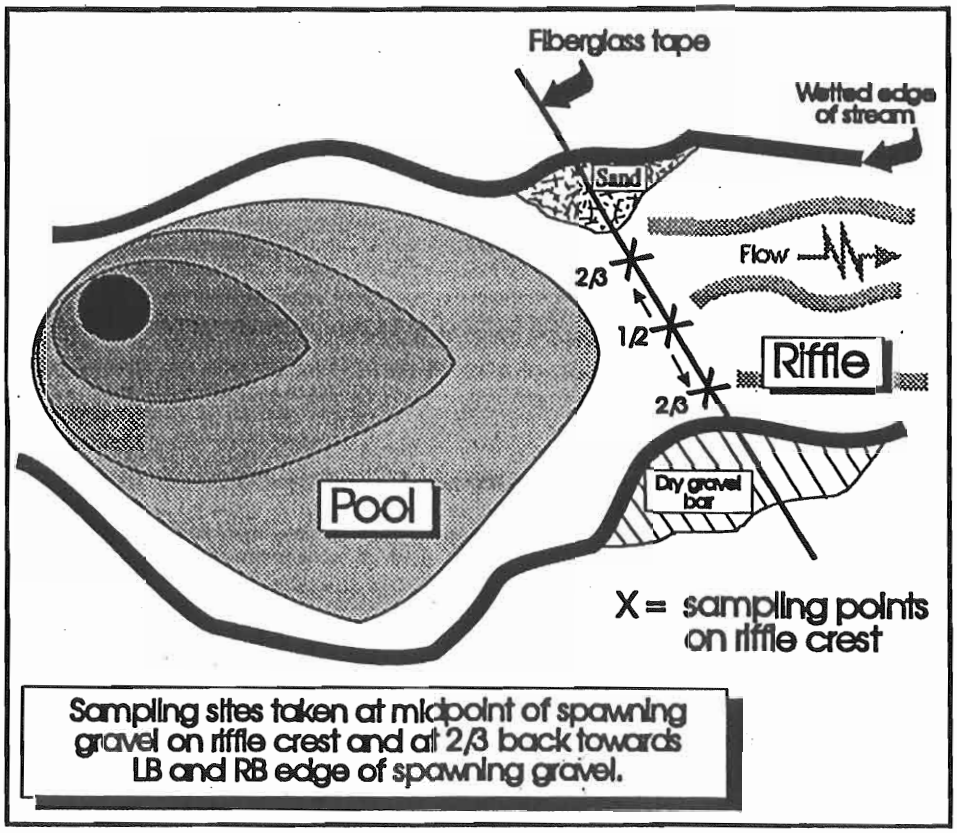


Figure 8. Sampling points at riffle crests.

RC/Patch # 3
Sample # 6
Bucket # 21
Notes: Large patch located in tail out of pool. Triangle pattern RB site

# attempts

Figure 9. Detail of Form 6.1: Example of collection information.

When a successful sample has been taken, use Form 6.1 to document all pertinent collection information. For each sample, note its RC # or P # (circle appropriate type), the Sample #, the Bucket #, plus any notes such as local conditions and number of attempts before successful (Figure 9).

At each patch selected for sampling, the shape of the patch helps to determine the pattern used to take gravel samples. If the patch shape is linear, follow the guidelines above for identifying sampling points in riffle crests. If the patch shape is large and wide enough, then use a triangular pattern to identify sampling points.

## Collecting Samples with the McNeil Gravel Sampler

The McNeil sampler was selected to collect samples of spawning gravel for analysis as recommended by Peterson et al. (1992). It was chosen for the following reasons:

1) it is a reliable sampling device that is simple to operate;

2) although bulky, it is relatively portable and requires little auxiliary equipment;

3) it has been used in Washington State for survival to emergence studies that were the basis of the Forest Practices Board cumulative effects threshold values for spawning gravel fine sediments.

The McNeil gravel sampler is designed to take a core sample of the gravel substrate. A schematic diagram of the sampler is shown in Figure 10. The bottom of the sampler consists of a 15 cm (6 inch) diameter stainless steel coring cylinder with an open bottom and top. The coring cylinder is designed to penetrate into the streambed gravel to a depth of 23 cm (10 inches). The top of the coring cylinder extends up through the bottom of the larger (35 cm diameter) collection basin, where gravel from the core is temporarily stored during excavation of the core. The collection basin is open on the top. A horizontal steel rod attached across the top of the collection basin acts as a handle.

There is also a plunger, inserted into the coring cylinder to retain sediment-bearing water after extraction of the sample. The plunger consists of two metal disks, just slightly smaller in diameter than the inside of the coring cylinder, attached to the end of a long handle. Between the metal disks is a piece of neoprene that is slightly larger than the inside of the coring cylinder and acts as a seal. A hole through the disks with a one-way flapper valve allows the plunger to be inserted without forcing the water down into the streambed, but prevents water from escaping when the sampler is lifted. When fully inserted, the plunger comes to rest on a small stop-ring on the inside of the coring cylinder.

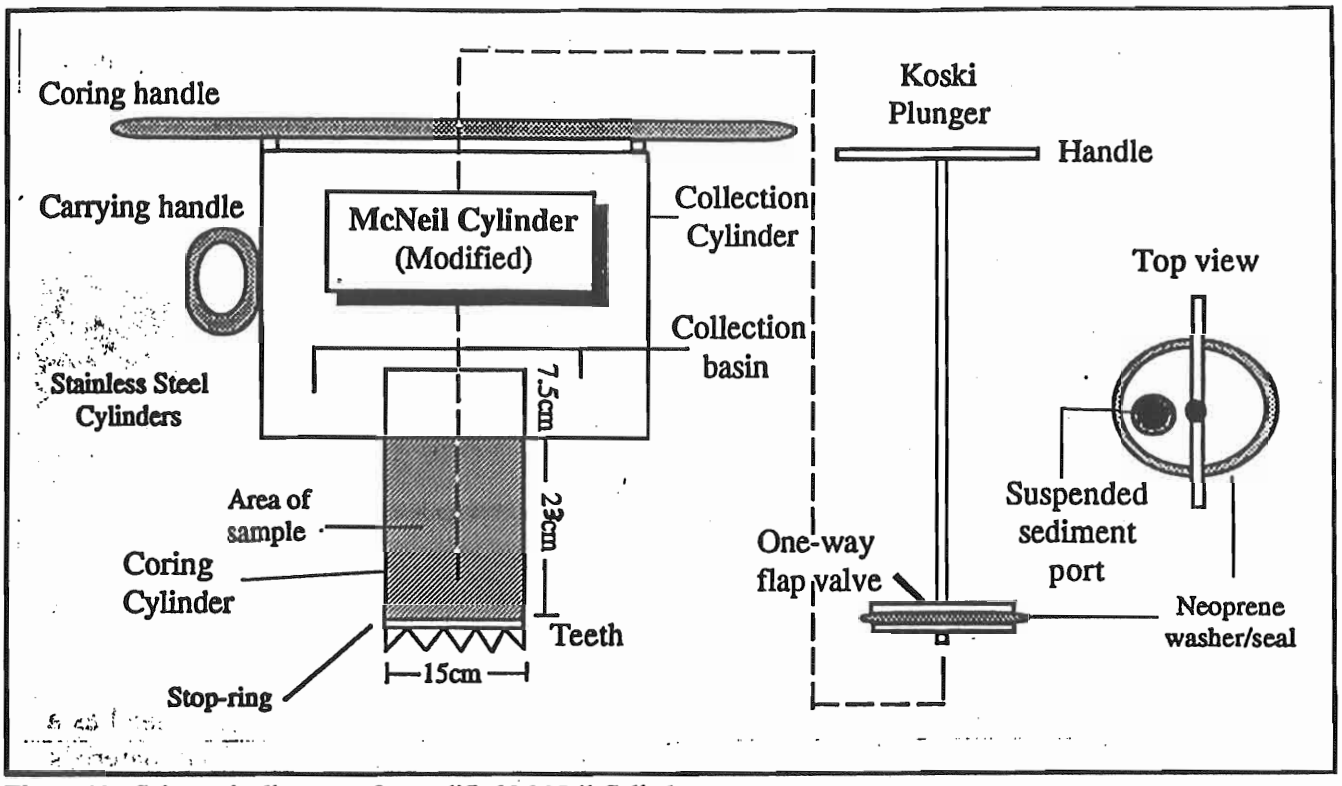


**Figure 10. Schematic diagram of a modified McNeil Cylinder.**

## *Taking a Sample with the McNeil Gravel Sampler*

**Step 1.** Before taking a sample, rinse the sampler to insure it is free of sediment. Approach the sampling site from the downstream side to avoid disturbance prior to sampling. Place the bottom of the coring cylinder on the surface of the substrate. Grasp the handle on top of the collection basin, placing one hand on each side of the rod outside of the basin (Figure 11).

Figure 11. Grasp handles.

Twist the handle back and forth, alternately pushing one arm forward away from your body and pulling the other back towards you. As you twist the sampler in this manner, hunch your shoulders over it, using the weight of your upper body to force the sampler straight down into the gravel (Figure 12).

Figure 12. Force cylinder into gravel.

The combined grinding and pressing action should force the sampler down into the substrate, however the rate of progress will depend on the size of the particles and the degree of compaction. Avoid side to side and up and down agitation which causes fine sediment particles to filter down through the large particles, changing the composition of the sample (Figure 13). If you encounter resistance, do not raise and lower the cylinder. The only time to lift the coring cylinder is when you want to remove the sampler and try a different site.

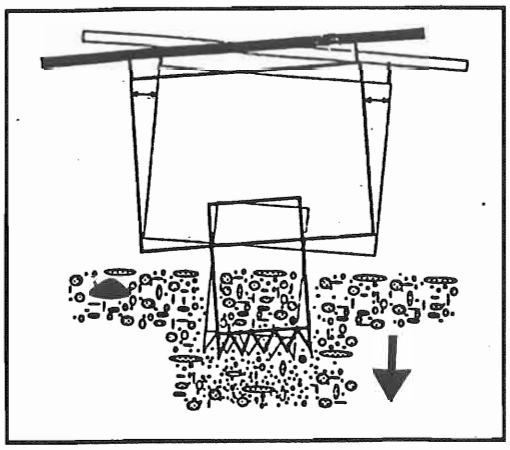

Figure 13. Avoid side to side and up and down movement while inserting cylinder.

The sampler is fully inserted when the bottom of the collection basin is resting on the streambed (Figure 14). Sometimes unseen large substrate particles, wood, or bedrock will prevent the sampler from being fully inserted. In these cases, remove the sampler, rinse it out, and try another undisturbed location in the immediate vicinity.

Figure 14. Use your hand to check if cylinder is fully inserted.

**Step 2.** After the sampler is successfully inserted, carefully remove the gravel/sand matrix from the coring cylinder with your hand (Figure 15).

Figure 15. Remove gravel matrix with hand.

Excavate the gravel slowly, layer by layer, using your hand as a scoop (Figure 16), so that both gravel- and sand-sized materials are removed together. It is very important that you keep your fingers tightly closed to prevent fine particles from sieving through then as you pull each scoop out of the core. As much as possible, avoid plucking out the larger particles and allowing the finer material to continually settle to the bottom of the excavation.

Figure 16. Use hand as scoop.

Place the excavated material in the collection basin around the coring cylinder and rinse your hand in the basin water to remove fine particles before taking another scoop out of the coring cylinder (Figure 17).

As you dig, occasionally run your fingers along the inside of the cylinder, feeling for the protruding stop-ring. When you locate the stop-ring, level the excavation off just below the top of the ring (Figure 18). The removal of the substrate sample is now complete. Occasionally a larger particle will partially protrude above the ring. In these cases, the particle should be removed, along with the surrounding material to avoid bias. In this case the excavation will go below the top of the ring, however it should not exceed the depth of the coring cylinder. If the protruding particle extends below the bottom of the coring cylinder, it will be necessary to start over with a new sample.

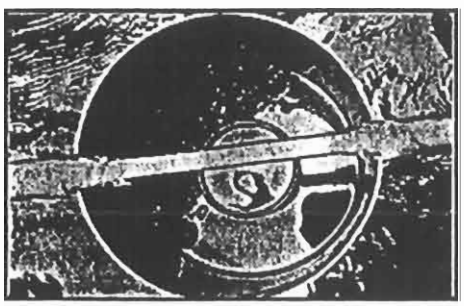

Figure 17. Collection Basin.

**Step 3.** After you complete digging, rinse the fine particles clinging to your hand and arm into the collection basin with the rinse bottle (Figure 19).

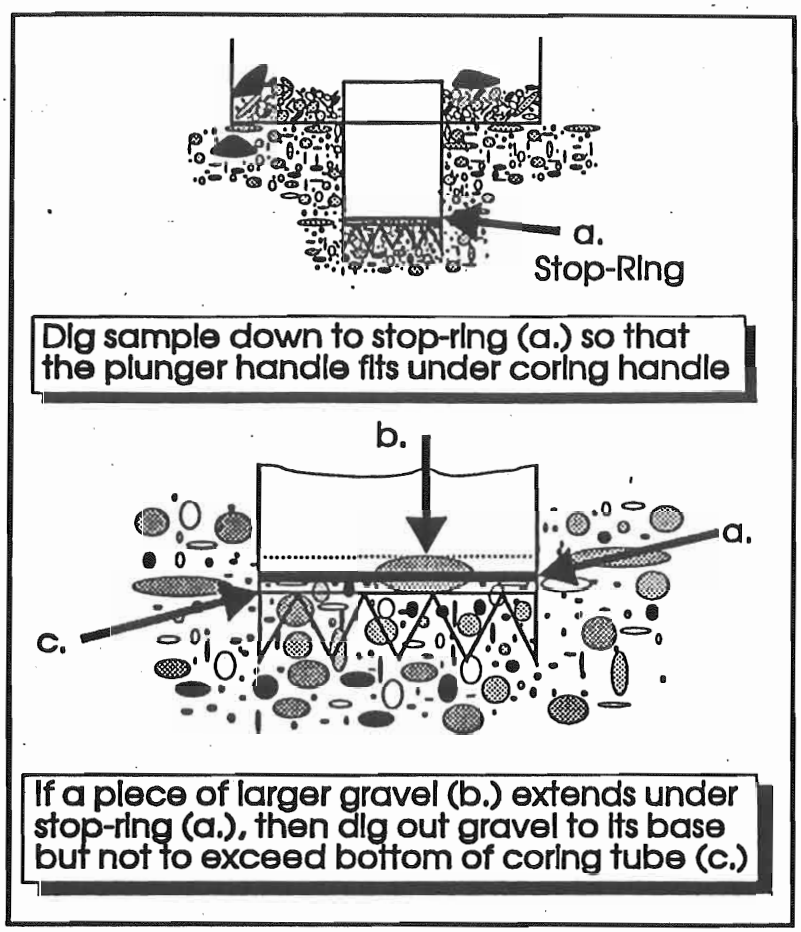


Figure 18. Stop-ring protocol.

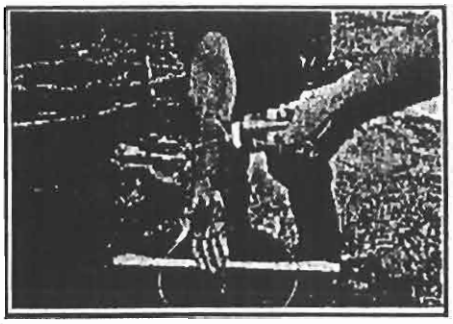

Figure 19. Rinse arms and hands.

Figure 20. View of plunger.

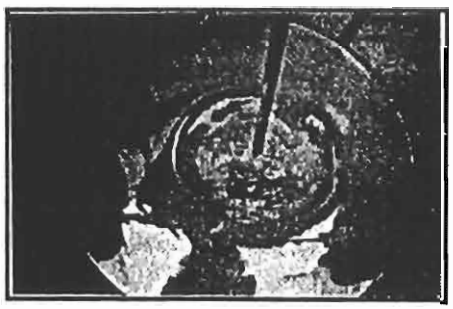

Figure 21. Insert plunger slowly.

Then, insert the clean plunger into the top of the coring cylinder (Figure 20) and slowly push the plunger down into the cylinder. Don't push the plunger too rapidly or water will not have time to pass through the one-way valve and silty water will be forced down into the substrate (Figure 21). If this occurs, you will often notice a turbid cloud emerging from the substrate just downstream of the sampler.

When the plunger comes to rest on the stop-ring near the base of the coring cylinder the sampler is ready to be removed (Figure 22). Many samplers are designed so that when the plunger is fully inserted and resting against the stop-ring, the plunger handle fits under the handle of the sampler.

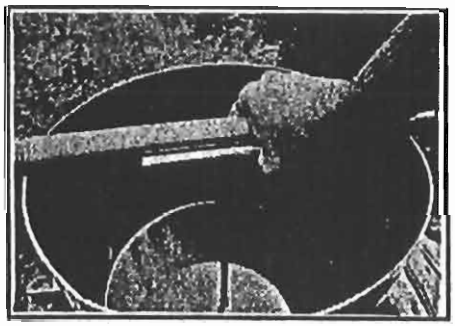

Figure 22. Plunger fully inserted.

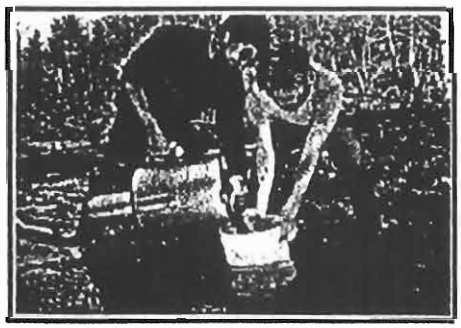

Figure 23. Pour sample into clean bucket.

**Step 4.** In one smooth motion, lift the sampler out of the substrate and carefully pour the gravel and water from the sampler into a clean plastic bucket (Figure 23). A five gallon bucket will usually hold a sample,

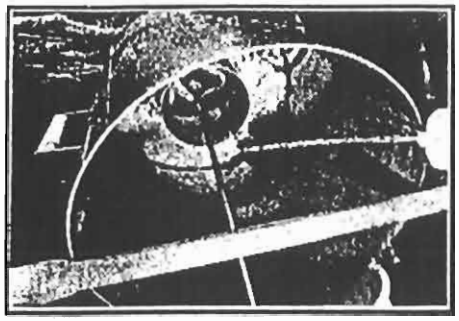

Figure 24. Rinse cylinder into bucket.

however samples taken in deep areas contain more water and may require two buckets.

After pouring the sample into the bucket, carefully rinse out the sampler with the rinse bottle, taking care to insure that fine particles that were inside the sampler end up in the bucket, while any on the outside of the sampler do not (Figure 24).

**Step 5.** Finally, fill out a label on waterproof paper with the date, stream name, segment number, riffle-crest number, bucket/sample number, and crew names (Figure 25). Appendix D provides a page of sample labels that can be copied on waterproof paper. The outside of the bucket and its lid should have a discrete number, inscribed or marked with permanent marker. Seal the bucket with a tight-fitting lid. Record the information on Form 6.1 or in your field notebook.

Date: _____
Stream: _____ Seg.# _____
Riffle Crest #: _____
Bucket/Sample # _____
Crew: _____

TFW Ambient Monitoring Gravel Sample

Figure 25. Gravel sample label for bucket identification.

# The Gravimetric Processing Method

The dry or gravimetric method of processing spawning gravel samples has its foundation in the engineering (materials testing) and soil sciences. Outside of Washington, fisheries biologists have increasingly used this methodology (Lotspeich and Everest, 1981, Shepard et al., 1984, Platts et al., 1989). Although the cost of equipment makes the gravimetric technique more expensive, it has a decided advantage in terms of precision. The analysis procedure is conceptually similar to that of the volumetric method, with the main differences involving drying of samples and weighing of individual sample size.

## Equipment Needed

11- Sieves (300 mm dia)- one each of the following sizes:

64.0 mm
32.0 mm
16.0 mm
8.0 mm
4.0 mm
2.0 mm
1.0 mm
0.85 mm
0.5 mm
0.25 mm
0.125 mm

1- Drying oven (Gilson BO-550). Note: Many options available here, check with various scientific supply companies. Regular domestic ovens will also work.
1- Triple beam balance (20 kg capacity)
6- Drying pans (stainless steel, 52.5 x 32.2 x 10.1 cm)
11- Weighing pans (34.29 cm diameter, 8.9 cm height)
1- Mechanical shaker
1- Sample splitter (necessary if sieves become overwhelmed by fines)
Filter masks
Forms for recording gravel composition data (Appendix C)
Pencils

Lab requirements for gravimetric processing are similar to those for the volumetric method. A dry, dust-resistant room, with a concrete floor, good lighting and ample electrical outlets is necessary. Because the shaking process is noisy, try to locate the lab away from other co-workers. A sturdy table to place the balance and record data is also nice. It is recommended that the mechanical shaker be bolted to a secure base, as vibration and movement of the unit can be significant.

## Processing Samples

Field collected samples (previously stored in individual, labelled 5-gallon buckets) must be dried prior to processing. Sample buckets should be left undisturbed for 48 hours to allow the suspended fraction to drop out. Carefully open the lids of the sample buckets to be processed. Inspect the volume of water in each gravel sample. If there is significant water in your sample, carefully siphon or pump away excess supernatant (clear water) to within five cm of the gravel layer.

Place samples in individual drying trays making sure that the bucket is cleaned of remaining sediment particles. Be sure to include the metal identification tag as well. Drying trays should be large enough to contain the entire McNeil sample. Oven dry your sample for 12-24 hours at between 50-105 degrees centigrade. Experience will dictate the time and temperature setting for efficient processing of your samples. If you are sampling in geologies dominated by clay, use a lower temperature setting, as some researchers have reported fracturing of gravel and rubble particles.

Once your samples have been dried and cooled, they can be sieved. Check to see that the sieves are in descending order. Place them into the shaker frame, and add the gravel sample to the sieve stack. Place the shaker lid over the largest sieve, then adjust and tighten the adjustment bolts and set the shaker timer for five minutes. In clay geologies a longer shaking time may be necessary. If using the recommended Phi-series of sieves it will be necessary to shake each sample through 11 sieves. Because standard shakers hold only 6 sieves, the investigator must shake the sample through the larger 5 sieves, then again through the final 6 small sieves. Once the samples have been shaken, remove each size sieve and place the sample portion into individual weighing pans.

As sieve size decreases, the sieves will become increasingly "clogged" with sediment. Be sure to thoroughly clean each sieve with the appropriate brush. It is a good idea to pre-mark each weighing pan to a corresponding size class and to clearly mark the tare weight of the pan. Samples can then be weighed on the balance. The total weight of the sample/pan minus the tare weight equals the sample weight. Record the weight of material in each sieve on the form in Appendix C.

# Data Analysis

Data analysis will be provided by the Ambient Monitoring Program for spawning gravel composition data collected by cooperators using the spawning gravel composition module. Forms are provided for recording spawning gravel composition data. Cooperators will have their data entered into a database where it will be analyzed and will receive a data summary sheet and a copy of their database on floppy disk.

Spawning gravel composition has been characterized in a variety of ways by different investigators. Young et al. (1991) evaluated 15 different measures of substrate composition. They determined that geometric mean diameter (Dg) was the most sensitive measure of survival to emergence and the percentage of particles less than 0.85mm was the most sensitive indicator of changes to substrate induced by land management activities. They concluded that no single measure would be adequate to describe both potential survival to emergence and alteration of substrate due to land management activities.

Consequently, substrate samples will be analyzed using both measures. The percentage of particles less than 0.85mm (volumetric equivalent) will be calculated for each individual sample and the segment average will be provided for use in Watershed Analysis. In addition, the geometric mean diameter (gravimetric equivalent) will also be provided. The results of the data analysis will be contained in a spawning gravel fine sediment segment summary report provided to cooperators.

## Data Analysis for Individual Samples

Information on the amount of material retained on each sieve will have been recorded in either grams or milliliters depending on the processing method used. This information will be entered into the database and a conversion factor will be used to calculate equivalent gravimetric values for volumetric data or volumetric equivalents for gravimetric data.

The amount of material retained on each sieve, the percentage of the total it represents, and the cumulative percentage less than the next sieve size will be calculated separately for both the volumetric and gravimetric values. The cumulative percent less than the next largest sieve size will be calculated for each sieve size by summing the amount of material on that sieve and all smaller size classes and dividing this figure by the total material in the sample.

Similarly, the percentage of fine sediments less than 0.85mm will be calculated by summing the total amount of material in the size classes less than 0.85mm and dividing by the total amount of material in the sample. The geometric mean diameter will be calculated with the formula used by Young et al. (1991) from Lotspeich and Everest (1981).

Information on the amount and percentage of material retained on each sieve, in both volumetric and gravimetric equivalents, will be reported for each sample in the spawning gravel fine sediment segment summary report. The cumulative percentage less than each sieve size, the percentage of material less than 0.85mm, and the geometric mean diameter for each sample will also be reported.

## Data Analysis by Stream Segment

The mean percentage of fine sediments less than 0.85mm (and standard deviation) and the mean value for geometric mean diameter will be calculated and reported for each segment in the segment summary report. The average value for geometric mean diameter is calculated by summing the individual geometric mean diameter values for all the samples in the segment and dividing by the total number of samples. The average value for percentage of fine sediments less than 0.85mm is calculated by summing all the individual sample values for percent fine sediment values less than 0.85mm and dividing by the total number of samples from the segment.

In addition, individual samples within the segment will be sorted into three categories utilized in Watershed Analysis. The categories are based on the percentage of fine sediment less than 0.85mm and include: samples with less than 12% fine sediment, samples with 12-17% fine sediment, and samples with greater than 17% fine sediment. The number and percentage of individual samples falling in each category will be calculated and displayed in graphic form in the segment summary report.

# Training, Field Assistance and Quality Control

This manual is intended as a reference for those collecting information on spawning gravel composition in conjunction with the TFW Ambient Monitoring Program and Watershed Analysis. It is difficult to rely solely on a manual to learn and implement the methodology, so the TFW Ambient Monitoring Program offers formal training sessions and informal field assistance visits to help cooperators learn the methodology.

In addition, the Ambient Monitoring Program also provides a quality control service to identify and correct inconsistencies in application of the methods and to ensure replicable and consistent data is being collected throughout the state. The quality control service entails both pre- and mid-season quality assurance (QA) surveys. The pre-season QA survey documents that your crews are collecting high quality data from day one. The mid-season QA survey documents crew consistency and whether training or corrections applied to problems during the pre-season QA survey were effective. For more information on quality control protocols, refer to the Qualtiy Assurance Module.

We encourage cooperators to utilize these services. Please contact the Northwest Indian Fisheries Commission (1-206-438-1180) for more information concerning the TFW Ambient Monitoring Program.

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# FIELD AND LABORATORY PROCEDURES AND EQUIPMENT FOR SAMPLING SPAWNING GRAVELS (adapted to Bern's thesis)

Klein, R. 1997

**NOTE: THESE PROCEDURES WILL YIELD A COMPLETE SIEVE ANALYSIS BY BOTH WEIGHT AND VOLUME. ALL OF THE MOST IMPORTANT SIZE DESCRIPTORS FOUND IN THE SCIENTIFIC LITERATURE CAN BE CALCULATED FROM THESE RESULTS.**

## Field Equipment and Procedures

### Equipment:

large (18"x18") sieves (in frames)
5-gal buckets (3 or more)
Shovel and flow diversion apparatus, or
McNeil-type sampling tube (12" diameter)
water displacement bucket
graduated cylinders (2)
sample bags (10"x17" Tyvek)
weighing pan with hanging chain assembly
weighing scales (light, medium, and heavy ranges)
ruler (mm) and pebble-o-meter (optional)
squeeze bottle for rinsing sieves and containers
tarps for wet sieved fractions (12 each 36"x36" pieces of erosion cloth or weed barrier fabric)
waterproof markers, pencils
sieve analysis forms

### Procedures:

1. Extract sample from streambed by chosen method.
2. Remove fines from bottom of McNeil hole prior to extracting sampler; add to rest of sample extracted by hand.
3. Subsample remaining turbid water in McNeil prior to removing it from streambed and measure depth of water in McNeil (this will be used to calculate the volume of this water so that total weight and volume of suspended fines left in McNeil may be calculated from suspended sediment concentration in subsample).
4. Wet sieve gravel down to 8 mm:

a. sieve as much of total sample as practical for each subsample sieved at a time;
b. place fractions from each sieved subsample on appropriate tarp, except <8 mm material;
c. place <8 mm material into labeled sample bag(s);
d. allow >8 mm fractions drain for at least 10 min.;
e. weigh all fractions (including >128 mm) and enter weights onto form (NOTE: use the light range weighing scale for subsample fractions within the scale's range; this will give more accurate weights: the form has large boxes which can accommodate the individual weights of subsamples from each size fraction: record these original data so they can be summed later);
f. after weighing, place fractions into displacement bucket and record volume of water displaced, record on form (NOTE: sieved fractions may have to be divided again to perform volume displacements, depending on the volume of sieved size fraction: the form has large boxes which can accommodate the individual volumes of subsamples from each size fraction: record these original data so they can be summed later);
g. measure b-axis diameter of largest rock in sample, record on form;

5. Bring <8 mm fractions of sample back to lab for dry sieving and volumetric analysis.
6. Place >8 mm sieved gravel back into its former location in the streambed.

**Laboratory Equipment and Procedures**

A. Drying

Equipment: cake pans, spatula, oven, labels

Procedures:

1. Empty contents of sample bags into cake pans and label pans as to sample number;
2. Spread out sample in cake pan;
3. Dry in oven overnight at 60 degrees centigrade (hotter temperatures will cause dehydration of water contained in clay particles which is not part of the interstitial water);
4. Gently crush clods to separate individual grains.

## B. Sieving and Weighing

Equipment: 8" diameter testing sieves (4, 2, 1, 0.85, 0.5, 0.25, 0.125, and 0.062 mm), sieve shaker, sieve brush, sample splitter, bench scales (light, heavy), data forms

Procedures:

1. Weigh dried sample and record weight on data form;
2. Split sample down to about 2 cupfuls of material;
3. Place unsieved portion back into sample bag and set aside;
4. Place subsample to be sieved in top (coarsest) sieve on stack and cover;
5. Shake for 5 minutes;
6. Weigh each fraction on bench scale and record weight;
7. Place sieved fractions into individual ziploc sandwich bags and place these back into large sample bag with the rest of sample for later volumetric analysis.

## C. Volumetric Analysis

Equipment: water displacement bucket, graduated cylinders, Imhoff cones and rack, rinsing squeeze bottles, sieved fractions from sieving, data forms

Procedures:

1. **Material Coarser Than 0.85 mm**: 1) measure the displacement volumes of individual size fractions by water displacement in a graduated cylinder or the water displacement bucket.
2. **Material Finer Than 0.85 mm**: 1) fill a graduated cylinder (250 or 500 ml??) exactly half full of water, 2) pour the dried and weighed <0.85 mm fraction into graduated the cylinder and record the resultant volume, 3) pour the <0.5 mm fraction into the same graduated cylinder (with the previous water and sediment still in it) and record the resultant volume, 4) continue to add each successively finer fraction until the entire set of sieved fractions (including the pan contents) has been added to the graduated cylinder and all resultant volumes have been recorded, 5) agitate cylinder and pour/rinse contents into Imhoff cone and immediately begin timing, 6) at **exactly 10 minutes** from beginning of timing, read and record volume from the scale on the Imhoff cone, 7) read and record volumes again at **30 minutes** and **1 hour**.

## D. McNeil Water Sample Analysis

This water sample is processed exactly the same as suspended sediment samples. The original volume of the sample is recorded, and the sample is filtered. The filters are then dried and weighed, and the concentration of the sample is calculated by dividing the weight of the sediment by the original sample volume. Finally, the total weight of the suspended sediment in the McNeil hole is calculated by multiplying the concentration by the original volume of water in the McNeil hole.

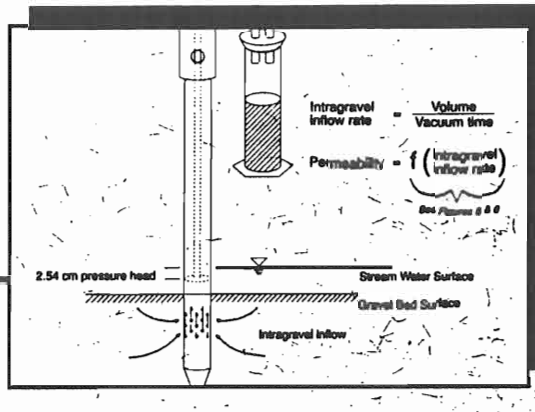
# APPENDIX D.

# SELECTED PROTOCOLS

## 10. SUBSTRATE PERMEABILITY

FHR Currents...

Fish Habitat Relationships Technical Bulletin
Number 15 April 1994




# Standpipe to Determine Permeability, Dissolved Oxygen, and Vertical Particle Size Distribution in Salmonid Spawning Gravels

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## Abstract

Gravel permeability, dissolved oxygen, and gravel particle size composition are substrate parameters affecting the survival of incubating salmonid embryos. Current methods of measuring these parameters cannot quantify all three without substantially disturbing the sample. To solve this problem, we developed a new technique to measure permeability and dissolved oxygen while extracting a freeze core from a single in-situ standpipe. The standpipe is similar to the Terhune Mark VI permeability standpipe, but it includes a plunger to seal the perforations and evacuate the water within the standpipe, allowing liquid nitrogen to fill the standpipe and freeze a substrate sample. This gives biologists the opportunity to associate local gravel permeability and dissolved oxygen concentrations with physical substrate characteristics, including particle size distribution and vertical stratification. We developed a relationship between gravel permeability and steelhead (Oncorhynchus mykiss) embryo survival using Tappel and Bjornn's (1983) gravel quality index. This relationship shows that for permeabilities greater than 10,000 cm/hr, embryo survival was greater than 85 percent; however, considerable scatter exists for permeabilities lower than 10,000 cm/hr.

USDA
Forest Service

## Introduction

All watersheds contribute a portion of their total sediment load to the stream as fine sediment. Fine sediments infiltrate the gravel column and can be detrimental to salmonid spawning habitat. The amount of fine sediment delivered to streams depends on several factors, including watershed geology, climate, vegetation, and land use. The latter is a critical issue for fishery biologists because it is the only factor that can be modified by alternative watershed management techniques. Salmonid eggs, buried under as much as a foot of gravel, depend on sufficient intragravel water flow for their survival and development. Platts, et. al., (1983) found that a large percentage (>20 percent) of fine sediment within spawning gravel impedes flow and the survival of eggs is jeopardized. To date, the principal parameter for assessing gravel quality has been the percentage of fine sediment within the entire gravel column (Chapman, 1988). Platts, et. al., (1983) and others have observed a direct relationship between percent fines and egg to emergence success for salmonids. Tappel and Bjornn (1983) performed a similar analysis, using a gravel quality index dependent on the particle size distribution less than 26.4 mm instead of percent fines. However, the interrelationships between percentage of fines, permeability, and dissolved oxygen (DO) have seen little attention. In his review of salmonid spawning gravel literature, Chapman (1988) concludes that further research of the physical and biological dynamics of redds is needed, including the effects of intragravel permeability, DO, and particle size distribution on egg survival.

These interrelationships have been neglected because measuring each parameter in-situ using a single sampling device has proved difficult. Gravel core samplers developed by McNiel and Ahnell (1960) and Walkotten (1976) do not permit measures of permeability or DO. In contrast, Terhune (1958) developed a standpipe that measured permeability and DO but could not extract a gravel core for particle size analysis. Because gravel permeability and particle size distribution can be spatially highly variable, a desirable sampling technique would be precise enough to adequately characterize localized gravel quality parameters. Currently, the only method of measuring in-situ permeability, DO, and particle size distribution is to:

1. drive a perforated standpipe into the gravel;
2. measure permeability and DO in place;
3. extract the pipe;
4. insert a non-perforated standpipe back into the gravel; and
5. apply a cryogenic medium into the standpipe to extract a gravel core.

This method is unacceptable because re-inserting the standpipe disturbs the integrity of the sample.

Instream bulk samples are typically obtained using a McNiel sampler (McNiel and Ahnell, 1960). For certain applications, this sampling technique can provide rapid and economical bed particle size information; however, it is limited by the difficulty in inserting the sampler to depths greater than 30 cm, and direct observation of vertical bed stratification is impossible. Conversely, standpipe freeze core samples can be as deep as 60 cm, and can also retain the natural bed stratification. This provides the opportunity to observe biological organisms (salmonid embryos and alevins, aquatic invertebrates, etc.) in a natural setting. The standpipe is particularly suited to sampling in salmonid spawning areas where water depths are less than a meter and velocities are less than one meter per second. The standpipe is limited because highly permeable gravel reduces the freezing effect of the cryogenic liquid, such that gravel samples are sometimes too small to be acceptable. In addition, the apparatus required is less portable than that for bulk sampling.

We have modified Terhune's permeability standpipe so that permeability, DO, and a freeze core can be taken without removing the standpipe, allowing us to compare these parameters with minimal gravel disturbance. The standpipe is driven into the gravel sample, and intragravel permeability and DO are measured. The standpipe is driven slightly deeper and a synthetic rubber plunger is placed into the pipe to evacuate water from the standpipe. Liquid nitrogen can now be poured into the standpipe, freezing the surrounding gravel to the outside of the standpipe. The pipe with the frozen core is extracted from the substrate, thawed to remove the gravel, either as an entire sample or separated into vertical strata which are then sieved into particle sizes and weighed.

## Methods

### Field Equipment

A stainless steel freeze core standpipe allows liquid nitrogen to serve as the cryogenic medium. The 3.8 cm (inner) diameter standpipe measuring

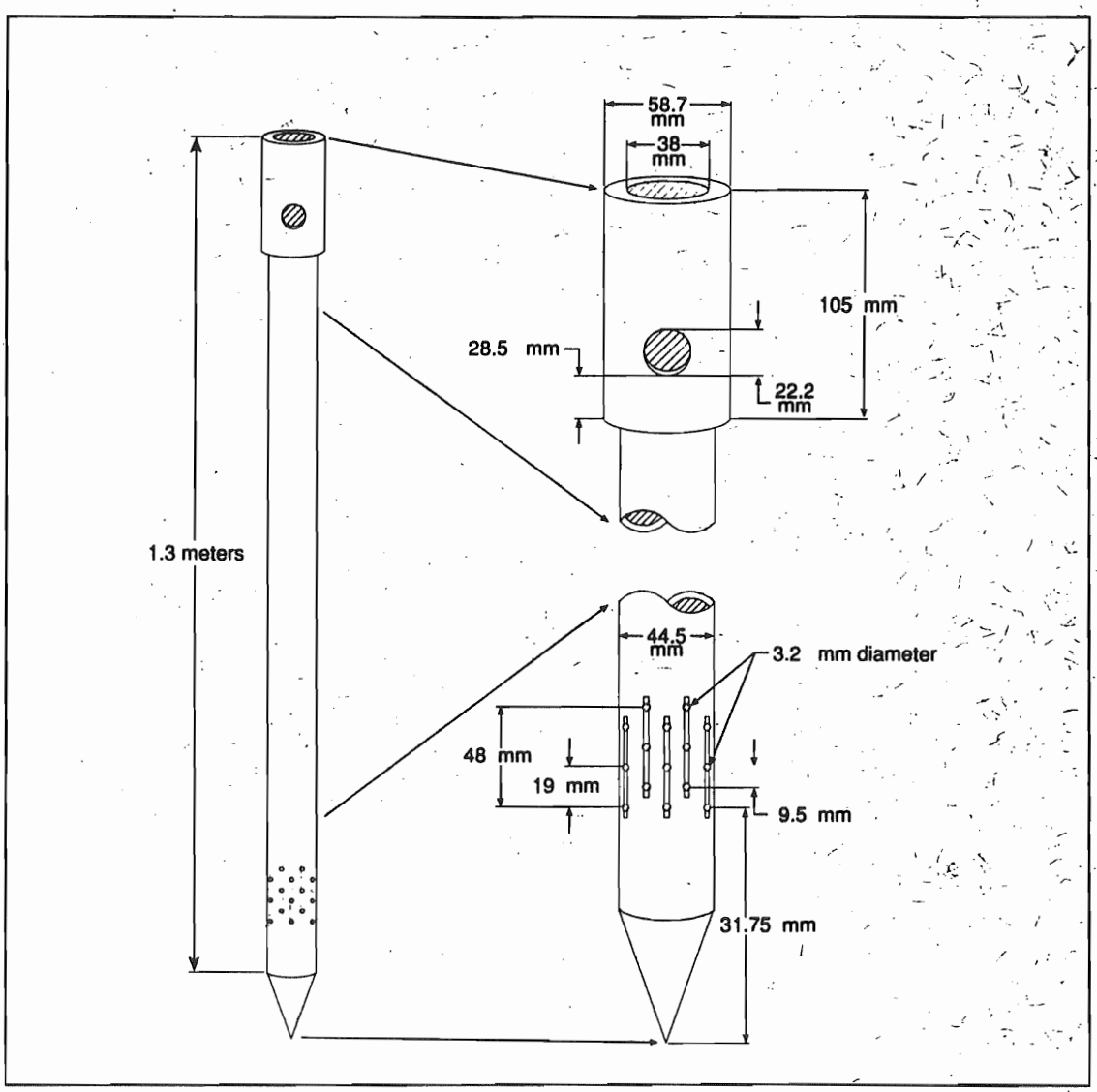


Figure 1. Modified Terhune Mark VI standpipe

1.3 meters long is closed at one end by a stainless steel driving point (Figure 1). It is identical to Terhune's (1958) standpipe except that a 3.8 cm diameter stainless steel pipe replaces Terhune's less durable 3.2 cm aluminum standpipe.

The lower end immediately above the driving point is perforated with forty-eight 3.2 mm diameter holes in 16 evenly spaced rows of three (Figure 1). The large number of holes is necessary to imitate a spherical sink, allowing the water to freely flow into the standpipe from anywhere in the adjacent gravel column (Terhune 1958). Each vertical row of holes is connected by grooves 1.6 mm wide and 1 mm deep to minimize blockage of the holes by small particles.

When the modified standpipe is driven into the gravel, intragravel water enters the pipe through the holes and rises to the level equal to the outside water surface. A graduated suction apparatus maintains a 2.5 cm pressure head (Figure 2), causing water to flow through the gravel and into the standpipe. In maintaining this pressure head,

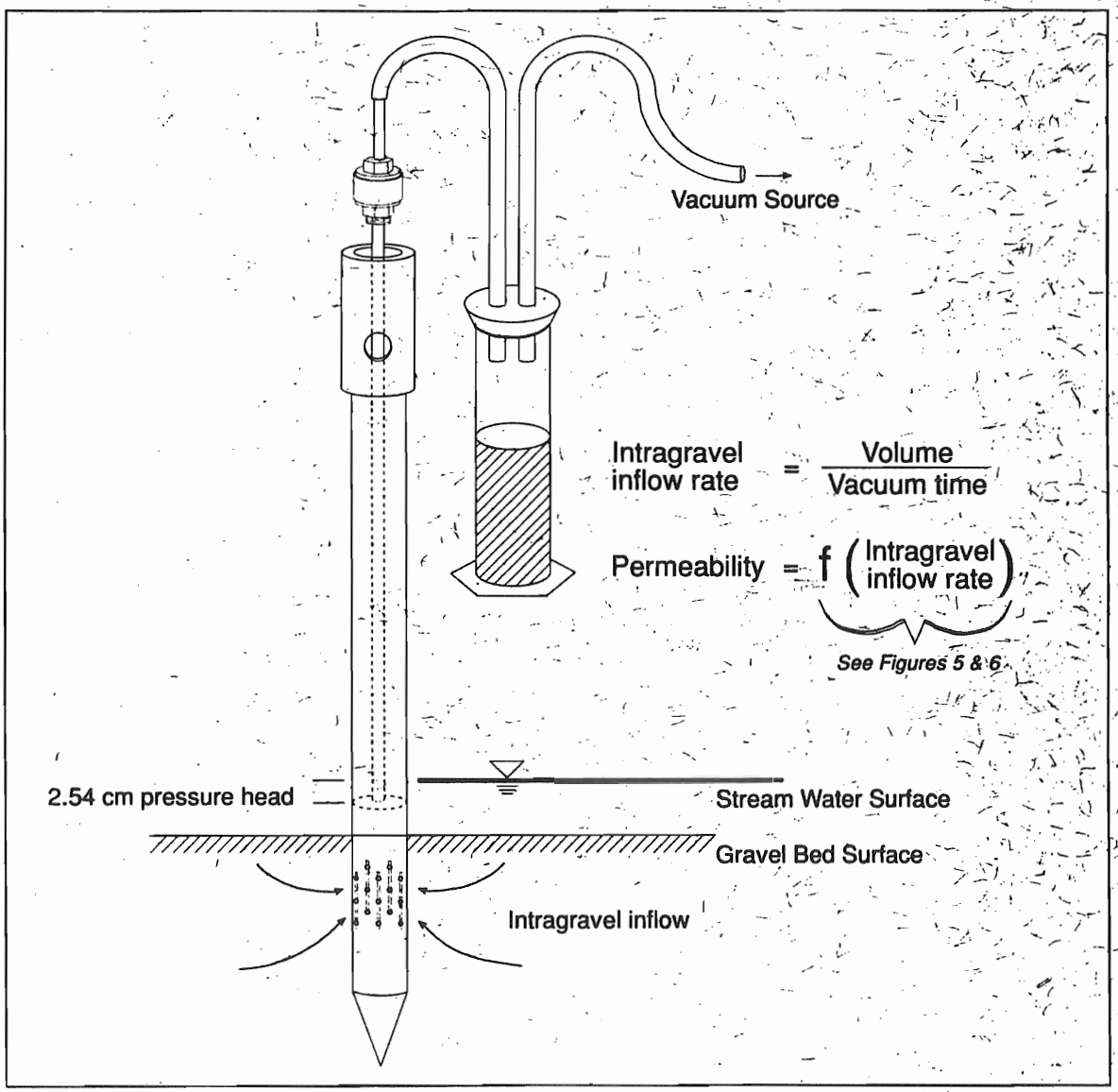


Figure 2. Permeability measurements using the modified standpipe

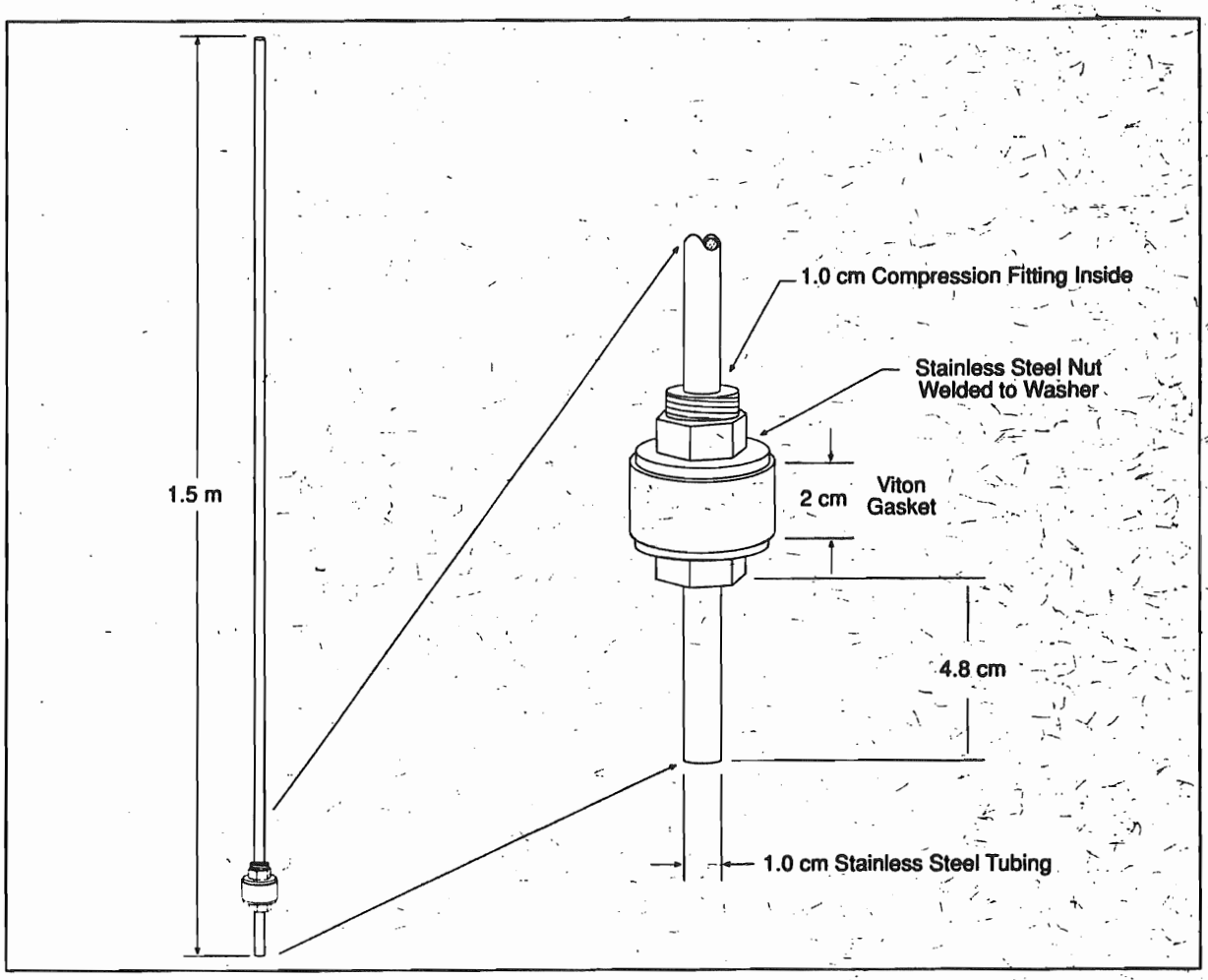


Figure 3. Freeze core plunger for the modified standpipe

the suction apparatus evacuates water from the standpipe at a rate equal to inflow. This water is stored in a 1,000 ml graduated cylinder so that the volume per unit time (i.e., inflow rate) can be measured.

Gravel permeability measurements require unimpeded intragravel water flow into the standpipe. However, a successful freeze core demands that water be excluded from the standpipe so that the maximum freezing effect of the liquid nitrogen is directed to the gravel/ standpipe interface. To make the permeability standpipe also function as a freeze core standpipe, a plunger prevents water from filling higher than the top of the perforations. The plunger is a 1.5 m long, 1 cm diameter stainless steel tube that has a synthetic gasket at one end (Figure 3). The gasket is made of "Viton," a synthetic rubber that resists cracking and splitting at extremely low temperatures. The outer diameter of the disk is cut to fit tightly into the standpipe.

When the plunger is fully inserted into the standpipe, the disk is located above the topmost perforation to prevent inflow above the perforations (Figure 4). To assure a satisfactory seal and allow removal of the plunger, a "socket" made of a 1.2 m long by 2.5 cm diameter iron pipe allows the operator to tighten or loosen the disk fitting while it is inside the standpipe. The disk is initially tightened to expand the flexible disk,

assuring a waterproof seal. Loosening the disk fitting after taking the core releases the seal and eases removal from the standpipe.

## Field Methods

### *Dissolved Oxygen Measurements*

Once a sample site is selected, the standpipe is driven into the gravel column until the perforations reach the desired sampling depth. To measure intragravel DO (or any other water quality parameter), water in the standpipe must be removed because it includes surface water. When water is pumped out of the standpipe, intragravel water refills the standpipe from the desired sample depth. An electronic probe can then be lowered into the standpipe to measure dissolved oxygen.

### *Permeability Measurements*

Two people are required to measure permeability. One person (pumper) holds the graduated cylinder and operates the pump while a second person (timer) lowers the inverted steel plunger into the standpipe and listens for a characteristic "slurp," indicating that the end of the plunger tubing has just made contact with the water surface inside the standpipe. A 2.54 cm wooden spacer is placed on top of the standpipe and a "visegrip" is attached to the plunger at the top of the spacer. When the spacer is removed, the plunger is lowered until the visegrip rests on top of the standpipe, thereby holding the end of the plunger tubing exactly 2.54 cm below the water surface within the standpipe (Figure 2).

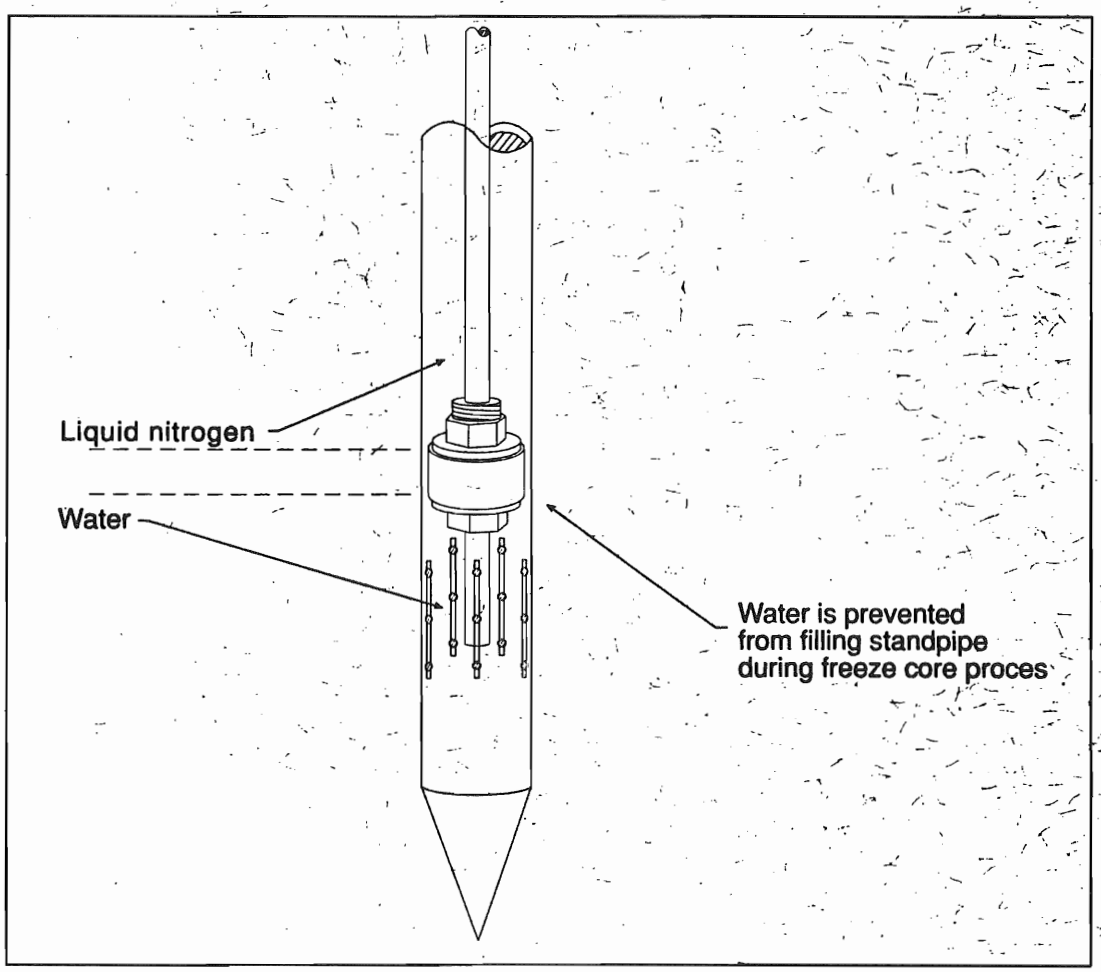


Figure 4. Schematic of freeze core plunger inserted in to the modified standpipe

*A bilge pump is used to extract water in measuring permeability.*

The timer then pinches the flexible tubing connected to the plunger and operates the stopwatch. The pumper operates the bilge pump (or other vacuum source), creating a vacuum throughout the graduated cylinder. Once a sufficient vacuum is generated (2-5 seconds), the timer simultaneously releases the pinched tubing and starts the stopwatch while the pumper continues. The vacuum immediately removes the top 2.5 cm of water, creating a pressure gradient that drives intragravel water into the standpipe. Water from inside the standpipe is continuously drawn into the graduated cylinder until the cylinder is almost full or an appropriate amount of time has elapsed (30-60 seconds). The timer simultaneously raises the plunger from the water surface and stops the stopwatch.

Inflow rate, the ratio of measured water volume per unit time, must be corrected to account for the initial 2.5 cm water column and the time required to remove it. The volume of the 2.5 cm of water (29.0 ml for the 3.8 cm pipe) is subtracted from the measured volume, and the time taken to remove it from the standpipe (estimated at 0.25 seconds) is subtracted from the measured time (Terhune 1958). The sample permeability is interpolated from an empirical permeability versus corrected inflow rate calibration curve (discussed below, Figure 5). This permeability value "KT" should be standardized to a temperature of 10 degrees Celsius by a viscosity correction factor "X" (Figure 6; Terhune, 1958) as:

**Equation #1:**

$$K_{10}=XK_T$$

*Liquid nitrogen is poured into the standpipe to freeze a substrate sample after the permeability has been measured.*

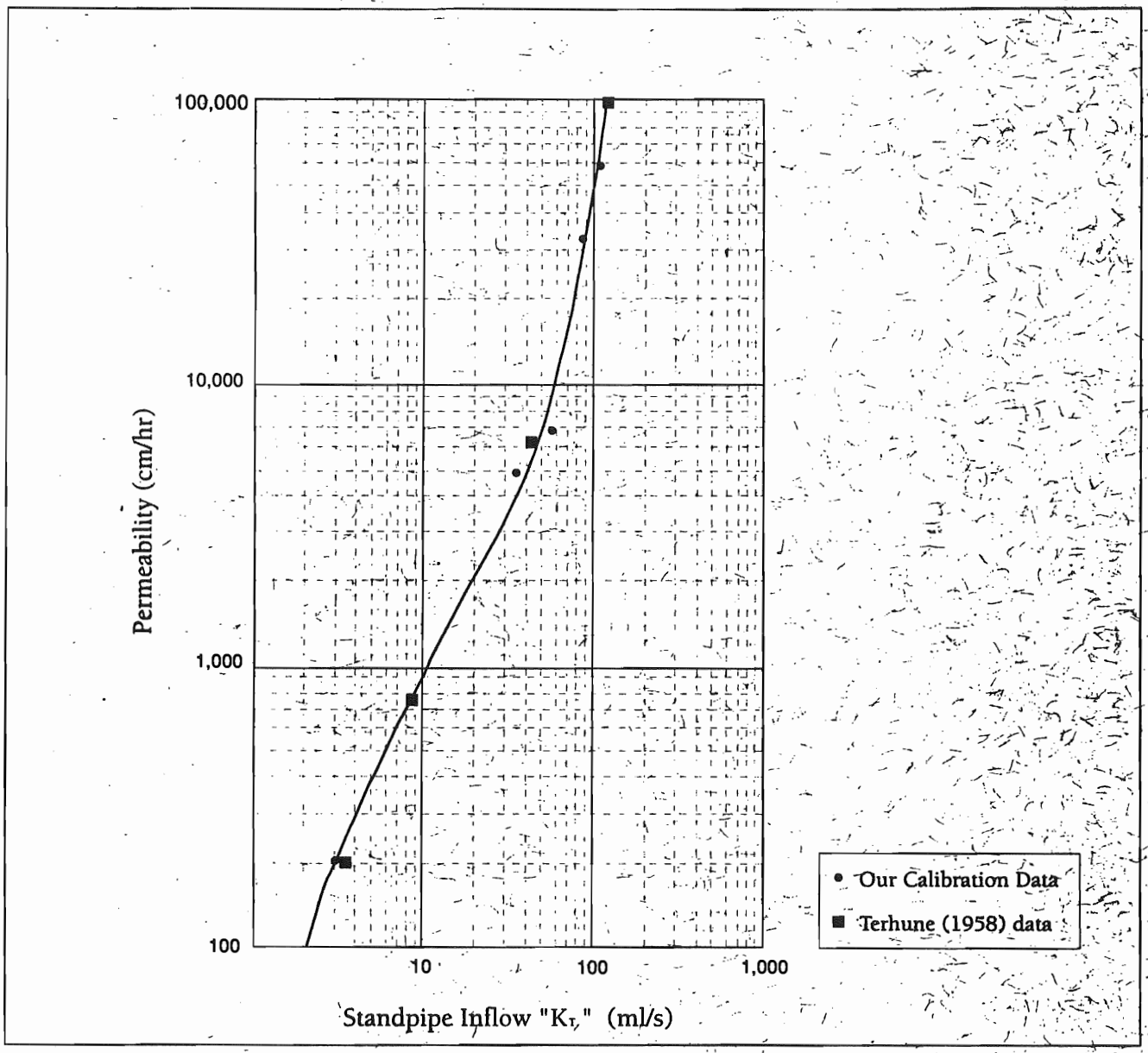


Figure 5. Permeability vs. standpipe inflow rate calibration curve

*Freeze Core Sampling*

Because the gravel core freezes to the standpipe above the perforations, the standpipe is driven an additional 5 cm so the permeability measurements will be represented in the gravel core. Next, the plunger is inserted into the standpipe; the vacuum apparatus is attached to the top end of the plunger. One person pumps water from the standpipe as the other slowly pushes the plunger into the standpipe until the disk is located just above the top perforations. By pumping water while inserting the plunger, water is not forced back through the perforations, which avoids flushing fines from the gravel sample. At the same time, the pumping removes most water from the plunger tubing, reducing metal fatigue to the tubing caused by ice expansion. Once the plunger reaches the top of the perforations, liquid nitrogen is poured from a Dewar flask into the standpipe,

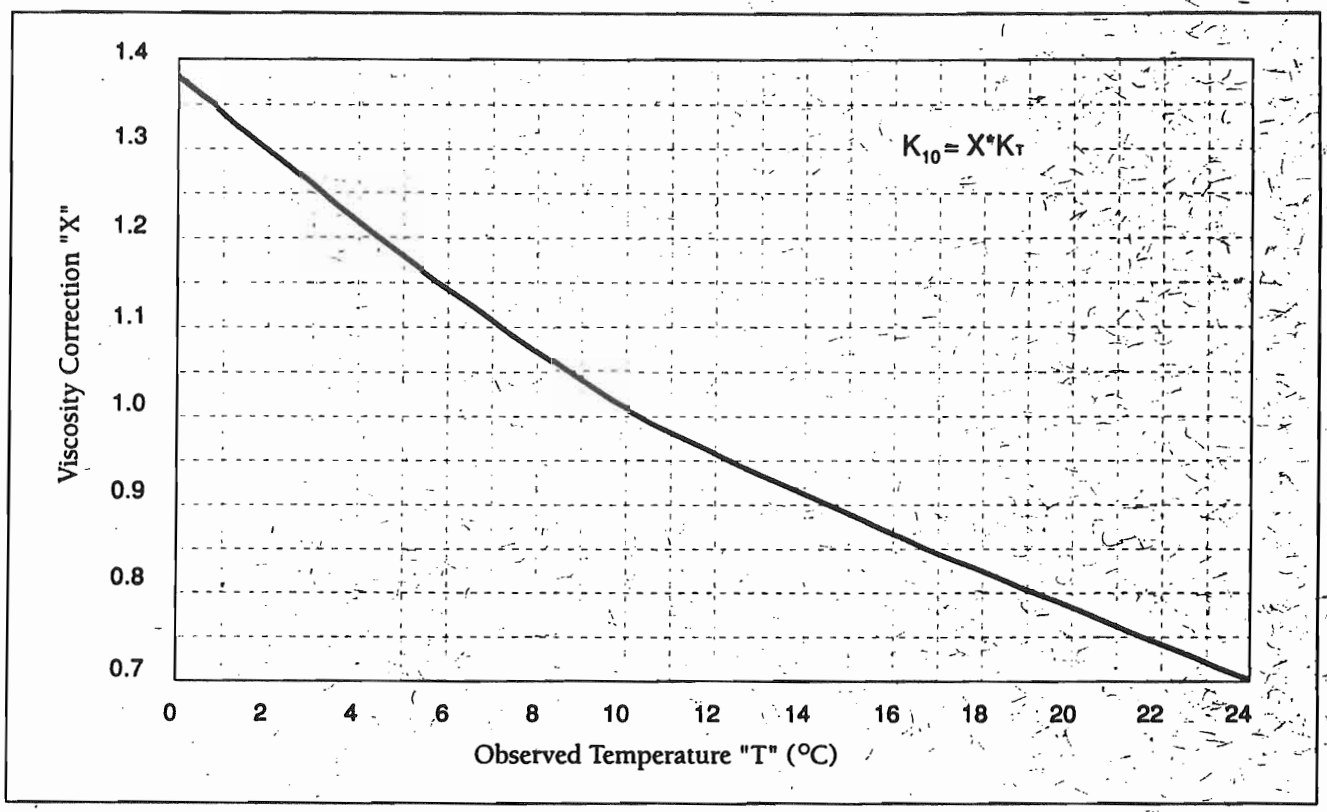


Figure 6. Permeability correction curve to account for viscosity changes with temperature

and the vacuum apparatus is removed from the plunger. As the liquid nitrogen boils and vaporizes in the standpipe, the gravel column begins to freeze to the sides of the standpipe.

In gravel sites exhibiting high permeability (>70,000 cm/hr), a successful freeze core often depends on deflecting the surface and intragravel water flow around the standpipe. This is accomplished by pushing a large sheet metal collar into the gravel surrounding the standpipe and placing a sandbag against the upstream side of the collar. The collar and sandbag must be used after the permeability measurements have been taken because they will reduce intragravel flow.

Best results are obtained when the liquid nitrogen level in the standpipe is maintained above the gravel surface. Eight to 10 liters of liquid nitrogen are usually sufficient to produce a 25-40 cm diameter core unless gravel permeability is high, in which case more nitrogen may be necessary. For samples with permeability more than 70,000 cm/hr, up to 15 liters of nitrogen may be required.

When the last of the liquid nitrogen in the standpipe is allowed to vaporize, a steel rod is inserted through the holes near the top of the standpipe. Two people then pull the standpipe (with the attached frozen gravel sample) from the streambed. The gravel sample is thawed, separated into vertical strata (Platts, et. al. 1983), and sieved to separate particle size classes.

*Permeability Calibration*

The Terhune method of determining permeability requires that permeability be interpolated from the measured sample inflow rate using a "Permeability vs. Standpipe Inflow" calibration curve (Figure 5).

Figure 7. Permeability vs. Tappel and Bjornn (1983) Steelhead Emergence Survival

The calibration curve that Terhune (1958) developed was appropriate for his 3.2 cm aluminum standpipe. Because our modified standpipe design uses a larger diameter stainless steel pipe, we redeveloped a calibration curve for the new standpipe.

We constructed a hydraulic flume permeameter to measure the permeability of a homogeneous but non-uniform gravel mixture. As water flowed through the gravel-filled permeameter, we measured the following four properties: 1) the flow rate through the gravel mixture (Q, cm3/hr); 2) the length of the gravel mixture (L, cm); 3) the average cross-sectional area of the wetted gravel mixture (A, cm2); and 4) the change in height of the water level over the distance L (h, cm) using simple piezometers. Permeability (K, cm/hr) of the gravel was then calculated according to the following equation developed by Darcy (1856) and adapted by Terhune (1958):

$$K = \frac{QL}{A\Delta h}$$

Once the permeability of the gravel mixture was determined, five modified standpipes were placed in the gravel mixture and the inflow rate for each was measured (as described in the previous section). Inflow rates for each gravel mixture were averaged. Five homogeneous gravel mixtures were used for the calibration curve (Figure 5).

Permeability (K) and average inflow rates (Q) were plotted on log-log paper to estimate the appropriate calibration curve (Figure 5). A curve was fitted by eye through the remaining five data points, and the curve for the modified standpipe was nearly identical to the Mark VI standpipe (Terhune 1958). The calibration results suggest that the calibration curve is applicable for Terhune's and our new standpipe, so future calibration is unnecessary if the perforations are prepared according to this paper or the Terhune (1958) design.

## Application

Gravel quality is a critical component of a healthy stream and the reproductive success of salmonids. The survival rate of eggs to emergence determines the initial population size of a cohort, and is, in part, dependent on permeability, DO, and particle size distribution. For the first time, measuring these gravel quality parameters with a single device at a single location is possible, providing an accurate and cost effective way of collecting these data.

One byproduct of the particle size distribution is that we are able to relate percent fines (Platts, et. al. 1983) or other gravel quality indices (Tappel and Bjornn 1983) to the survival rate of eggs to emergence. Additionally, this technique is a quick and cost effective way for fisheries managers to monitor temporal and spatial variability of gravel quality parameters in streams. This technique has several potential management applications, including:

(1) Substrate sampling within selective redds would provide data relating egg to emergence survival rate, producing better estimates for yearly cohort production for a given stream;
(2) Localized spawning habitat quality could be assessed by measuring particle size distributions, permeability and DO; and
(3) Long term monitoring of particle size distributions, permeability, and DO could document impacts of land use practices on gravel quality within an entire watershed or the contribution from a single tributary.

### Permeability vs. Salmonid Survival

Gravel particle size distribution and permeability are inter-dependent. For example, we collected 185 in-situ permeability/particle size distribution measurements on Freshwater Creek, McCloud River, Trinity River, and Tuolumne River, and found a positive correlation between permeability

and several gravel quality indices. Two gravel quality indices, the fredle index and the Tappel and Bjornn index, have been related to salmonid emergence survival (Platts, et. al., 1983; Tappel and Bjornn, 1983). We then:

(1) computed the respective index from our particle size data;
(2) predicted survival for steelhead using the above survival relationships; and
(3) compared log (permeability) the survival estimates.

Of these, the Tappel and Bjornn survival index provided the best results (Figure 7). The Tappel and Bjornn index is:

$$\text{Steelhead Survival \%} = 94.7 - 0.116S_{9.5}S_{0.85} + 0.007(S_{9.5})^2$$

where $S_{9.5}$ and $S_{0.85}$ is the percent (by weight) of the sample that is smaller than 9.5 mm and 0.85 mm, respectively. The best fit regression equation for steelhead ($r^2 = 0.55$) is:

$$\text{Steelhead Survival \%} = 97.95 - e^{-0.88(\log \text{permeability})}$$

Our data suggest that for permeabilities above 10,000 cm/hr, steelhead emergence survival is greater than 85 percent. However, considerable scatter is evident at lower permeabilities. This inhibits the usefulness of this technique as a management tool because low gravel permeabilities are commonly observed on impacted watersheds; therefore, the ability to assess the impact of watershed disturbance to salmonid survival is problematic. Therefore, confidence in Equation (3) is low for permeabilties lower than 10,000 cm/hr.

A considerable portion of the scatter in Figure 7 is a result of estimating the value of both the dependent (salmonid emergence survival) and independent (permeability) variables. The dependent variable (permeability) is estimated by measuring inflow and interpolating from Figure 5, and the independent variable is estimated by measuring the particle size distribution and then calculating survival from Tappel and Bjornn's model. Each of these steps adds to the uncertainty in the permeability vs. salmonid emergence survival relationship. Therefore, a desirable alternative would be to derive a direct relationship between standpipe inflow and salmonid emergence survival. We are currently seeking funding to fulfill this research need.

## Acknowledgments

This study was funded in part by Humboldt State University, Humboldt State University Foundation, and the USDA Cooperative State Research Program (McIntire-Stennis). The authors gratefully acknowledge Dr. Terry Roelofs, Dr. William Trush, and the Humboldt State University Fisheries Department for their support and patience. Additional thanks go to Don Allan and others who helped develop the methodology and conduct the field testing of the modified standpipe.

Photographs by Michael G. Harmon.

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# *APPENDIX D.*

# *SELECTED PROTOCOLS*

## *11. SEDIMENT TRANSPORT CORRIDORS (STCs)*

## STCs, Sediment Transport Corridors

A STC is a visible corridor whereby sediment can enter or is entering the stream channel. When any STC is encountered you should record its meter location, the direction from which it drains and note whether it has an effect on the stream choosing between "virtually unnoticeable", "sediment deposition", and "significant aggradation". The surface area of the STC is estimated by measuring its width and length to the nearest 1/2 meter. The STC should be sketched noting any possible causes or apparent sources.

# Sediment Transport Corridors

STC drains from: Left bank Right bank (facing upstream)

Effect on stream: virtually unnoticable sediment deposition significant aggradation

other: _____

Possible causes or sources: _____

_____

_____

_____

STC dimensions:
length_____width_____depth_____

If this is generated by a fill, what are the dimensions of the fill, and what is its present condition (put this on the sketch, also)

length_____width_____depth_____

condition _____

If this is a gully, what are the upstream and downstream controls (hard surfaces limiting erosion)?

Please Sketch below: