Sediment Production and Delivery in the Garcia River Watershed, Mendocino County, California

An Analysis of Existing Published and Unpublished Data

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Introduction

For over 10 years, the Garcia River watershed has been the focus of resource management discussions and studies by landowners within the basin, as well as county, state and federal resource managers. In June, 1997, Pacific Watershed Associates was requested by the U.S. Environmental Protection Agency (EPA), State of California Water Quality Control Board (RWQCB) and Tetra Tech, Inc., Fairfax, Va. to prepare a preliminary sediment budget for the Garcia River watershed. The purpose of the sediment budget is to assist the EPA in establishing Total Maximum Daily Load (TMDL) standards for sediment in the Garcia River watershed.

The Garcia River watershed has been divided into 12 California Watershed Analysis Areas (CALWAA) by the State of California for general planning purposes. This subdivision has also been adopted for the development of TMDL's (Figure 1). For each of these CALWAA sub-watersheds, we have been asked to determine past sediment production and delivery, by erosional process, and if possible, to define significant data gaps, and make recommendations as to how sediment production can be reduced to address establishing TMDL's.

Typically, a sediment budget quantifies sediment sources (inputs), by each erosional process, as well as changes in the amount of channel stored sediment, and sediment outputs as measured at gaging stations over a designated time frame (Reid and Dunne, 1996). Quantifying sediment sources involves determining the volume of sediment delivered to stream channels by the variety of erosional processes operating within the watershed. For the Garcia River watershed, these can be divided into 4 primary processes or sediment delivery mechanisms: 1) mass movement (landslides), 2) fluvial erosion (gullies, road and skid trail crossing failures, and stream bank erosion), 3) surface erosion (rills and sheetwash) and 4) land management activities which directly place sediment in stream channels.

The first three processes can deliver sediment to stream channels both naturally and as a result of land use activities. Sediment production by mass movement processes occurs commonly during large, infrequent storm events (episodic erosion), whereas fluvial and surface erosional processes can occur in any water year (chronic erosion) or as a result of large storms (episodic erosion).

The fourth sediment delivery mechanism, the direct sedimentation to stream channels by heavy equipment, is a land use practice that was widespread in the Garcia River watershed prior to 1975. Since the inception of the California Forest Practices Act in 1975, the practice of yarding logs down stream channels which resulted in direct sedimentation into stream channels has been prohibited. However, over the last three to four decades, many lower order stream channels continue to flush formerly introduced sediment to downstream anadromous reaches of stream. Over the last two decades, the primary location where this mechanism of sediment delivery still

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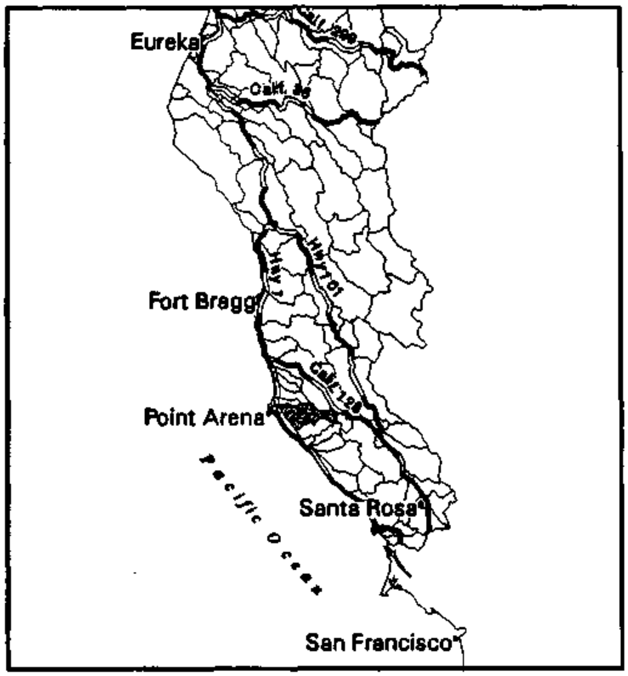
Figure 1. Location of Garcia River Watershed



The 73,222 acre Garcia River Watershed covers 114 square miles of Northern California grasslands, ruggedly forested terrain, oak woodlands, and coastal prairies through which the Garcia River drains into the Pacific Ocean.

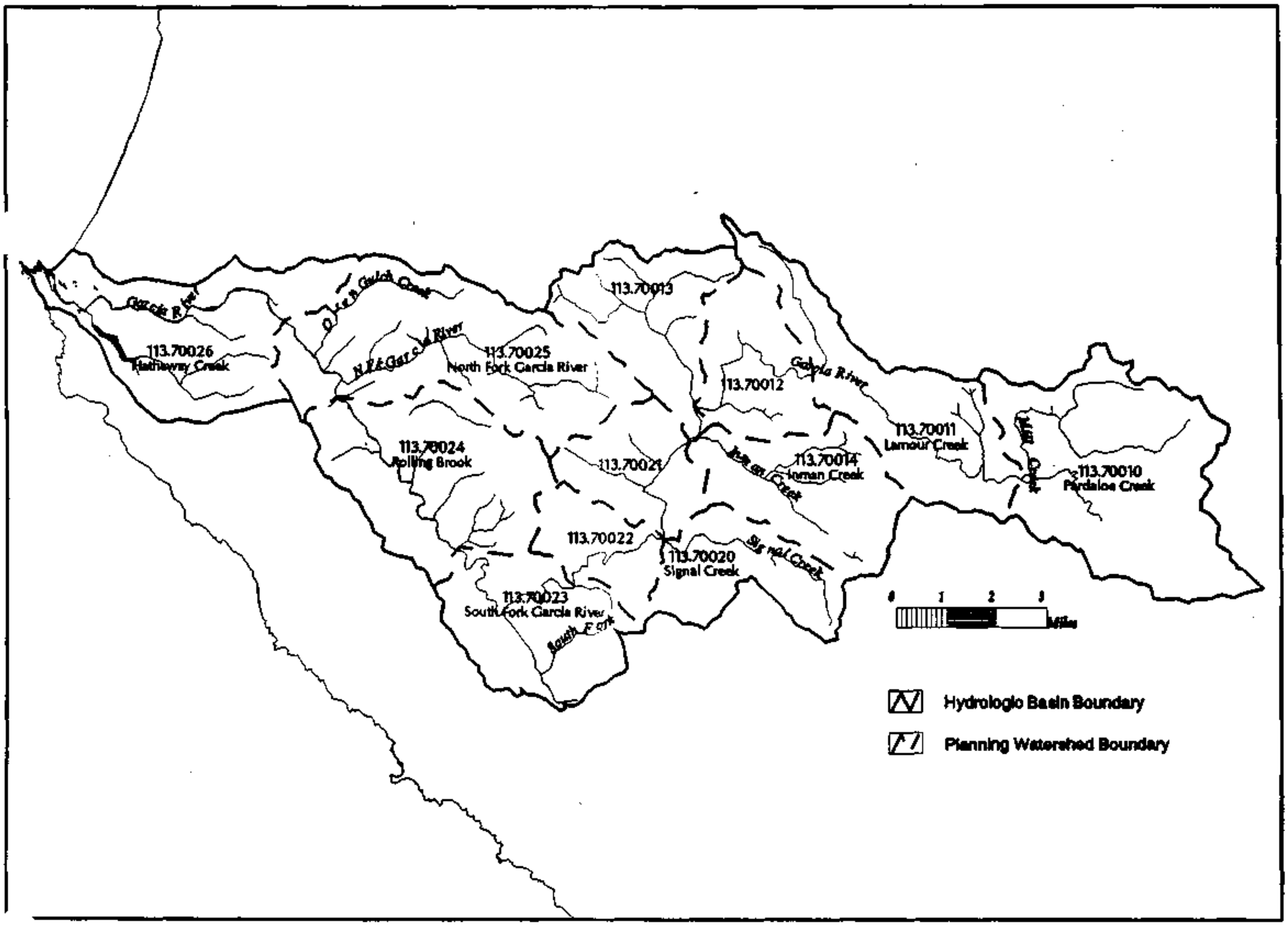


Figure 2. Garcia River Hydrologic Basin and Planning Watersheds

Plotted by CDF's Coast-Cascade GIS
Santa Rosa, California

occurs, to some extent, is where heavy equipment sidecast spoils along road and skid trail approaches to deeply incised stream channels.

Changes in the amount of sediment stored in stream channels is usually measured in the field by analyzing surveyed channel cross sections or by field surveys which estimate the amount of past channel filling and subsequent downcutting that has occurred. Analyzing changes in channel stored sediment can answer questions such as how much of what type of sediment is transported and where is it deposited, how does introduced sediment interact with sediment which was already in storage in the channel, and how does the transport affect overall stream morphology (Reid and Dunne, 1996).

Quantifying sediment outputs requires determining annual transport rates of bedload and suspended sediment past a given point in the watershed (often the mouth or outlet with the next higher order channel). This is typically measured at a gaging station and requires a number of years of sampling to establish a meaningful record.

Reid and Dunne (1996) suggest seven steps are involved in the construction of a reconnaissance-level sediment budget that employs rapid measurements and estimates of physical processes based on air photo analysis, field evidence and published information:

1. Careful definition of the problem,
2. Collection of background information and data,
3. Subdivision of the watershed and project area into uniform or representative sub-areas,
4. Analysis and interpretation of aerial photography,
5. Field inventory, analysis, and calibration,
6. Data analysis, and
7. Checking and verification of results (reality check).

The development of a sediment budget for a large watershed area, such as the Garcia River watershed, can best be accomplished by dividing or stratifying the area into subunits of similar characteristics, such as soil, bedrock, vegetation, topography and land use. Each sub-unit is then characterized by constructing budgets for representative areas within it. These can then be confidently extrapolated throughout each sub-unit to arrive at an estimate of the overall sediment budget for the watershed.

In the budgeting process one evaluates the overall relative magnitude of each major hillslope and channel erosion process operating within the watershed through a) field sampling, verification and mapping, b) aerial photographic analysis, c) computer (GIS) modeling and d) an analysis of existing data and literature. The availability, quality and scale of aerial photography, digital data and completed resource maps will dictate the level of analysis that is obtainable for the watershed.

Watershed Characteristics

The Garcia River drains a 114 mi^2 watershed located in the northern California Coast Range in southwestern Mendocino County (Figure 1 and 2). The only city in the watershed is Point Arena, located near the mouth of the watershed. Elevations within the Garcia River watershed range from sea level at the basin outlet to 2,470 feet at Pardaloe Peak.

Annual precipitation averages 40 inches near Point Arena to over 60 inches in the upper half of the watershed (MCRCD, 1992). Snow fall occurs seasonally in the higher elevations of the watershed, but rarely accumulates to great depths. Thus none of the five largest flood events in the nearby Navarro River watershed were associated with rain-on-snow melt events (LP WWAA93, 1997). Stream gaging records for the Garcia River watershed have been collected by the US Geological Survey between 1952 to 1956, and between 1962 to 1983, and by the Friends of the Garcia River (FROG) since 1992. Philip Williams and Associates (1996) provide a good summary of stream flow records for the Garcia River watershed.

The Garcia River watershed is elongated in an east to west direction and exhibits a wavy or sinuous main stem with most tributaries displaying a trellis-like drainage pattern. Much of the lower 15 miles of the main stem Garcia River, and the South Fork Garcia River, flows within the active fault valley of the San Andreas Fault.

The portions of the watershed located east of the fault are largely responsible for the majority of sediment production, and are underlain by rocks of the Coastal and Central Belts of the Franciscan Complex (CDM&G, Santa Rosa Quad, 1982). Rocks of the Coastal Belt are located in the western half of the watershed (roughly west of Falls Creek), and consist of highly sheared and fractured massive, hard greywacke sandstone with interbedded shales, mudstones, and lesser amounts of conglomerate. Rocks of the Central Belt crop out in the eastern half of the Garcia River watershed. Lithologically, the Central Belt is a tectonic melange comprised of highly sheared, fractured and faulted mixture of predominately volcanic and meta-volcanic rocks, with lesser amounts of sheared shales, sandstones and cherts.

For the most part, hillslopes underlain by both Belts are naturally unstable and prone to debris sliding and deeper seated landslide mechanisms. The hillslopes are generally steep to very steep, and streams have eroded deep canyons throughout most of the watershed resulting in prominent inner gorge slopes adjacent most reaches of stream.

Investigation Methods and Limitations of this Analysis

This analysis involved reviewing several studies and reports prepared over the last 10 years documenting watershed conditions and changes which have occurred in the watershed over the last 100 years. We also reviewed four volumes of miscellaneous short reports and field notes, compiled by NCRWQCB personnel (Alydda Mangelsdorf), documenting spotty quantitative data and largely qualitative observations taken over the last 50 years at scattered locations throughout the Garcia River basin.

Our analysis relied heavily on the O'Connor Environmental Inc. (OCEI, 1997) report since it is the only basin wide analysis which utilizes a single methodology for determining sediment sources. Given the limitations on available data for constructing a sediment budget on the Garcia River watershed, we have followed the OCEI example and stratified the Garcia by sub-watersheds

(CALWAA units) rather than by subunits of similar watershed characteristics. Time constraints precluded revisiting all the raw data and recalculating sediment production by bedrock, soil, vegetation, etc. subunits.

We have attempted to test the validity of the OCEI estimates with the other reported data, as well as preliminary sediment budget results for the Redwood Creek watershed and from the nearby Navarro River and Caspar Creek watersheds.

In addition to reviewing available existing reports, we analyzed 1952, 1965 and 1996 stereo aerial photographs to assess channel and riparian conditions through time as a function of sediment delivery to stream channels. Results from the aerial photograph interpretation of channel and riparian condition is discussed in relation to preliminary results of changes in channel stored sediment recently measured in selected lower Garcia River tributaries (Surfleet and Koehler, 1997).

The Garcia River, like most watersheds in the Pacific Northwest, lacks sufficient data on sediment transport and changes in channel stored sediment to construct a definitive sediment budget. Likewise, most Pacific Northwest watersheds have soft or spotty data quantifying the frequency and magnitude of sediment sources and delivery mechanisms which occur in wildland watersheds.

Existing background information and data for the Garcia River watershed largely addresses mass movement and to a lesser degree, surface erosional processes. Data from several studies has been collected and analyzed using significantly different methodologies. Fluvial erosional processes, which will be a significant components of any sediment budget in watersheds like the Garcia which are underlain by fractured and sheared sedimentary rocks, have not been quantified in any of the available documents.

The scope of work for this project involved compiling available information, and involved no field work to check, calibrate or verify any results reported in the reviewed documents or conclusions made in this document. Therefore, conclusions must be regarded as a preliminary determination of sediment production and delivery over the last 40 years. Future field investigations will greatly improve the quality of both the data and the conclusions.

Summary of Relevant Documents

The only available document which specifically addresses sediment sources throughout the entire Garcia River watershed is a draft report prepared by O'Connor Environmental, Inc. (OCEI) during the summer of 1997 for the Mendocino County Resource Conservation District (MCRCD). The analysis included aerial photographic interpretation of mass movement histories, as well as surface erosion assessments utilizing Geographic Information System (GIS) analysis and aerial photographs.

Most documents reviewed for this project focus mainly on four limited portions of the Garcia River watershed. The four areas are: 1) the lower 10 miles of the Garcia River main stem (related to gravel mining activities and the estuary), 2) lands owned and managed by Louisiana-Pacific

Corporation Timber Corporation (LP), 3) lands owned and managed by Coastal Forest Lands, Ltd., (CFL) a timber company, and 4) Pardaloe Creek (Figure 2). Past studies in these four areas cover approximately 65% of the Garcia River watershed, however the quality of the data for each area varies markedly. Data on sediment sources, transport and channel stored sediment is largely absent for the remaining 35% of the watershed.

The most relevant documents for establishing the distribution and magnitude of sediment sources throughout the Garcia River watershed are the OCEI report (1997), the CFL SYP report (1997), the Philip Williams & Associates report (1996), the LP Sustained Yield Plan (SYP) for WWAA93 (1997), *Overview of stream channel conditions, North Fork Garcia River* (Monschke, 1996), and a memo detailing sediment storage on LP properties in the Garcia River (Surfleet and Koehler, 1997). Other documents provide useful but limited information necessary to develop a sediment budget for the watershed.

Watershed Condition

Peak stream flows measured at the Salmon gaging station at river mile 10 during the winters of 1994/1995 and 1995/1996 are some of the highest discharges measured on the Garcia River. In spite of this, numerous sources note that the lower 10 miles of the Garcia River shows minor changes in stream bed elevation and channel cross sectional area (Philip Williams & Assoc., 1996; Mendocino County Water Agency, 1997). The reports go on to state that the current channel morphology in the lower Garcia River mainstem appears to be relatively stable and has good definition of channel structure, including pools, riffles and bars. The channel appears to be in a state of "dynamic equilibrium" (Philip Williams and Assoc, 1996).

Recent RAPID analysis of channel conditions (as defined by Grant, 1988) in the lower North Fork Garcia River, a major lower Garcia River tributary, indicates the stream channel and riparian canopy continue to recover from large influxes of sediment delivered to the stream between 1963 and 1975 (Higgins and Hagans, 1996). The lack of major aggradation and thalweg incision in the lower Garcia River main stem during the last few years suggests that stored sediment in tributary streams was not significantly mobilized, and/or that recent sediment production throughout the watershed from upstream hillslope areas was not severe (Philip Williams & Assoc., 1996).

Other studies (MCRCD, 1992; Moffatt and Nichol, 1995) describe estuarine processes, and conclude that the historic trend of estuary filling and reduction of the tidal prism has reversed because of a reduced sediment supply from upstream areas. This trend is further documented by channel incision and reduced width to depth ratios following the 1995 storm in the estuary. Severe bank erosion documented at various locations in the lower Garcia River channel appear to be associated with local land use changes (removal of riparian vegetation and channel encroachment) and obstacles such as fallen trees (Moffatt and Nichol, 1995). Philip Williams & Assoc. (1996) estimated the average annual bedload sediment transport rate for the Garcia River in relation to gravel extraction rates for the period from 1966 to 1993. They suggest that over the last 27 years, more gravel has been extracted from the lower river than has been supplied to stream channels from upstream areas.

All these studies conclude that the Garcia River sediment transport regime, as a whole, is recovering from the widespread erosion and sediment delivery which occurred between the late 1950's and the mid-1970's. The findings suggest several possibilities: 1) land use activities conducted over the last two decades are more protective of water quality values, and are having a net beneficial effect (compared to pre-1975 land use activities) by reducing some sources of accelerated, man caused erosion and sediment delivery to stream channels in the Garcia River watershed (it is noteworthy that during the past 10 years, approximately 43% of the Garcia River watershed has experienced a renewed period of timber harvesting and road reconstruction), 2) the great majority of the suspect geomorphic locations capable of generating landslides, with and without land use, already failed or occurred prior to the 1995 storm, and the bulk of potential erosion associated with thousands of poorly constructed road and skid trail stream crossings constructed prior to 1975 has also already occurred, and/or 3) the types of recent storm patterns, intensities, durations and antecedent moisture conditions, combined with the changes in styles of modern land use, (i.e. pre- and post-1974) are not generating high rates of sediment production.

Discussion of Sediment Sources

Mass Wasting

Estimates of mass movement sediment production and yield within the Garcia River watershed are limited to 4 sources: 1) the OCEI mass wasting assessment (1997), 2) the CFL Watershed and Aquatic Wildlife Assessment, Section #2 (1997), 3) *the Overview of stream channel conditions, North Fork Garcia River* (Monschke, 1996) and 4) Geomorphic maps of portions of the watershed prepared by the California Division of Mines and Geology (CDMG, 1984). The CDMG geomorphic maps have limited value because they only cover a small portion (approximately 25%) of the watershed.

Documents such as the LP SYP (WWAA 93, 1997) are not very useful for quantifying past sediment production because they mainly provide estimates of the percent of lands prone to mass movement. Likewise, the Garcia River Watershed Enhancement Plan (MCRCD, 1992) and the CFL Star worksheet data sets largely address future erosion risks and do not systematically quantify past erosion. While this is valuable data and information needed to guide future watershed restoration efforts, it does not assist greatly in developing a sediment budget or analysis of sediment sources in the watershed.

Largely through the analysis of aerial photographs, OCEI (1997) estimates annual and total sediment delivery to stream channels within the Garcia River basin from all mass movement processes to be 144 tons/mi^2/year and 657,000 tons, respectively (Table 1). Sediment production rates are for a 40 year time period, and include the periods of 1957 to 1965, 1965 to 1978, and 1978 to 1996.

Half of the CALWAA areas produced high values of mass movement sediment delivery (within 25% of the highest yield). These were the North Fork (#12), Larmour (#2), Blue West (#3), South Fork (#10), Blue East (#4) and Rolling Brook (#13). Conversely, four CALWAA units produced very low total volumes of sediment yield (i.e. less than 30% of the highest yield CALWAA), and these were Hathaway *(#1*1), Pardaloe (#5), Signal (#9) and Inman (#7).

Table 1. Estimated total sediment delivery (tons) and average sediment delivery rates (tons/mi^2/yr) from mass wasting over the period of record (approximately 1957 to 1996) for individual sub-watersheds, Garcia River (taken from OCEI report, 1997).

Sub-watershed	Map#	Area (mi^2)	Sediment (tons)	Sediment delivery rates (t/mi^2/yr)
Larmour	2	10.2	87,000	213
Blue West	3	7.7	80,000	260
Blue East	4	6.2	75,000	302
Pardaloe Creek	5	16.4	6,000	9
Hot Springs	6	5.4	51,000	238
Inman Creek	7	8.6	28,000	82
Graphite South	8	4.1	65,000	396
Signal Creek	9	6.2	19,000	77
South Fork Garcia	10	8.7	76,200	218
Hathaway Creek	11	12.3	0	0
North Fork Garcia	12	16.2	96,000	148
Rolling Brook	13	12.5	74,000	148
TOTAL		114.0	657,000	144 (avg)

OCEI (1997) indicated over 80% of the mass movement features, and presumably the volume, were associated with land management activities (>60% from roads and skid trails?, and about 20%, by number, within harvest units). The remaining 20% of the estimated sediment yield should be viewed as a minimum volume of natural, background sediment production from mass movement processes for each CALWAA for this time period. Results reported in the CFL SYP (1997) indicate 42% of all shallow landslides are associated with roads and skid trails, and reported no clear correlation between tree removal and frequency and distribution of landslides.

The OCEI analysis indicates rates of sediment delivery throughout the Garcia River basin vary greatly. One half of the CALWAA units delivered sediment to stream channels at a considerable higher rate than the basin average of 144 t/mi^2/yr, and these include Graphite South (#8), Blue East (#4), Blue West (#3), Hot Springs (#6), South Fork (#10) and Larmour (#2). Both the North Fork, which produced the largest volume of sediment from mass movement processes, and the Rolling Brook CALWAA delivered sediment at approximately the average unit rate for the Garcia River watershed.

To what degree differences in land management practices within different CALWAA areas played in influencing higher volumes and/or rates of sediment yield is not discernable from existing data. Both the percent of each CALWAA underlain by steep hillslopes capable of generating landslides, and the percent of the sub-basin in commercial wood species suitable for timber harvesting could be influencing both the volumes and rates of sediment yield. However, the data suggests that the four CALWAA areas with low total volumes of sediment yield (Hathaway, Pardaloe, Signal and Inman) also delivered sediment to streams at low rates through time. These four CALWAA areas may be inherently more stable and less prone to either natural or management induced mass wasting.

According to OCEI (1997) four CALWAA areas produced landslide derived sediment in higher volumes in the 1978 to 1996 period than in the 1957 to 1965 period (Figure 2). These are the Rolling Brook, North Fork, Inman and Blue East CALWAA units. The Inman CALWAA experienced its highest rate of landslide sediment production in the 1978 to 1996 photo interval. High volumes and rates of sediment production are understandable in watersheds which were heavily managed prior to 1978. Prior to 1974, there were no Forest Practice Rules (FPR) throughout the State to moderate forest management activities, nor did most counties have enforceable County Grading Ordinances.

Presumably, land management activities conducted through the 1980's and early 1990's have been conducted within the FPR. Escalating volumes and rates of sediment yield in the Rolling Brook, North Fork, Inman and Blue East CALWAA units suggest that either these watersheds may be more sensitive to disturbance than perceived by land managers and State regulators, and/or that the current FPR are not adequately protecting water quality resources, and/or that land use activities have not been implemented in the field as proposed or recommended in the FPR.

The only available data with which to compare the volumes of sediment yield from mass movement processes developed by the OCEI study is provided in the CFL Watershed and Aquatic Wildlife Assessment, Section *#2* (CFL-WAWA, 1997). The CFL analysis was conducted utilizing a single set of aerial photographs (1995) and was performed for two primary purposes. The first was to determine the frequency, size and distribution of mass movement throughout the CFL ownership, and second, to use the data to stratify the landscape into five zones of geomorphic sensitivity to guide future watershed management activities (i.e., landscape risk analysis). The CFL analysis attempted to identify all landforms which displayed any evidence as being formed by mass wasting processes. The OCEI analysis attempted to define mass movement features which were initiated or active during a given time interval (i.e. between 1957-1965, 1965-1978 and 1978-1996).

Figure 2. Sediment Delivery by Mass Wasting by Sub-watershed, Garcia River, c.1957-1996

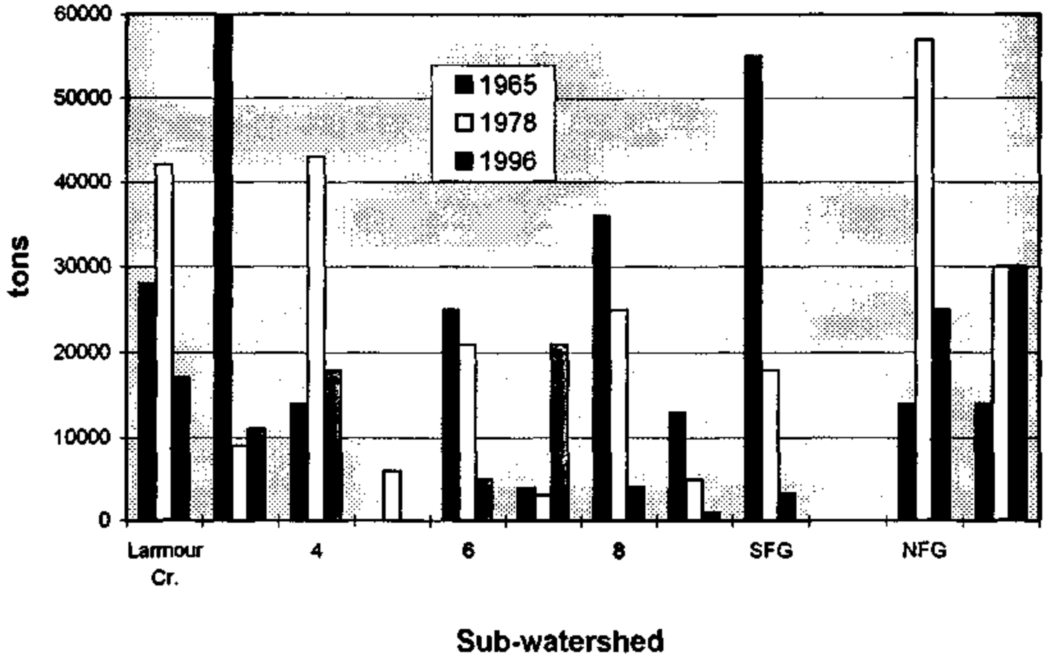


Figure 3: Sediment Delivery Rate by Mass Wasting, Garcia River, c.1957-1996

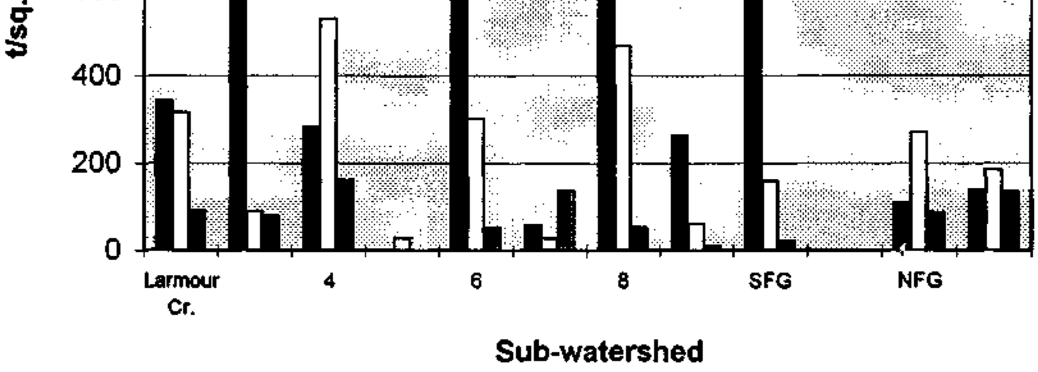


Table 2. Comparison of adjusted landslide sediment delivery volumes reported by OCEI and CFL,

CALWAAName and No.	CFL Lands in the CALWAA (mi^2 & %)	Adjusted CFL Sed. Del. (tons)	Modified OCEI Sed. Del. (tons)	Percent Difference
Signal (113.70020)	5.88 (95%)	985	22,800	2300%
Graphite South (113.70022)	3.63 (89%)	1,825	78,000	4200%
Inman (113.70014)	7.03 (82%)	3,255	33,600	1000%
North Fork (113.70025)	12.15 (75%)	16,120	115,200	700%

The ratio of shallow and deep-seated landslide features for both studies is similar, however the CFL data identified over twice as many individual features (909) on only 33% of the Garcia River watershed currently in CFL ownership (38.18 mi^2). A large portion of the difference is accounted for when the OCEI data is adjusted upwards by 75% to account for the difference in landslide area measured in the two studies. The minimum size feature measured in the OCEI study was 200yd^2 versus 50yd^2 in the CFL report. It is also very likely the CFL analysis identified many inactive or dormant pre-1957 shallow and deep-seated mass movement features.

We attempted to compare the volumes of sediment delivery from mass movement processes for the four CALWAA areas which CFL has more than 75% of the ownership (Table 2). We applied the same assumptions to the CFL data which OCEI used to convert areas to volumes (i.e. average depth of each landslide equals 3 feet, average sediment delivery rate equals 50%). These values were chosen since the vast majority of features measured in both studies were shallow rapid debris slides. We applied these values to CFL data presented in Table 2.1 of the CFL-WAWA ("Recent, about 15 year old shallow debris slide and debris torrent landslides") which roughly accounts for the same time frame as in the OCEI study. The calculations for volume of sediment yield for the percent of land in CFL ownership was adjusted to apply for the whole CALWAA unit. In addition, we modified the estimate of sediment delivery in the OCEI study by 20% to account for the volume of sediment associated with sites smaller than 100 yd^2 which were not measured in the OCEI study.

As can be seen in Table 2, the correlation is poor in all four sub-watersheds. Since the CFL estimates of recent slide mass are always considerably smaller, cover a slightly shorter time frame and exclude the 1995/1996 water year, it is difficult to explain the differences.

The OCEI (1997) estimate of mass movement includes both shallow and deep-seated landslides. CFL tallied deep-seated landslides separately in Table 2-4 of the CFL-WAWA. If we apply the assumptions used by OCEI for deep-seated slides to the areas of slide identified by CFL in Table 2-4, the percent difference between the two analyses gets even greater. CFL has identified total acres experiencing some form of disrupted ground as deep-seated. Much of this may not be active. Consequently, we can not apply the OCEI assumptions because the two analyses measured very different types of features. The OCEI measured only active features, whereas CFL measured all landforms with evidence of historic or pre-historic activity.

Finally, we tallied CFL estimates, based on field surveys, for total volume of sediment delivered to the North Fork Garcia River during the winter of 1994/1995, when the storm flows of record were recorded in the watershed (Monschke, Appendix II, 1996). We assume this to be a minimum sediment production value since only selected portions of the watershed were visited in the field. Monschke reported 7,250 yds^3 of sediment was delivered to the North Fork from mass movement features. This equates to approximately 9,780 tons of sediment.

Monschke's one year estimate of sediment production, during a large return interval storm, tends to support the CFL SYP estimate of recent sediment delivery over the last 15 years rather than the OCEI estimate. However, the 1986 flood was the fourth largest flow on the Garcia River and could have produced significantly higher amounts of sediment than documented by Monschke making the total sediment production over the 1978 to 1996 time period much higher, and possible closer to the OCEI estimate.

California Department of Forestry and Fire Protection (CDF&FP) data indicates 82% of the North Fork watershed has been harvested over the last 10 years. CFL has indicated widespread upgrading and closure of portions of the road system throughout the North Fork occurred as the timber harvesting was carried out. It is also possible the CFL efforts are substantially reducing overall sediment yield within the watershed, thereby accounting for the presumable lower estimate when compared to the OCEI estimate.

In the absence of additional estimates of sediment production throughout the Garcia River watershed, we consider the OCEI analysis as the best available basin wide data to determine the relative role of mass movement by CALWAA units in the watershed. In the synthesis section which follows we will discuss how these values compare to other northcoast watersheds.

Fluvial and Surface Erosion

Roads Erosion

Estimates of road and skid trail sediment production and yield within the Garcia River watershed are limited to 3 data sources: 1) the OCEI mass wasting assessment (1997), 2) the CFL Watershed and Aquatic Wildlife Assessment, Section #3 (1997), and 3) the LP SYP (WWAA 93, 1997). All three documents contain estimates of surface erosion from bare soil areas. However, none of the documents attempt to quantify sediment production associated with road and skid trail crossing failures (washouts), gully volumes associated with past stream diversions, and from fill failures along roads. Data from other northcoast watersheds suggest these are all potentially important sediment sources (Hagans and Weaver, 1987; Weaver and others, 1995; Best and others, 1995).

Table 3. Estimated annual sediment delivery to streams (tons) from roads, skid trails, and creep processes for sub-watersheds of the Garcia River, Although estimates are given with several digits, the estimates should be considered to have at most two significant digits (from OCEI report, 1997).

Sub-watershed	Map No.	Area (mi^2)	Annual sediment yield (tons)			
			Roads	Skid trails (0-2 yrs)	Skid trails (>2 yrs)	Background (creep)
Larmour	2	10.2	913	15,760	2,080	652
Blue West	3	7.7	1,287	11,860	1,555	491
Blue East	4	6.2	2,165	9,558	1,262	396
Pardaloe Creek	5	16.4	1,961	3,780	499	1,043
Hot Springs	6	5.4	2,740	8,240	1,088	341
Inman Creek	7	8.6	3,970	13,189	1,741	546
Graphite South	8	4.1	1,676	6,317	834	261
Signal Creek	9	6.2	3,178	9,514	1,256	394
South Fork Garcia	10	8.7	393	13,462	1,777	557
Hathaway Creek	11	12.3	1,888	2,832	374	782
North Fork Garcia	12	16.2	7,653	24,961	3,295	1,033
Rolling Brook	13	12.5	1,428	19,249	2,541	797
TOTALS		114	29,252	138,723	18,311	7,293

OCEI (1997) clearly explains the assumptions made in deriving estimates of road and skid trail sediment contributions over the last 40 years. In general, the analysis followed procedures developed by the Washington State Watershed Assessment Manual (WA-DNR, 1994). Table 3 and Figures 3 and 4 are taken directly from the OCEI report and summarize estimates of annual sediment delivery, total sediment delivery and average annual sediment delivery rates, respectively. Background erosion estimates by OCEI (1997) in Table 3 follow the WA-DNR (1994) procedures and are an estimate of the annual sediment contribution to stream channels from natural hillslope creep processes.

In four CALWAA areas, roads were judged to contribute substantially higher amounts of annual sediment delivery to streams (Table 3), as well as total estimated sediment delivery volumes (Figure 3) and higher annual sediment delivery ratios (Figure 4) than the other sub-watersheds. These are the North Fork (#12), Inman (#7), Signal (#9) and Hot Springs (#6).

Figure 4: Estimated Total Sediment Delivery, Garcia River, c.1957-1996

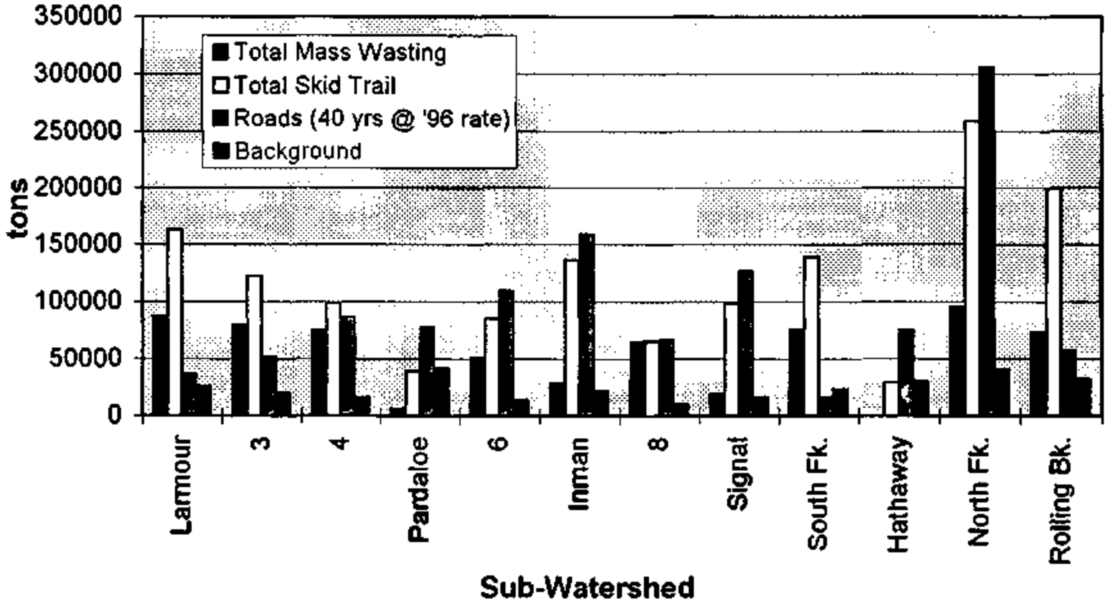
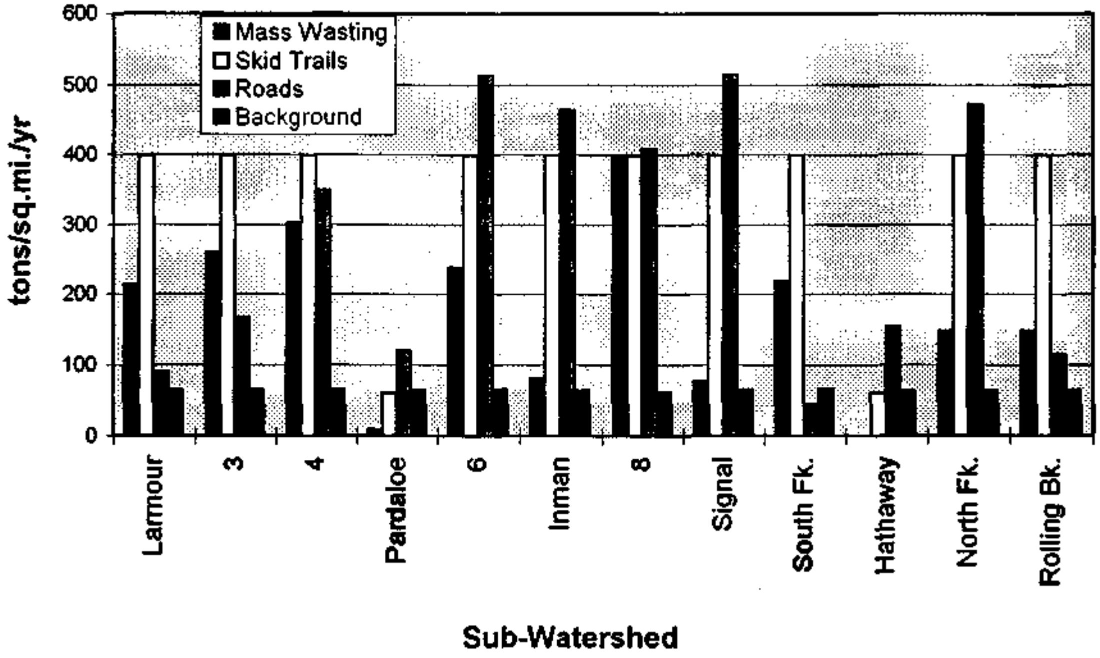


Figure 5: Estimated Average Sediment Delivery Rates by Source Process, Garcia River, c.1957-1996



The CFL SYP (Section #3, 1997) followed a similar methodology to the OCEI analysis (i.e., modified WA-DNR, 1994). CFL divided their road system into three sediment delivery ratings (i.e. high, moderate and low), and determined the total miles of road and miles of road in each of the rating categories. Unfortunately, the tables are not in a useable format for calculating sediment production from road prisms, fill slopes, ditches and cutbanks, nor does the CFL SYP assign potential annual or total erosion and sediment delivery volumes or rates for the road categories.

In an effort to use the CFL statistics for comparative purposes, we applied the OCEI correction factors and assumptions used for sediment delivery (see Table 8 in OCEI report) to the tallied miles of road, by use-class, within 200 feet of stream channels. The values were then adjusted upwards to account for road sediment production from the whole CALWAA unit, not just the CFL lands. The comparison was run on the four CALWAA units where CFL has the majority of the land ownership. Table 4 presents the results.

Table 4. Comparison of road annual sediment delivery rates (tons/acre/year) for common areas reported by OCEI (1997) and CFL SYP (1997).

CALWAA Name and No.	CFL Lands (mi^2 &%)	CFL Road Miles within 200 ft. of Class 1 and 2 Streams			Est. CFL Sed. Del. (t/mi^2/yr)	OCEI Sed. Del. (t/mi^2/yr)	Percent Diff.
		Permanent	Seasonal	Total			
Signal (113.70020)	5.88 (95%)	6.06	10.18	16.24	177	513	289%
Falls (113.70022)	3.63 (89%)	2.37	3.75	6.12	108	409	379%
Inman (113.70014)	7.03 (82%)	4.95	20.40	24.99	195	461	236%
North Fork (113.70025)	12.15 (75%)	12.79	13.23	26.02	141	472	335%

The visual correlations are generally poor. Like the estimates of mass movement sediment delivery where the adjusted CFL data reported much lower masses of delivery (Table 2), the road sediment production estimates are also considerably lower than the estimate from the OCEI analysis. The CFL SYP discusses the potential for road sediment delivery to Class 1 and 2 streams. If road miles within 200 feet of Class 3 watercourses have not been included in the road mileages listed in the SYP, then some of the differences in annual yield could be accounted for. Sediment delivered from roads to any watercourse capable of sediment transport, albeit a low transport, small stream, is sediment in the natural drainage network and should therefore be included in the analysis.

The same comparison was performed on the one LP CALWAA unit where they manage 92% of the watershed. Within the South Fork Garcia River (#113.70023), the LP SYP indicates there are 6.5 miles of road within 100 feet of streams. We have no way of determining which of these roads are permanent, seasonal or temporary, so we assumed the 6.5 miles of road to be seasonal roads and applied the appropriate OCEI correction factors. The low amount of timber harvesting in the watershed over the last decade (15%), supports low road use levels and a lower sediment production rate.

The calculation indicates approximately 38 t/mi^2/yr of sediment delivery occurs in the South Fork from all roads. The OCEI estimate was 45 t/mi^2/yr suggesting only an 18% difference in the estimates. Assuming the LP estimates include Class 3 streams, then the estimates would be very similar, or the adjusted LP estimates would be slightly higher than the OCEI values, if the miles of road within 200 feet of watercourses were used in the calculations.

To summarize, we have applied the OCEI factors to miles of road, delineated by the two SYP's, as being capable of delivering sediment to streams. The large differences between the CFL and OCEI estimates of sediment yield clearly suggests that the assumptions made, in terms of which segments or lengths of road are delivering sediment to streams, are responsible for a big portion of the differences. However, this does not imply we are in agreement with the assumptions made in the WA-DNR (1994), which OCEI followed, as accurately predicting sediment production from roads.

Surely most roads in close proximity to streams deliver sediment, but it may not always be 100%. Our experience suggests many other segments of road greater than 200 feet from watercourses also delivery sediment. Sediment delivery from roads anywhere on the hillslopes can occur if, because of the road prism shape, large drainage areas are created which concentrate rainfall to the extent that rill and gully erosion can occur. Runoff from the road prism onto moderate to steep hillslopes can create man-made gullies with high volumes of sediment delivery to streams.

As with the estimates of mass wasting sediment production, the OCEI estimates are the only basin wide estimate of road sediment production. In the synthesis section which follows we will discuss how these values compare to other northcoast watersheds.

Hillslope Erosion (Skid Trails)

It is difficult to analyze the various estimates of sediment delivery from hillslopes throughout the Garcia River watershed for several reasons. Both of the SYP's and the OCEI report utilized different methods to compute hillslope erosion and sediment delivery. Secondly, each method presented utilized somewhat different assumptions. Third, we did not have access to raw data nor GIS capability necessary to normalize the assumptions and recalculate the estimates of erosion and sediment yield. The following is a discussion of the various methods and assumptions utilized.

Throughout the Garcia River watershed, the OCEI study recognized the existence of a dense and extensive tractor skid trail network which had been constructed by 1965, and re-constructed several times over the last 40 years. In order to account for past sediment production and yield from surface erosion on hillslopes throughout the Garcia River watershed, OCEI assumed that the past sediment yield from the skid trail networks, due to their role in disrupting the natural hillslope and surface water drainage pattern, would be a significant majority of the sediment yield and therefore a good surrogate to approximate hillslope contributions (O'Connor, personal communication). The OCEI report estimated representative skid trail densities and applied a number of correction factors, similar to those used to estimate road contributions, to estimate total sediment delivery from the hillslopes (see Table 8 in OCEI report).

The most noteworthy assumptions made by OCEI (1997) are: 1) most skid trails were used to access trees three times over the 40 year period, 2) for the first 2 years following each entry, the base erosion rate was 121 tons/acre of skid trail prism/yr and sediment delivery was 25%, and 3) for the remaining 34 years, the erosion rate was 66 tons/acre of skid prism/yr and sediment delivery was 25%. According to the OCEI report, average annual sediment yield from the skid trail network was 400 t/mi^2/yr for all CALWAA units except Pardaloe and Hathaway.

The CFL SYP hillslope erosion estimates are based on soil erodibility (K factors) as determined from NRCS soil data and on the steepness of the hillslopes. CFL determined what percent of the hillslope on their lands, by CALWAA, fell into three surface erosion potential classes (i.e. high, moderate and low potential). We do not believe these surface erosion potential classes are the same as CDF&FP Erosion Hazard Rating categories.

The major assumption made by CFL was that only steeper hillslopes within 200 feet of a stream were capable of delivering sediment to a stream. The CFL classification resulted in 2.4% of the 18,362 acres managed by CFL in the lower half of the Garcia River watershed as having a high potential for hillslope surface erosion to deliver sediment to stream channels. No apparent attempt was made by CFL, nor PWA in this analysis, to apply a surface erosion lowering rate to each of the classes in order to estimate erosion and sediment delivery from their lands. The assumptions and methods are so different to preclude any comparison.

The LP SYP took a different approach than the previous studies, and used the Critical Sites Erosion Study (CSES) by Lewis and Rice (1990) as the basis for predicting increases in erosion from hillslopes and roads, as well as research conducted at the USFS Pacific Southwest Experimental Station as the basis for predicting sediment yield. Both predictions are based on a per entry basis. The LP analysis assumes the findings of Rice and Lewis (1991) are correct, which states that 68% to 85% of measured hillslope erosion from forest lands occurs at critical sites (i.e. locations where erosion exceeds 100 yd^3/acre), and that 60% of the measured erosion comes from less than 1% of the forest lands. The LP sediment yield predictions are for all road and hillslope erosional sources, excluding stream crossing failures and stream bank erosion (Lewis and Rice, 1990).

The LP SYP increased the erosion and sediment delivery estimates developed through the use of CSES relations for critical and non-critical sites by 40%, in order to account for smaller sediment sources measured by Rice and Datzman (1981) which were un-accounted for in the CSES study. The LP analysis used the CSES-derived relations in conjunction with GIS to predict erosion rates on individual 10 meter grid cells for both roads and harvest areas.

Sediment yield for each grid cell was computed by multiplying the estimated erosion by a sediment delivery ratio. For the Garcia River watershed, LP used a constant sediment delivery ratio equal to 20%. Based on the modified CSES analysis, LP predicted the average increase in total erosion from WWAA 93 (LP lands in the Garcia River watershed) to be approximately 12.0 yd^3/ac/entry; and the predicted average sediment yield from LP ownership in this WWAA at approximately 2.4 yd^3/ac/entry. Only in the South Fork CALWAA unit does LP manage the majority (92%) of the sub-watershed so as to provide for comparison. The LP estimate of sediment production equals 168 t/mi^2/yr for the South Fork Garcia River. The LP estimate of road and hillslope sediment yield is 265% lower than the OCEI estimate.

We have limited confidence in all three analyses of sediment production from hillslopes within CALWAA units in the Garcia River watershed. Much of this is based on the large number of documented hillslope erosional processes not accounted for in either of the analyses. The LP approach, which relies heavily on Dr. Rice's statistically significant sampling studies, under-estimates the hillslope locations, positions and mechanisms by which sediment can be delivered to stream channels. Likewise, the WA-DNR (1994) procedures, utilized by both OCEI and CFL with slight variations, also rely heavily on weak assumptions concerning the distance from a stream channel in which sediment can be delivered to streams, and, in our opinion, significantly under-estimates sediment delivery percentages.

In the synthesis section, we will compare and contrast the Garcia River estimates of sediment production with the Redwood Creek watershed and the nearby Navarro River and Casper Creek watersheds.

Stream Channel Analysis

A component of our analysis of Garcia River watershed data was to review stereo aerial photography to determine stream channel response to the influxes of sediment between 1952 and 1996. PWA reviewed 1952, 1965 and 1996 photos utilizing a modified RAPID approach (Grant, 1988) to document channel conditions. The 1978 aerial photos were reviewed, but the stereo coverage was insufficient to accurately map channel conditions. Stream channel reaches which displayed enlarged channel widths and open riparian canopies were interpreted as "response reaches" of stream channel which were affected by influxes of sediment. Some portion of the reaches identified as "response reaches" may in fact be reaches where timber harvesting of all riparian overstory and understory vegetation had occurred.

Because of budget constraints, we did not have the luxury of quantifying actual changes in channel width opening, but instead chose to document when and where open canopy conditions existed along the stream channels. Table 5 presents results of the RAPID analysis of "open" stream riparian conditions through time in relation to the total miles of stream identified in the CDF&FP GIS. Main stem reaches of the Garcia River downstream from the mouth of Rolling Brook Creek were not measured because they had contiguously open canopy conditions from 1952 to the present.

Table 5. Changes in riparian canopy closure utilizing aerial photographs between 1952 and 1996, Garcia River watershed.

CALWAA Name & #	Class 1,2 & 3 Stream Miles (CDF data)	Miles of Open Stream			Percent of Open Stream			% Change 1952 to 1966	% Change 1966 to 1996	% Harvest last 10 yrs
		1952	1966	1996	1952	1966	1996			
Larmour (113.70011)	45.7	2.0	9.4	8.6	4%	21%	19%	+17%	-2%	13%
Blue West (113.70013)	37.1	5.4	9.4	4.2	15%	25%	11%	+10%	-14%	35%
Blue East (113.70012)	40.2	3.5	5.1	4.3	9%	13%	11%	+4%	-2%	52%
Pardaloe (113.70010)	83.6	1.8	0.5	3.9	2%	1%	5%	-1%	+4%	12%
Graphite South (113.70021)	36.8	2.1	5.3	3.7	6%	14%	10%	+8%	-4%	62%
Inman (113.70014)	79.6	1.7	4.1.	1.5	2%	5%	2%	+3%	-3%	76%
Hot Spring (113.70022)	25.8	1.7	5.7	3.1	7%	22%	12%	+15%	-10%	76%
Signal (113.70020)	41.9	0.0	4.6	1.2	0%	11%	3%	+1 1%	-8%	70%
S.F.Garcia (113.70023)	22.7	4.4	9.2	5.6	20%	41%	25%	+21%	-16%	15%
Hathaway (113.70026)	34.0	0.0	0.0	0.0	-	-	-	--	-	~
N.F.Garcia (113.70025)	106.0	0.7	5.5	2.8	1%	5%	3%	+4%	-2%	82%
Rolling Brook (113.70024)	39.0	1.1	5.0	1.5	3%	13%	4%	+10%	-9%	20%

Note: The main stem of the Garcia River downstream of the mouth of Rolling Brook Creek was not measured since the canopy was continuously open in 1952.

The 1952 aerial photos indicate all the CALWAA units, with the exception of Signal Creek, had some amount of riparian canopy openings. In Blue Waterhole, Inman and Pardaloe, timber harvesting had commenced by 1952, and the vast majority of canopy opening appear associated with tractor activities in and adjacent streams and from the harvesting of riparian conifers. Canopy opening within the remaining CALWAA units appeared to be largely natural and associated with either streamside debris slides, wide river and stream valleys, or lower gradient, channel response reaches of stream where aggradation had recently occurred. Most of the main stem Garcia River from above Larmour Creek to the estuary exhibited open canopy conditions in the 1952 photos.

By 1965, virtually the entire Garcia River watershed had been heavily roaded and tractor logged. All CALWAA units except Pardaloe showed increases in the percent of open canopy conditions. It is difficult to not attribute most of the increase in open canopy to land use activities. Some portion of the observed channel changes were the result of accelerated erosional processes and channel aggradation, and clearly some was the result of tractor activity directly in stream channels. Instream channel conditions appear to have been most severely impacted and degraded in 7 CALWAA areas (Table 5). These included Larmour, Blue West, Graphite South, Hot Spring, Signal, South Fork Garcia and Rolling Brook.

The 1996 photos indicated all CALWAA units except Pardaloe displayed decreases in the amount of open canopy conditions compared to the percent open in the 1965 photos (Table 5). Five CALWAA (Blue West, Blue East, Inman, South Fork Garcia and Rolling Brook) display total miles of open riparian canopy within 25% of what was identified on the 1952 photos. While three of these CALWAA were already heavily managed by 1952 and exhibited disturbed stream canopies (Blue West, Blue East and Inman), the assessment of canopy conditions suggests, in most CALWAA units, conditions continued to improve as a whole. This evidence tends to support the beneficial effects of improving forest practices, the implementation of stream protection measures over the last decade or so, and decreasing erosion and sedimentation rates.

Table 5 also lists the percent of the land base in each CALWAA area which has been harvested by some type of silvicultural practice over the last 10 years (from CDF&FP data). Three of the five CALWAA which had the least amount of land re-harvested in the last 10 years displayed the greatest amount of improvement and increases in closed riparian canopies. They are Blue West, South Fork Garcia and Rolling Brook.

The two CALWAA with the lowest amounts of timber harvesting in the last decade (Larmour and Pardaloe) showed a very low decrease or slight increase in open canopy conditions when compared to 1965. An explanation for the lack of improvement may be that both the Larmour and Parladoe CALWAA areas have generally open landscapes with the highest percent of land covered with grasslands, oak woodlands and chaparral. Likewise, reaches of streams may have been impacted during erosional events which occurred in the 1970's and 1980's. The OCEI (1997) analysis indicated the largest amounts of sediment production occurred in both these CALWAA during the period between 1965 and 1978. Both these CALWAA areas may actually be experiencing decreases in the amount of open canopy that may have been present in 1978. We had no aerial photography available to confirm this hypothesis.

Changes in Channel Stored Sediment

Historically, efforts to document changes in the amount of sediment in storage in gravel bars and along stream channels has focused on the lower 10 miles or so of the main stem Garcia River and within the North Fork Garcia River. These are the main storage zones for the river. A large number of channel cross sections were surveyed along the main stem by the Mendocino County Water Agency in 1991 to begin to better understand the potential affects of commercial gravel extraction on channel and sediment transport processes. Subsequent to 1991, longitudinal profile and cross section surveys have be conducted by MCRCD (1992), Fugro West, Inc (1994), Swanson and Associates (1993), and Philip Williams and Associates (1995).

Within the North Fork Garcia River, CFL timber company initiated channel cross sectional surveys in 1989, and has resurveyed them in subsequent years, to determine the extent of channel changes which are occurring in a sub-watershed undergoing fairly intensive forest management (Monschke, 1996). As stated earlier in this report, none of these studies document negative impacts occurring, such as significant channel aggradation or reduction in pool habitat depths, even in response to the storm of record for the Garcia River during the winter of 1995/1996.

Throughout the remainder of the Garcia River watershed, no quantitative data on channel elevation or morphology changes is available for analysis. The analysis of stream channel and riparian conditions presented earlier, as well as the OCEI (1997) analysis, indicate many reaches of stream channel throughout the CALWAA units were directly and indirectly impacted by tractor activity and aggradation, respectively, in the 1966 and the 1978 aerial photographs. Sediment introduced to stream channels during these time frames has been reworked and transported to downstream higher order streams at variable rates.

During the summer of 1997, LP initiated studies on the amount of, and changes in, channel stored sediment on several stream channels within the lower Garcia River in the South Fork and Rolling Brook CALWAA units (Memo from Surfleet and Koehler, 1997). They surveyed 12.7 miles of stream channel in order to estimate the amount of channel stored sediments which were likely present in the 1960's. To do this they relied on interpreting field evidence of channel filling as expressed by recent, modern episodes of gravel terrace and floodplain formation. In addition, they estimated the void through the terraces/floodplains created by subsequent downcutting and transport of sediment over the last several decades.

Surfleet and Koehler (1997) documented changes in channel stored sediment in portions of six separate stream channels covering 6.9 miles (54%) of the total stream miles surveyed. The six portions of stream are all the downstream-most and highest order reaches of tributary streams. The reaches are generally lower gradient channels where the likelihood of storing introduced sediment is highest, (i.e. they function as watershed response reaches of stream). All of these stream reaches have drainage areas ranging from about 1.5 mi^2 to 5 mi^2. They estimate the stream channels stored approximately 124,000 yd^3 of sediment in terraces and floodplains in the 1960's. Today, these same channel reaches now store approximately 89,280 yd^3, representing a 28% reduction. These channels are continuing to recover from past inputs.

Only one of the six stream reaches, the lower 9,100 feet of the South Fork Garcia River, showed an increase in channel stored sediment (Table 6). Surfleet and Koehler (1997) hypothesis that the aggradation in the lower South Fork is due, in part, to the release of sediment previously stored in tributaries to the South Fork. We concur, and a review of Table 6 indicates both the Little South Fork and Fleming Creeks, both tributaries to the South Fork, are estimated to have released nearly 10,500 yd^3 of previously stored sediment over the last 30 years or so. This is very close to the amount of increase in stored sediment estimated for the South Fork (10,600 yd^3).

Table 6. Changes in channel stored sediment volumes between the 1950's/1960's and 1997, in selected stream channels on LP lands, lower Garcia River watershed (from Surfleet and Koehler, 1997).

Stream Name	Length (feet)	Estimated Original Terrace Volume (yd^3)	1997 Terrace Volume (yd^3)	Change in stored sediment over 35-45 year period (yd^3)	Percent Change
Lee	6875	5110	2931	-2179	-43%
Rolling Brook	5800	63136	39050	-24086	-38%
Mill	1500	25227	16870	-8355	-33%
South Fork	9100	10582	21195	+10613	+100%
Little S.F.	7500	15784	7715	-8069	-51%
Fleming	5500	4116	1703	-2413	-59%
TOTALS	36,275	123,955	89,284	-34,489	-28%

The five remaining reaches which were surveyed by LP (the lower portions of Lee, Rolling Brook, Mill, Little South Fork and Fleming Creeks) all showed reductions in channel-stored sediment of between 33% and 59% (Table 6). Unlike the stored sediment which was exported from the South Fork tributaries, mobilized sediment in Lee, Rolling Brook and Mill Creeks was delivered directly to the main stem Garcia River channel. It is interesting to note that the total volume of sediment released from the three tributaries over approximately 3 decades (34,620 yd^3) represents only 70% of Mendocino County's (1995) estimated annual gravel extraction rate (49,688 yd^3) in the lower river over approximately the same time frame.

In the remaining 5.8 miles of stream channels surveyed by LP personnel, the channels appear to store relatively low volumes of sediment and no substantial changes were documented. Surfleet and Koehler (1997) documented a total of 21,015 yd^3 of stored sediment in these remaining channels. These are generally lower order and steeper channel reaches which would probably be classified as transport reaches. All these stream reaches appear to have drainage areas smaller than a square mile. For significant quantities of sediment to be stored in these steeper channel reaches, logjams and/or larger streamside debris slides must occur which block the channel, or the channel has to be physically filled by tractor activities.

The preliminary data on changes in channel stored sediment collected by LP generally agrees quite well with the finding of Pitlick (1995). Dr. Pitlick studied sediment production and routing in 16 diverse tributary streams draining Franciscan Complex geologies in the Redwood Creek watershed, Humboldt County, CA. For redwood dominated, high relief basins, similar to those mapped by LP in the Garcia River basin, Pitlick estimates that as of 1981 the channels stored only 49% of the total amount of sediment delivered to them between the period 1954 and 1981. He also found that the percent of introduced sediment still in storage was largely a function of the presence of large organic debris and logjams (i.e. 72% of the sediment still in storage was upstream of debris). Conversely, for Douglas-fir dominated, high relief basins, which are more akin to vegetation types in the upper half of the Garcia River watershed, Pitlick (1995) found that over a 27 year period, only 22% of the introduced sediment was still in storage, and of this, 41% was stored behind large organic debris.

Preliminary Sediment Source Analysis

The analysis of available watershed data on the Garcia River shows minimal correlation between results reported in the various documents which we have reviewed. Consequently, it is difficult to determine defensible values for past sediment production, by erosional processes, in the watershed. As a means of "grounding" the various sources of existing data for the Garcia River, we have chosen to compare these results with sediment production values determined for the Redwood Creek watershed, in coastal Humboldt County, as well as data from the nearby Navarro River and Casper Creek watersheds.

We first summarized the predicted range of sediment yield by various erosional processes for the Garcia River basin. Table 7 has been constructed by using data presented in the LP and CFL SYP's (1997), the OCEI (1997) report and the CDF&FP GIS database. Adjusted sediment source estimates in Table 7 means we used CEL and LP data from their SYP's, and applied correction factors and assumptions used in the OCEI report. Modified data means we only adjusted OCEI data by some percent to account for differences documented in other studies.

Over the last 40 years, the OCEI (1997) analysis for the Garcia River watershed suggests the total sediment production from landslides, and surface erosion on roads and skid trails is 860 tons/mi^2/year (Table 7). The OCEI authors acknowledge that there are several other sediment production mechanisms and processes un-accounted for in their analysis. Using the OCEI assumptions on LP road data presented in their SYP for the South Fork Garcia River produces good agreement of average annual sediment yield for road surfaces (Table 7). However, all other efforts to use the OCEI assumption with SYP data have produced considerably lower estimates of long term sediment yield rates from landslide and surface erosional processes (Table 7).

Table 7. Summary of estimated annual sediment yield by a variety of methods and sources for applicable portions of the Garcia River watershed.

Data Sources and Periods of Record	Area: Garcia Basin minus Hathaway (102 mi^2)	4CALWAA units w/CFL lands >75% (35.1mi^2)	So Fk. Garcia River w/LP lands >90% (8.7mi^2)
Modified OCEI landslides (1957-1996)	192 t/mi^2/yr	178 t/mi^2/yr	
Modified OCEI landslides (1978-1996)	82 t/mi^2/yr	97 t/mi^2/yr	
Adjusted CFL landslides (1957-1996)		48 t/mi^2/yr	
Adjusted CFL landslides (1978-1996)		42 t/mi^2/yr	
Adjusted CFL deep-seated landslides (1957-1996)		635 t/mi^2/yr	
OCEI Roads (1957-1996)	268 t/mi^2/yr	463 t/mi^2/yr	45 t/mi^2/yr
Adjusted CFL Roads (1957-1996)		156t/mi^2/yr	
Adjusted LP Roads (1957-1996)			38t/mi^2/yr
LP estimate Road/Slopes			168 t/mi^2/yr
OCEI skid trails (1957-1996)	400 t/mi^2/yr	400 t/mi^2/yr	400 t/mi^2/yr

Redwood Creek Data:

The 280 mi^2 Redwood Creek watershed has experienced some of the most intensive study to understand watershed erosional processes in North America. Since the early 1970's, studies intended to determine natural and disturbance caused erosion and river sedimentation have been conducted by the US Geological Survey, the National Park Service, the US Forest Service and several Universities. The end result of extensive research conducted throughout the watershed is the construction of a preliminary sediment budget by Madej and others (unpublished report). The sediment budget was constructed for the period from 1954 to 1980.

We believe the estimated values for sediment production from Redwood Creek are applicable to the Garcia River watershed for purposes of comparing the relative percent of sediment yield derived from different areas and different erosional processes . Both basins have similar bedrock geologies and overlying soils, rainfall patterns and intensities, vegetation types and land use histories. Both watersheds are dominated by steep hillslopes and steep gradient, gravel bedded stream channels, with dense redwood forest in the lower watershed, and mixed conifer, oak woodland and scattered grasslands in the interior portions of the watershed. Between 1950 and 1978, over 80% of the Redwood Creek watershed was roaded and logged, primarily utilizing tractors (Best, 1995). Our review of aerial photographs covering the Garcia River suggest a very similar land use history.

For the Redwood Creek basin, Madej and others (unpublished report) estimated sediment production from nine different sources or locations for the combined fluvial and surface erosion processes. These include stream bank erosion along mainstem and tributaries; surface erosion on bare ground; haul road and skid trail stream crossing failure; gullies associated with haul road stream diversions; rills and gullies on skid trails; and surface erosion from haul roads, cutbanks and inboard ditches. For mass movement processes, they estimated amounts of sediment yield for five different types or locations, including mainstem and tributary streamside landslides, earthflows, forested blockslides and debris torrents.

The per unit area rates of sediment production for the Redwood Creek watershed are significantly higher than what the existing data suggests for the Garcia and nearby Navarro River watersheds. However, we believe the relative frequency at which the various sediment production processes occur in the Garcia and Redwood Creek watersheds is useful for comparative purposes. For example, combined sediment production from landslides in the Redwood Creek watershed is 2,400 t/mi^2/yr whereas the best estimate for the Garcia is 192 t/mi^2/yr (Table 8). Likewise, in the Redwood Creek watershed, sediment yield from fluvial and surface erosional processes accounted for 56% of the total yield, and mass movement processes accounted for 44% (Madej and others, unpublished). The OCEI (1997) analysis, the best available data for the Garcia River watershed, suggests 78% of the total estimated sediment yield is associated with surface erosional processes and 22% is associated with mass movement processes (Table 8).

Navarro River Data:

In the nearby Navarro River watershed, Entrix, Inc., published a sediment budget for the watershed prepared by Trihey and Associates (1997). They estimated the total amount of sediment yield for the period 1954 to 1996, as well as the rates of sediment production for landslides, gullies and road related erosion. For landslide and gully erosional processes, the Trihey and Associates sediment budget divided the Navarro into 4 sub-areas based on similarities in bedrock geology, geomorphology and dominate vegetation type. The results from the Coastal-Belt forested Geo-Veg unit (566 t/mi^2/yr) appear most applicable for comparison with the western half of the Garcia River watershed, and the Coastal-Belt grass-scrub unit (1021 t/mi2/yr) appear most applicable for the eastern half of the Garcia basin.

For road related erosion, several different models based largely on road densities were run to estimate sediment yield. Trihey and Associates (1997) estimated road related sediment production for the whole Navarro watershed to be 377 t/mi^2/yr. For the combined North Fork and lower main stem sub-watersheds, which we believe to be most similar and comparable to the Garcia River watershed, they estimated a road related rate of 545 t/mi^2/yr.

Table 8. Comparison of sediment production, by processes, for the Garcia River, Navarro River, Casper Creek and Redwood Creek watersheds.

Sediment Source Mechanism	Garcia River minus Hathaway Sediment Yield Rate (t/mi2/yr) & (% of total budget)	Navarro River Sediment Yield Rate (t/mi^2/yr) & (% of total budget)	Redwood Creek Sediment Yield Rate (t/mi^2/yr) & (% of total budget)	Caspar Creek Sediment Yield (t/mi^2/yr) & (% of total budget)	
				So. Fk. Caspar Creek (big storms, poor logging)	No. Fk. Caspar Creek (big storms, no recent logging)
Landslides	192t/mi^2/yr (22%)	566 t/mi^2/yr (51%)	2400 t/mi^2/yr (44%)		
Road Surface	268 t/mi^2/yr (31%)	545 t/mi^2/yr [1] (49%)	167t/mi^2/yr (3%)		
Road Cutbanks and Ditches	--	--	100t/mi^2/yr (2%)		
Haul Road & Skid Trail Crossing	--	--	223 t/mi^2/yr (4%)		
Gullies from Diversions on Roads & Skids	--	--	1 125 t/mi^2/yr (21%)		
Skid Trail Surface Erosion	400 t/mi^2/yr (47%)	--	780 t/mi^2/yr (14%)		
Streambank Erosion	--	--	690 t/mi^2/yr (13%)		
TOTALS	860 t/mi^2/yr (100%)	1111 t/mi^2/yr (100%)	5485 t/mi^2/yr (101%)	1,420 t/mi^2/yr (100%)	680 t/mi^2/yr (100%)

[1] Includes sediment production from road surfaces, as well as an estimate of surface erosion on skid trails, and fluvial erosion associated with roads.

Caspar Creek Data:

For many decades the Caspar Creek watershed has been the focus of studies on watershed processes and response to disturbance. The majority of these studies have been conducted by the USDA Forest Service, Redwood Science Lab and by the CDF&FP. . Rice and others (1979) determined sediment yields from the South Fork Caspar Creek, a heavily managed watershed, for the time period 1967 to 1976 to be 1420 t/mi^2/yr (Table 8). Rice and others interpreted the yields to be well higher than background rates due to several large storms which occurred during the period and due to poor pre-Forest Practice Rules forest management activities.

Napolitano (unpublished Master Thesis, 1996) analyzed sediment transport and storage in the North Fork Caspar Creek for the periods 1963 to 1976 and 1980 to 1988. For the period 1963 to 1976, Napolitano reported total sediment yield to be 680 t/mi^2/yr (Table 8). During this period, the basin experienced two 27-year return interval storms and at least one major landslide. Most logging in the basin was done prior to the Forest Practice Rules. For the period 1980 to 1988, the total sediment yield was 180 t/mi^2/yr. During this later period, the lower sediment yield is associated with smaller storms (largest was <7-year return period) and improvements made in protecting water quality from land use activities.

Napolitanos' estimates of sediment yield should be considered as minimums since only changes in channel stored sediments were quantified in relation to measured bedload and suspended sediment yields. The only hillslope sediment sources measured by Napolitano were streamside landslides and bank erosion.

New Data Received October 10, 1997

On October 10, 1997, PWA received revised estimates of sediment yield from OCEI. The revisions were based on results of Level II Watershed Analysis (WA), involving substantial field assessments, conducted by Louisiana-Pacific during the summer of 1997 (Surfleet and Koehler, 1997a). The Level II analysis followed procedures in the Washington State Watershed Assessment Manual (WA-DNR, 1994).

The LP Level II WA preliminary results are summarized in a September 10, 1997 memo sent to the Regional Water Quality Control Board (NCRWQCB) and to OCEI. The field sampling and assessment work was conducted solely on LP lands, in the Rolling Brook and South Fork CALWAA units. LP estimated sediment yield over a 45 year time frame (1952 to 1997), whereas the OCEI report analyzed sediment yield over a 40 year period (1957 to 1996).

The LP Level II analysis significantly modifies our previous estimates of sediment yield for landslide, road and skid trail erosional processes. There are five major preliminary findings by LP which substantial affect the OCEI and PWA analysis and which increase the rates of sediment production throughout the Garcia River watershed listed in Table 8.

LP field studies indicate the "Depth of Slides" are deeper than estimated in the OCEI study. LP found shallow rapid slides averaged 4 feet deep and road related fill failures averaged 6 feet deep, whereas OCEI assigned a depth of 3 feet for all shallow landslides. Second, LP assigned a 75% sediment delivery ratio for shallow rapid slides as opposed to a 50% delivery ratio used by OCEI. For debris flows or torrents, LP assigned a sediment delivery ratio of 85-100% as opposed to 75% used by OCEI. Third, LP added a new category of sediment yield titled "SMALL INNER GORGE SLIDES" which included slides which could not be seen on air photos but which were present in the field. This category accounted for 22% and 31% of the LP estimated total sediment yield in the Rolling Brook and South Fork watersheds, respectively.

Fourth, LP utilized a number of different assumptions and field observations to determine that road related sediment yield in the Rolling Brook and South Fork watersheds is considerably higher than estimated by OCEI. Unlike the OCEI study, the LP field studies measured sediment yield from a variety of previously un-estimated sources of road sediment including culvert washouts, gullies and fill failures. LP indicated that the field estimates of road related yield should be added to the previously reported surface erosion rates presented in Table 7.

The LP Level II analysis indicates that road related sediment yield in the South Fork averages 387 t/mi^2/yr compared to the OCEI estimate, based on no field work, of 45 t/mi^2/yr. For the Rolling Brook basin, LP estimates road yield at 238 t/mi^2/yr compared to 120 t/mi^2/yr in the OCEI study.

Finally, LP utilized a number of different assumptions and field evidence to estimate skid trail sediment yield. They estimate average sediment yield to be considerably lower than the OCEI estimate. Over the 45 year budget period, LP estimated the rate at 225 t/mi^2/yr for lands in the Rolling Brook CALWAA unit; and 215 t/mi^2/yr in the South Fork watershed. Because of improvement in forest practices during the period 1978 to 1997, LP estimates sediment yield rates from skid trails to be considerable less than the long term average (Surfleet and Koehler, 1997a).

Based on these significant changes in a number of sediment source parameters, we have modified Table 13 (Taken directly from the OCEI 2nd draft) to incorporate results of the LP Level H analysis and also adjusted the slide volumes to reflect the greater number of slides identified by CFL. Table 9 summarizes the results by CALWAA units and changes the OCEI original estimate of mass wasting for the Garcia River watershed from 144 t/mi^2/yr to 405 t/mi^2/yr.

The revised OCEI and PWA sediment yield rates presented in Table 9 still differ significantly from the LP estimate which are based on the Level II analysis. For example, Table 9 suggests mass wasting yields of 421 t/mi^2/yr and 491 t/mi^2/yr for the Rolling Brook and South Fork CALWAA units, respectively. The LP estimates are higher at 826 t/mi^2/yr and 794 t/mi^2/yr for the Rolling Brook and South Fork CALWAA units, respectively (Surfleet and Koehler, 1997a).

An alternative approach to resolving the differences between the OCEI estimated sediment yield and the LP estimate would be to assume the LP Level II analysis in portions of two CALWAA areas is a more accurate estimate of sediment production. In doing so, one could adjust the sediment yield in the remaining 10 CALWAA areas by some ratio based on the LP estimates. We believe the OCEI values do indeed under-estimate long term average sediment yield, largely due to limitations imposed by Level I watershed analysis procedures. However, we did not undertake such an exercise because of time constraints and because we were unsure about

Table 9. Estimated total sediment delivery and average sediment delivery rates from mass wasting over the period of record (approximately 1957 to 1996) for individual Cal Water Planning Units in the Garcia River watershed. Adapted from O'Connor Environmental, Inc. (1997, draft) and Pacific Watershed Associates (1997 draft) by Mangelsdorf, 1997 (Table 6, draft)

Planning Unit	Predominant Sub-basins	Area (mi^2)	Original Sediment Delivery Rate ($t/mi^2/yr$)	Original Sediment Delivery estimate (tons)	Shallow rapid landslide component (tons)	Shallow rapid landslide component adjusted based on L-P data (tons)	Other landslide component adjusted based on CFL data (tons)	Estimated Inner gorge component (tons)	Total modified sediment delivery estimate	Modified annual sediment delivery rate ($t/mi^2/yr$)
113.70025	N. Fk & Garcia	16.2	157	102,000	78,000	117,000	28,800	136,100	281,900	435
113.70011	Larmour Ck & Garcia	10.2	211	86,000	34,800	52,200	61,440	85,700	199,340	489
113.70013	Blue Waterhole Ck.	7.7	263	81,000	29,400	44,100	61,920	64,700	170,720	554
113.70023	S. Fk & Garcia	8.7	218	76,000	21,600	32,400	65,280	73,100	170,780	491
113.70012	Stansbury Ck, Whitlow Ck & Garcia	6.2	298	74,000	16,400	24,600	69,120	52,100	145,820	588
113.70024	Rolling Brook, Lee Ck, Hutton Gulch & Garcia	12.5	156	78,000	40,400	60,600	45,120	105,000	210,720	421
113.70022	Beebe Ck & Garcia	4.1	396	65,000	27,500	41,250	45,000	34,400	120,650	736
113.70021	Graphite Ck & Garcia	5.4	238	51,000	35,900	53,850	18,120	45,400	117,370	543
113.70014	Inmann Ck.	8.6	79	27,000	13,600	20,400	10,680	72,200	103,280	300
113.70020	Signal Ck.	6.2	77	19,000	8,100	12,150	13,080	52,100	77,330	312
113.70010	Pardaloe & Mill Creeks	16.4	8	5,500	5,500	8,250	0	137,800	146,050	223
113.70026	Hathaway Ck, Garcia & estuary	12.3	0	0	0	0	0	103,300	103.300	210
113.700	Total	114.5	145 avg	664,500	311,200	466,800	423,960	961,900	1,852,660	405

applying sediment yield estimates derived from such a small portion of the watershed to the whole watershed.

Synthesis

Table 10 summarizes currently available data to estimate rates of sediment production from various sources, and includes the revised OCEI (2^{nd} draft) and the LP Level II estimate of rates for the Garcia, as well as sediment budget efforts for three other watersheds: Redwood Creek, the Navarro River and Caspar Creek. For each category of sediment yield where data is available, we have listed the results as sediment yield rates and the percent of the total budget the individual sediment source contributed to streams during the budget period. While each approach is summed as 100% of the total sediment sources in the watershed, this is clearly not the case since each budget has several un-quantified or poorly quantified erosion and sediment delivery mechanisms. As additional data is collected on the role of various erosional processes, the relative percents will change. For example, comparing Tables 8 and 10 one sees that the OCEI estimate of sediment production via landslides nearly doubles in relative percent as a result of incomporating the LP Level II analysis results.

The Redwood Creek budget covers a period of time where, for all intents and purposes, there were few or no modern Forest Practice Rules in effect. We acknowledge that the Redwood Creek unit sediment yield rates are higher than what is realistically expected to be occurring in most northern California watersheds over the last two decades. However, the percentages from the various sources may be a fair representation of where and how sediment is being produced today. We have chosen to compare Redwood Creek percentages of sediment yield for the following categories: landslides (both shallow and deep-seated), streambank erosion, surface erosion on bare ground, haul road and skid trail stream crossing failure and gully erosion.

While each of the estimates of sediment production for the Garcia and Navarro River and Caspar Creek have utilized different approaches and methods, as well as measured different sediment sources, there is general agreement in the total estimate of sediment yield rate between the watersheds (Table 10). Because the LP estimate has involved the greatest amount of field measurements to quantify a wide variety of sediment sources, we believe the estimated long term average annual sediment yield rates are a more accurate prediction of the basin's erosional history.

Table 10 suggests mass wasting processes in the Garcia, Navarro and Redwood Creek have accounted for between 41% and 59% of the total sediment yield. If one believes the LP category of "Small Inner Gorge Slides" includes streambank erosional processes, then the LP and Redwood Creek estimates of relative percent of sediment yield by streamside mass movement processes are very similar at 59% and 57%, respectively (Table 10).

Compared to mass movement processes, combined fluvial and surface erosional processes represent a similar range of sediment yield values (41% to 59%) in the three watersheds. Comparing the LP estimates with Redwood Creek data suggests a similar percent is associated with road surface erosion (3%) and road and skid trail fluvial erosion is responsible for between 25% to 38% of the total sediment yield in the two watersheds (Table 10). The difference in

Table 10. Revised Table 8 based on new data received from L-P. Comparison of sediment production, by process, for the Garcia River, Navarro River, Casper Creek and Redwood Creek watersheds.

Sediment Source Mechanism	Garcia River minus Hathaway Sediment Yield Rate (t/mi2/yr) & (% of total budget) (OCEI, 1997 (2nd draft)	Rolling Brook & So. Fk. Garcia River, Level II analysis (LP Data)	Navarro River Sediment Yield Rate (t/mi^2/yr) & (% total budget) (Trihey &Assoc, 1997)	Redwood Creek Sediment Yield Rate (t/mi^2/yr) & (% total budget) (Madej & others (unpublished)	Caspar Creek Sediment Yield (t/mi^2/yr) & (% of total budget)	
					So. Fk. Caspar Creek (big storms, poor logging)	No. Fk. Caspar Creek (big storms, no recent logging)
Landslides	462 t/rni^2/yr (41%)	810t/mi^2/yr (59%)	566 t/mi^2/yr (51%)	2400 t/mi^2/yr (44%)		
Road Surface	268 t/mi^2/vr (24%)	38 t/mi^2/yr (3%)	545t/mi^2/yr[1] (49%)	167t/mi^2/yr (3%)		
Road Cutbanks and Ditches	--	--	--	100t/mi^2/yr (2%)		
Haul Road & Skid Trail Crossing	--	532 t/mi^2/yr (38%)	--	223 t/mi^2/yr (4%)		
Gullies from Diversions on Roads & Skids	--		--	1125t/mi^2/yr (21%)		
Skid Trail Surface Erosion	400 t/mi^2/yr (35%)	--	--	780 t/mi^2/yr (14%)		
Streambank Erosion	--	Included in landslides	--	690 t/mi^2/yr (13%)		
TOTALS	1130t/mi^2/yr (100%)	1380t/mi^2/yr (100%)	1111t/mi^2/yr (100%)	5485 t/mi^2/yr (101%)	1,420 t/mi^2/yr (100%)	680 t/mi^2/yr (100%)

Includes sediment production from road surfaces, as well as an estimate of surface erosion on skid trails, and fluvial erosion associated with roads.

relative percent with likely become more similar as other categories of sediment production are quantified. Likewise, the overall rates and relative percents may change when results of Level II or equivalent sediment production studies are included from the remaining 80% of the Garcia River watershed.

Each of these estimates of sediment production undoubtedly are under-estimating the actual .- extent of each category of erosion and sediment yield. For example, the Redwood Creek sediment budget (Madej and others, unpublished report) has been constructed for a watershed which has an extensive gaging record of bedload, suspended sediment and water discharge for several stations in the basin. However, even with the extensive database to quantify sediment output from the basin, the estimate of total sediment production and delivery from all source categories listed in Table 10 still does not account for 14% of the total past sediment yield.

Table 10 suggests anywhere from 40 to 60% of the total sediment yield in the Garcia River watershed is associated with man-caused fluvial and surface erosional processes. The erosion has and continues to occur to some degree along roads, skid trails and other bare soil areas associated with the variety of land use activities which take place throughout the watershed. With the exception of bare soil areas associated with wildland forest fires, we suggest these fluvial and surface erosional processes are accelerated, largely man-caused sources of sediment delivery to stream channels throughout the Garcia basin. Both processes are amenable to significant reductions in their annual contribution as part of a water quality attainment strategy for sediment.

Based on our experience in watersheds throughout the Pacific Northwest, we believe eliminating the majority of the existing and potential sources of fluvial and surface erosion sediment yield to stream channels is technically attainable. However, to do this will require a conscientious effort by landowners and agencies to properly upgrade or "storm-proof roads, and/or properly "hydrologically close" high risk road segments. The major difficulty may be in locating funding sources to implement all the needed corrective measures, given the extensive history of road and skid trail construction, use and abandonment which has occurred throughout the watershed.

Both the LP and the CFL SYPs' specifically recognize the necessity for reducing sediment yield associated with fluvial and surface erosion processes. Both plans describe generic procedures for assessing their respective ownerships to identify sites in need of erosion prevention or erosion control measures. However, inventories to identify sites of future erosion and sediment yield in the basin have not yet occurred. As a first step in the process of reducing management-related sediment yield, such inventories must first be conducted. This will allow for the development of a prioritized list of erosion prevention projects where existing and potential sediment sources can be treated. We suggest landowners in the basin develop a timetable for the systematic collection of data (treatable sediment source) and implementation of identified treatment sites. However, it is imperative that some form of a quality review committee be established to review and ensure that individual landowner assessments, and subsequent proposed erosion prevention or control activities, truly are addressing erosional processes that are or have the potential to impact water quality.

Based on the field inventories, erosion control and prevention sites can be prioritized for implementation. This can include upgrading culvert sizes and armoring stream crossing fill slopes to prevent future erosion, eliminating diversion potentials at all road and skid trail stream crossings (by constructing critical rolling dips), excavating potentially unstable road and landing fill materials[1], and disconnecting road surface, ditch and cutbank runoff from adjacent streams by employing some combination of road outsloping, rolling dip construction or installation of ditch relief culverts in the immediate vicinity of stream crossings.

Table 10 estimates of mass wasting sediment yield may include some landslides associated with roads and skid trails, as well as natural and harvest-related hillslope failures. Determining the degree to which management activities may be influencing hillslope failures not connected to roads and skid trails is difficult and is often subject to debate. None-the-less, it seems prudent to strive to better understand the natural topographic, geologic, hydrologic, geomorphic and biologic controls on the incidence and magnitude of hillslope failures, as well as the influence(s) of land management activities on slope stability. Landscape locations which have historically displayed a heightened sensitivity to land management (ie., they show a greater frequency or increased magnitude of mass movement following harvest activities) should be identified and managed in a more protective manner.

Both the LP and the CFL SYP's, and the OCEI 2nd draft (1997), indicate that from 40 to 60% of all identified mass movement features are associated with roads and skid trails. Significant reductions of this source of sediment yield should be attainable if the risk of road fill failure is diligently evaluated and modified construction techniques are implemented carefully along all road, skid trail and landing locations. Avoidance is perhaps the best tool for eliminating road-related mass movement features. Keeping roads away from well known "suspect" geomorphic locations on the landscape, including steep headwall swales, major breaks-in-slope and steep inner gorge hillslopes, is a critical first step. Existing roads which cross these high risk sites need to be carefully analyzed for signs of potential failure and either upgraded or decommissioned. The key to achieving a significant reduction in road, skid trail and landing sediment yield, from both mass movement and fluvial processes, will be to objectively assess the risk of sediment delivery to any Class 1, 2, or 3 stream.

Recognizing and estimating attainable reduction in the risk of sediment delivery from non-road-related hillslope mass movement processes is more problematic. The methodology for delineating landslide risk and susceptibility being developed by LP in their SYP offers the significant potential for objectively evaluating landslide risk or potential within headwall swales. However, the methodology may not be affordable to many smaller industrial and ranch land owners in the Garcia River watershed. Until the time that a regional or basin-by-basin methodology for analysis of hillslope failure risk is developed and agreed upon by state and federal agencies and landowners, assessment of failure risk will continue to be performed by a variety of watershed science professionals, each with different skill levels, experience levels and probably utilizing different methodologies.

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[1] Potentially unstable sites include sidecast areas and fill slopes which already exhibit instability (cracks, scarps, etc.) over steepened landing and sidecast materials which exhibit a risk of sediment delivery to a stream, perched materials above stream channels, and road fills placed in "suspect" geomorphic locations (including steep headwall swales, steep slopes below a prominent slope-break, or steep inner gorge slopes).

As a consequence, any percent value chosen for reducing hillslope sediment production may be difficult to attain. However, we believe that a significant reduction in the magnitude and frequency of hillslope mass movement is attainable over a 10 to 20 year time frame. We base our optimism on advances being made in modeling watershed processes, such as the LP methodology, and the ever increasing participation by professional geologists in the location, design and construction of wildland roads and the layout and design of harvesting prescriptions for steep, potentially unstable lands. As with mass movement along forest roads, avoidance of potentially unstable terrain is the most effective tool for reducing sediment yield from non-road related landsliding.

In-stream Stored Sediment

CFL has suggested in Chapter 6 (Synthesis and Prescription) of their SYP, dated September 1997 that remobilization of instream stored sediment will be a primary source of sediment that may adversely affect fisheries resources on CFL property for an indefinite time to come. We concur, in a general sense, that previously introduced stored sediments, whether mechanically placed by bulldozers or naturally delivered by stream sediment transport, is episodically remobilized (eroded) from the channel and transported down stream. This sediment source could be relatively significant in some channels. However, much of the remaining sediment stored in and along stream channels is now in moderate or long term storage and may have lengthy residence times before it re-enters the stream system. Further mapping and evaluation of the magnitude and spatial distribution of this sediment source is needed.

CFL cites Monschke (1996, pers. comm.) as the basis for their findings, but offers no quantitative data on the extent of channel stored sediments, and their residence time, in relation to other sediment sources. CFL references Madej and Ozaki (1996), who analyzed more than two decades of channel changes and sediment transport in the Redwood Creek Watershed, Humboldt County, CA., as supportive evidence for their conclusions. The Madej and Ozaki studies document channel changes and sediment transport along the main stem of Redwood Creek, which would be a similar setting to the main stem of the Garcia River. Most CFL stream reaches are located along steeper tributary watersheds to the main stem Garcia River. As will be discussed later, tributary stream channels respond very differently to channel stored sediments than main stem reaches due to a variety of factors including channel gradient, channel width-to-depth ratio and channel stream bed and bank characteristics (bedrock or alluvial banks).

The only quantitative data on volumes of channel stored sediment currently available for tributary stream channels in the Garcia River basin was collected by LP during 1997 (Surfleet and Koehler, 1997). Their data, as discussed earlier, indicates most of the six downstream (i.e. lower gradient, higher order) reaches of tributary streams surveyed have experienced significant flushing and loss of channel stored sediment (33% to 59% reduction) between approximately the early 1960's and 1997. While no data was presented by LP in their preliminary analysis as to the predicted residence time of the remaining stored sediment, we would suggest that the majority of the remaining stored sediment is probably being retained in longer term residence categories as defined by Madej, (1995) (i.e. semi-inactive storage compartments).

This implies that the remaining sediments in storage will be removed at an increasingly slower rate in the future. Significant channel widening and bank erosion will require larger flows than have been experienced over the last decade. Most of the readily accessible stored sediment has probably been removed. Pitlick (1995), Madej (1995) and Hagans and others (1986) have documented that stream channels which have experienced severe channel aggradation or filling frequently retain some portion of the introduced sediments in long term, semi-inactive storage compartments in the form of elevated, lateral gravel bars that may remain for a century or longer.

Analysis of the LP data on changes in channel stored sediment (Surfleet and Koehler, 1997) serves to moderate some of the CFL estimates of future channel erosion as a source of sediment yield and habitat degradation. As stated earlier, LP recently inventoried 12. 7 miles of stream channels within their ownership in the lower Garcia River. Based on their descriptions, we estimate approximately 6.9 miles (54%) of the surveyed streams were third or fourth order stream channels and 5.8 miles (46%) were first, second and small third order channels. According to the LP data, the higher order stream channels currently contain the majority of remaining stored sediment in both the terrace/flood plain setting and the active channel compartment (Table 11). The steeper, lower order channels either did not store large volumes of sediment, or they have flushed much of their stored sediments to downstream areas.

Table 11. Channel stored sediment in sample stream reaches of the Garcia watershed (modified from Surfleet and Koehler, 1997)

Inferred Stream Order	Length of inventoried stream (mi)	Sediment stored in terraces and floodplains		Sediment stored in the active channel	
		(yds^3/mi)	(%)	(yds^3/mi)	(%)
1 and 2+	5.8	3,650	19%	1,150	16%
3 and 4	6.9	12,900	81%	5,000	84%
Totals	12.7	--	100%	--	100%

The LP data indicates 12,900 yd^3/mile and 5,000 yd^3/mile are currently stored in the lower gradient, higher order terrace/floodplain stream reaches and active channel storage compartments, respectively (Table 11). We suggest a small percent of the terrace/floodplain stored sediment will be remobilized, largely through bank erosion processes, and be delivered to downstream reaches over the next several decades. Much of it is now in longer term storage and may take up to a century, or longer, to release. However, stored sediments in the active channel compartment generally have much shorter residence times and can be expected to move more quickly (Madej and Ozaki, 1996). Remobilization of active channel-stored sediment could serve as a measurable contributor to sediment yield which can continue to delay full aquatic habitat recovery.

Along the remaining 5.8 miles of stream channel surveyed by LP (Surfleet and Koehler, 1997), we interpret the streams to be third order or less, steeper gradient channels, which are largely bounded by bedrock slopes and banks. Within these smaller class 2 and class 3 channels, the LP data indicates channel stored sediments currently average 3,650 yd^3/mile in terrace/floodplain settings and 1,150 yd^3/mile in the active channel (Table 11). This is considerably lower than the quantities documented in higher order stream channels and when compared to the total estimated annual rate of sediment production in Table 10, accounts for a relatively small percentage of the annual yield. The LP data suggests that stored sediment within steeper gradient, lower order tributary channels will not be a sizeable source of future sediment yield to fish bearing streams when compared to other potential hillslope sediment sources.

Surely there are locations along tributary stream channels where obvious and significant quantities of stored sediment are currently residing. These sites might be candidates for erosion prevention (through direct excavation of the stored sediment), but they must be carefully evaluated in terms of both residence time and release rates to downstream areas, as well as the potential for resource damage from heavy equipment operations. Efforts to improve water quality and fish habitat through large scale channel modifications and "improvements" (such as direct excavation) do not guarantee beneficial results. We suggest land managers conduct extensive, site-specific, field studies before embarking on any in-channel excavation projects aimed at reducing channel stored sediment. This analysis should include an evaluation of the potential benefits and impacts of such an operation, an evaluation of natural release rates and residence times of the sediment if it is left undisturbed and an evaluation of cost-effectiveness of the proposed in-channel work compared to other erosion prevention projects which could be conducted elsewhere.

Conclusions

Much of our initial attempt to determine the dominant processes and source areas of sediment production throughout the Garcia River watershed was based on the Level I watershed analysis conducted by OCEI (1997), and aided by SYPs' prepared by CFL and LP, two of the larger landowners in the watershed. The receipt of LP Level II watershed analysis preliminary findings, based on field studies conducted during the summer, 1997, greatly improved our ability to assess the relative magnitude and distribution of sediment sources in the Garcia basin.

Over a 45 year period (1952-1997), the best available data for a portion of the lower Garcia River watershed indicates the long term sediment production rate averages, at a minimum, 1400 t/mi^2/year. The minimum rate of long term sediment production for the Garcia compares reasonable well with estimates of long term sediment production in two other north coastal watersheds, the Navarro River basin and the Caspar Creek watershed.

The Garcia River watershed estimated sediment production rate for the period of record should be considered a minimum value because several categories of sediment production have not been quantified by the existing studies. These include surface erosion on skid trails, and erosion and sediment yield from road cutbanks and ditches. In addition, a Level II watershed analysis is needed throughout the more inland portions of the Garcia basin to determine if this long term rate is applicable to the entire watershed.

Results detailed in the OCEI and LP Level II draft reports indicate overall sediment production rates have decreased throughout most of the Garcia basin, especially during the time interval of 1978 to 1997. Much of this reduction is generally attributed to improvements in forest and road management practices. The greatest rate reductions appear to be associated with landslide processes and surface erosion occurring on skid trails. The data suggests we have made only modest gains in reducing the rate of fluvial, mass movement and surface erosion occurring along roads.

Based on the currently available data, this analysis estimates combined mass movement and streambank erosional processes have accounted for between 40% to 60% of the average annual sediment production in the Garcia River watershed over the 45 year period from 1952 to 1997. Consequently, a comparable 40% to 60% of the long term average annual sediment production is associated with fluvial and surface erosional processes largely occurring along roads, skid trails and other bare soil areas.

Of this latter, non-landslide component, our best estimate is that 65-75% of the sediment yield was associated with fluvial erosion at haul road, ranch road and skid trail stream crossings, and gullies along roads, skid trails and on adjacent hillslopes caused by stream diversions and concentrated runoff. The remaining 25-35% is judged to be derived from surface erosion processes (sheet wash and rill erosion) occurring on roads, cutbanks, ditches, skid trails and other bare soil areas. Our best estimate of sediment production attributed to each erosion process is generally supported by the results of the LP Level II analysis completed this past summer.

We believe the majority of management-related, accelerated sediment production and yield associated with fluvial, surface erosion and road-related mass movement erosional processes can be prevented in the future. This assumes the recommended tasks (inventorying and implementation) are fully funded and successfully completed.. The estimated reductions are based on our experience in controlling erosion and sediment yield from managed landscapes in the Pacific Northwest, and especially in north coastal California.

Attaining reductions in the magnitude and frequency of mass movement processes occurring on hillslopes not associated with roads and skid trails is more problematic and subject to debate. However, we believe the increased use of geologic analysis in developing timber harvest plans and improvements being made in modeling watershed processes can lead to a significant reduction in mass wasting processes occurring within management landscapes. This is attainable through the avoidance of highly unstable stream-side areas and the use of modified harvest methods in sensitive geomorphic locations including unstable stream-side geologies, steep inner gorge slopes and steep swales.

The amount of channel-stored sediment in tributaries throughout the lower Garcia River watershed is estimated to be considerably lower today than during the 1950's and 1960's (Surfleet and Koehler, 1997). Much of it has been flushed downstream or completely out of the system. However, this same data indicates that higher order, lower gradient tributary streams still contain appreciable quantities of stored sediment both in the active channel and on adjacent terraces/floodplains. It may take decades to remobilize and route currently stored sediments in the active channel of tributaries and, as a consequence, significant improvements in channel stability and habitat quality may be delayed in many portions of the Garcia. The magnitude and extent to which channel stored sediments are present in tributaries throughout the remainder of the Garcia River watershed is unknown at this time. However, we would encourage exercising careful planning and caution before any efforts are made to embark on extensive channel excavation or modification activities. Monies may be more cost-effectively spent on other erosion prevention endeavors.

An analysis of riparian canopy conditions between 1952 and 1996, utilizing stereo aerial photographs, indicated 10 out of 11 CALWAA units within the Garcia River watershed showed reductions in the amount of stream canopy closure between 1952 and 1966. Between 1966 and 1996, 10 out of 11 CALWAA units showed increases in the amount of canopy closure. In 1996, half of these CALWAA units exhibited closed canopy conditions to within 25% of 1952 conditions. The results are encouraging and suggest efforts to establish streamside protection zones are having some beneficial effects.

Finally, this effort should be considered a preliminary analysis. It describes the relative magnitudes of various erosional processes operating in the watershed over the 45 year period of record. It describes the role of each process in producing and delivering sediment to streams in the Garcia River watershed, as well as how land use activities have likely affected these processes. Without conducting original field work, we have based our analyses and conclusions on the best available data, most of which was recently collected and some of which was still being delivered to us as we prepared this analysis. Site-specific information from the Garcia was supplemented by reviewing the results of other sediment budget studies conducted in wildland watersheds of north coastal California. The fact that new data was provided to us late in the process was a benefit, since it provided valuable insight and clarity on the magnitude and distribution of sediment sources for several portions of the watershed, and has resulted in a higher level of confidence in our conclusions. As new data from additional Level II watershed analysis or sediment source investigations or sediment transport studies becomes available, findings in this document should be updated and revised accordingly.

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