Zayante Area Sediment Source Study

Presented to

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by

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EXECUTIVE SUMMARY

The San Lorenzo River is identified as an impaired waterway under the Federal Clean Water Act for sediment and nutrients affecting drinking water, fisheries and recreational beneficial uses (California Regional Water Quality Control Board Basin Plan Region 3 and CWA). In order to gain compliance, the Regional Water Quality Control Board (RWQCB) and local agencies are required to prepare and implement water quality improvement programs to meet targets for Total Maximum Daily Load (TMDL) of specific pollutants ranging from nitrates and sediment to trash.

Since the 1940's, excessive sediment delivery to the San Lorenzo River has been identified as having a significant negative impact on the water supply and the quality of salmonid habitat (DWR, 1958). This impairment is often attributed to extensive road building and development in the entire San Lorenzo River Drainage Basin over a terrain where natural conditions combine structurally weak geologic materials with a high level of seismic activity, steep hillslopes and high seasonal rainfall. Earlier studies have suggested that disturbance related erosion in the San Lorenzo River has increased sediment production by 2-3 fold over the past 150 years (Brown, 1973; HEA, 1980). On the eastern side of the watershed in the Zayante Area, erosion rates observed in the 1970's suggest sediment production is 4-6 times historic background rates (Brown, 1973; HEA, 1980).

For habitat impairing sediment, the TMDL process begins with identification of pollution problems (in this case sediment sources), followed by quantification of sediment sources, then design and implementation of an erosion control program to reduce sediment input and achieve "target" aquatic habitat conditions to gain "compliance".

The geographic area for this study is limited to the Zayante Area Streams of the Newell Creek, Bean Creek, Zayante Creek, Love Creek, and Lompico Creek drainage basins. The Zayante Creek Watershed has been a consistent source of habitat-impairing fine sediment to the Lower San Lorenzo River (DWR, 1958; Santa Cruz County, 1979 and 1997; City of Santa Cruz Water Department, 1996). Moreover, the geologic, physiographic and land use conditions in the Zayante Area appear to be a reflective sample of the entire San Lorenzo Watershed. However, the most apparent erosive geologic formation within the watershed, the Santa Margarita Sandstone, occurs almost exclusively within the Zayante study area.

Strictly speaking, the San Lorenzo River Sediment Source Study is an attempt to reduce sediment input in ways that measurably improve fisheries production by creating cleaner spawning gravels and more favorable conditions for food production and rearing. Under this premise, reducing sediment sources alone will produce more productive fisheries with improvements reflected in physical measurements of spawning gravels and pool depths (i.e. less fine sediments in spawning riffles and deeper pools). Realistically, these physical conditions are also dictated by factors other than sediment supply. Channel morphology and sediment transport hydraulics may be affected by episodic and variable sediment loading events that occur naturally. Nineteenth century land use disturbances, added to modern activities such as woody debris logjam removal or destruction of stabilizing riparian vegetation, are important influences on fisheries production, independent of sediment supply. Sediment is but one of a number of physical and biotic variables, both natural and human-induced, that influence fishery conditions.

Sediment supply is an important factor that merits attention and action. However, the resource management institutions involved in the TMDL effort should not lose sight of other short term and strategic stream channel enhancement actions that would improve channel morphology (dimensions and pattern) or enhance recruitment of instream large organic debris (i.e. large conifer logs or equivalent structures). These improvements may be as or more effective measures in improving spawning gravels and pool depths than sediment source reduction alone. Conserving existing high quality streams will prevent conditions from getting worse. These actions may produce more immediate results given that the apparent magnitude of an effective sediment reduction program will likely involve large expenditures and widespread landowner and agency cooperation. Specific studies regarding these measures are just beginning (e.g. the City of Santa Cruz San Lorenzo River Lagoon Enhancement Plan, and the San Lorenzo River Watershed Salmonid Enhancement Plan by Santa Cruz County).

In the face of limited data and immense variability, quantifying sediment loading and relating it to specific land use factors must be viewed as *an index of severity* rather than an absolute statement of sediment volume. This stems largely from the variable nature of sediment transport and circumstances of available data. Sediment generation and loading to streams is subject to a high level of variability in time and space, particularly since detachment and transport is dependent upon rainfall and stream flow.

The goal of this study is to provide the following from an analysis of the Zayante Area Streams:

1) Define sediment problems through a description of the processes that generate and distribute sediment through stream systems;

2) Determine the level of disruption caused by different land uses occurring in the Zayante Area Streams;

3) Provide a context to conditions in the San Lorenzo River and implications for a watershed-wide TMDL;

4) Estimate sediment loading for the modern "impaired" watershed conditions and identify current disturbance types (roads, urbanization activities, timber harvests, horse stables, accelerated channel and bank erosion). Identify non-point and point sources of sediment by location;

5) Estimate the volume of sediment sources that are "controllable" and could be eliminated to reduce sediment loading to meet numeric targets;

6) Recommend a prioritized set of sediment reduction measures for implementation with the goal of reducing sediment input to a level that removes the sediment-related "impairment" of beneficial uses as defined by the RWQCB;

7) Develop an aquatic habitat monitoring network of selected streambed sites to characterize streambed conditions and monitor for improvements gained from future erosion control measures; and

8) Recommend a data collection program to monitor sediment related problems to measure the success of treatments and gain a better understanding of overall sediment sources.

Articulating a TMDL is essentially an exercise in estimating a sediment budget, an exercise that scientists approach with trepidation and caution (Reid and Dunne, 1996; EPA, 1998; EPA, 1999). As a basis of a defensible scientific assessment, the focus should be upon the portion of the sediment load that is actually important to impairment. Erosion and sedimentation were certainly part of the primordial landscape and an essential element for building alluvial valleys, beaches, spawning gravels and substrate for abundant anadromous fish that were recorded in early explorer's accounts. Critical distinctions must be made as to which parts of the sediment loading are important. Chronic erosion of a gully incised in sandy soil, that in every rainfall event delivers sand immediately to an adjacent stream, is probably a more significant problem than episodic landslides that occur during periods of high streamflow and deliver a supply of coarse sediments.

It is widely accepted that chronic erosion of fine sediment is damaging to salmonid habitat and that is the focus of this study.

Estimates of impaired sediment load (Load Allocation in TMDL language) were derived from a Geographic Information System (GIS) analysis of road networks, combined with field measurements using erosion rates published for roads and timber harvest plots in the nearby Soquel Demonstration Forest by the California Department of Forestry (Cafferata and Poole, 1993) and adjusted by findings from this study. Erosion from public and private roads and non-timber harvest lands were calculated using sediment yield rates from the same CDF study. Watershed sediment yields derived from stream sediment transport data measured at stream gages on the San Lorenzo River and Zayante Creek were examined against sediment yields derived from erosion rates by each source (HEA, 1980; Brown, 1973; USGS, 1970-1990). The major sources of erosion, identified in the study area, were classified into the following categories:

- THP roads (Hillslope and Inner Gorge);
- Public and private roads (Hillslope and Inner Gorge);
- Active and recent THP parcels;
- Other Urban and Rural Lands;
- Mass wasting; and
- Channel erosion

The erosion and sedimentation rates, modified from sediment yield rates in the CDF study, were then applied to sediment source categories in the Zayante Study Area. The final sediment yields were then integrated over all subwatersheds within the Zayante Study Area to produce an estimated sediment yield for the study area (See Table 4.4). The resulting sediment yield from all categories combined is 115,100 tons yr^{-1}. When divided by the drainage area the estimated sediment yield rate is 2,930 tons mi^{-2} yr^{-1}. This can be compared to the synthetic sediment yield developed from the Zayante Creek gage at Zayante. The gage shows a sediment yield of 5,400 tons mi^{-2} yr^{-1} based on field measurements taken in the early 1970's. Though the estimated sediment yield calculated for this study is substantially lower than gage estimates from Zayante Creek, this lower value makes sense when considering factors such as the trapping efficiency of Loch Lomond reservoir and sediment reduction efforts in recent decades.

As part of a TMDL, estimates of the percent "controllable load" and "remaining load" allocation were made for each sediment source category (**Table ES-1**). In general, these estimates represent a judgment similar to those made in previous investigations from other sediment TMDLs that have been approved by the USEPA (Redwood Creek, 1998; Protocol for Developing Sediment TMDLs, 1999). The "controllable load " reflects a number of qualitative and quantitative factors, including the effectiveness of past erosion control and drainage projects.

The remaining load allocations for the Zayante Study Area, if sediment source reductions are achieved, result in a total sediment yield of 88,400 tons yr^{-1} or 2,250 tons mi^{-2} yr^{-1}. If the reductions are met, fine sediment loading would be reduced to a level 1/2-1/3 of the sediment yield rate measured at Zayante Creek in the 1970's.

For sediment impairment in the San Lorenzo River and Zayante Area Streams, the strategy would be to reduce chronic fine sediment input through implementation of erosion control measures and to monitor stream channel conditions for substrate quality and pool development. To do this, ***numeric targets*** were developed to assess future improvements in streambed substrate quality to a level that removes the impaired condition.

Sediment Source	Area or Length Represented by Source (inner gorge length)	Erosion Rate	Delivery Efficiency	Sediment Delivery Rate to Streams	Sediment Yield (tons/yr)	Percent Controllable	Controllable Load (tons/yr)	Percent of Total Controllable Load	Remaining Load/Allocation (tons/yr)
Hillslope THP Roads and Skid Trails [1]	42.9 miles	413 tons/mi/yr	42%	173 tons/mi/yr	7422	50%	3711	13.9%	3711
Inner Gorge THP Roads and Skid Trails [2]	8.2 miles	413 tons/mi/yr	100%	413 tons/mi/yr	3387	50%	1694	6.3%	1694
Hillslope Public and Private Roads [3]	148.5 miles	120 tons/mi/yr	42%	50 tons/mi/yr	7425	50%	3713	13.9%	3713
Inner Gorge Public and Private Roads [4]	54.1 miles	120 tons/mi/yr	100%	120 tons/mi/yr	6492	50%	3246	12.1%	3246
Active and Recent THP Parcels [5]	4.5 square miles	206 tons/mi^2/yr	42%	87 tons/mi^2/yr	393	30%	118	0.4%	275
Other Urban and Rural Lands [6]	35.7 square miles	1310 tons/mi^2/yr (50% classified as mass wasting)	42%	550 tons/mi^2/yr (50% classified as mass wasting)	21615	30%	6485	24.2%	15131
Mass Wasting (Natural and Human Caused) [7]	39.3 square miles	3570 tons/mi^2/yr	42%	1500 tons/mi^2/yr	58950	10%	5895	22.0%	53055
Channel Erosion [8]	23.5 miles	400 tons/mi/yr	100%	400 tons/mi/yr	9432	20%	1886	7.1%	7546
Estimated Total					**115116**	**23%**	**26747**	**100%**	**88369**

Measured Sediment Yield @ Zayante Gage (tons/mi^2/yr)	**5400** [9]
Estimated Sediment Yield for Study Area (in tons/mi^2/yr)	**2930**
Expected Sediment Yield after Erosion Control Treatments (in tons/mi^2/yr)	**2249**

Table ES-1: Sediment Yield and Source Load Allocation for the Zayante Study Area. Sediment yields were generated from values averaged over each subwatershed (Table 4.3) and adjustments based on known sediment sources and best professional estimates. Percent controllable was based on BMP's and current sediment source control methods. Since length or area measurements are rounded, calculations may not produce exact values.

***** Footnotes on Following Page***

Footnotes for Table ES-1

1) Erosion rates from Hillslope and Ridge THP Roads and Skid Trails is taken from CDF (1993) estimates for Forestry Roads Currently in Use with a delivery efficiency assumed to be 42%. Soil bulk density was assumed to be 85 lbs/ft^3.

2) Erosion rates from Inner Gorge THP Roads and Skid Trails is taken from CDF (1993) estimates for Forestry Roads Currently in Use with a delivery efficiency assumed to be 100%. Soil bulk density was assumed to be 85 lbs/ft^3.

3) Erosion rate from Hillslope and Ridge Public and Private Roads was estimated using a combination of road surveys conducted by SH&G and CDF(1993) estimates for Non-Forestry Roads with a delivery efficiency assumed to be 42%. SH&G estimated erosion rates from road cuts using a USDA-NRCS method. This rate was then tripled to account for erosion from road surfaces, inside ditches and road shoulders producing an erosion rate of 120 tons/mi/yr, which was comparable to the CDF rate.

4) Erosion rate from Inner Gorge Public and Private Roads was estimated using a combination of road surveys conducted by SH&G (see Footnote #3) and CDF(1993) estimates for Non-Forestry Roads with a delivery efficiency assumed to be 100%.

5) Erosion from THP lands taken from CDF (1993) estimates of 0.28 yd3/ac/yr, which converts to a sedimentation rate of 87 tons/mi2/yr (assuming 42% delivery efficiency). This estimate was assumed to only include surface erosion features such as rilling, gullying and sheetwash. Soil bulk density was assumed to be 85 lbs/ft^3.

6) Erosion rates from Other Urban and Rural Lands were estimated from sedimentation rates in Loch Lomond Reservoir (Brown, 1973). This estimate was assumed to include surface erosion features as well as erosion from mass wasting from an assortment of land uses including urban and rural residential and timber harvests. Therefore, 50% of the estimated value was subtracted from this category and added to the mass-wasting category.

7) Sediment Yield from Mass Wasting was estimated by taking 50% of the value from Other Urban and Rural Lands and adding estimated erosion rates from known active landslides in the project area. An additional amount was also added to account for unknown mass wasting sources. This category also accounts for mass wasting from timber lands and roads that was not accounted for in Categories 1-5.

8) Sediment Yield from Channel Erosion is assumed to come from two sources, bank erosion (assumed to be 60% of the process) and channel downcutting (assumed to be 40% of the process). Bank erosion was estimated based on field surveys conducted by Don Alley. The total cut area for the survey was calculated and multiplied by an assumed retreat rate of 0.5 feet per year. The volume was then divided by the total stream mileage surveyed to produce a sediment yield per mile of stream. Since no data are available for rates of channel downcutting in the Santa Cruz Mountains, channel downcutting was assumed to amount to 40% of the Channel Erosion sediment yield. The combined value of bank erosion and channel downcutting was converted to tons/mi^2/yr by multiplying by the stream mileage in the studied watersheds and dividing by the total drainage area. Soil bulk density was assumed to be 100 lbs/ft^3.

9) Based on average annual synthetic suspended sediment load estimate from Zayante Creek, based on data collected in the early 1970's, plus an additional 10% to account for bedload (see Appendix C in Technical Addendum).

The targets chosen to assess improvement in impaired conditions are ***embeddedness*** and ***percent fines less than 4 mm.*** Based on the scientific literature, the target for embeddedness was set at 25% for particles 16 mm in size or greater; the target for percent fines at 30%. The targets can be modified in the future as new data is developed.

To reduce chronic fine sediment input into streams, erosion reduction programs can be developed that target erosion sources within different environmental settings:

SETTING 1: IDENTIFIED POINT SOURCES

SETTING 2: INNER GORGE ROADS IN SANDY SOILS

SETTING 3: INNER GORGE ROADS OUTSIDE SANDY SOILS

SETTING 4: SEDIMENT LOADS FROM ROADS ON HILLSLOPES

SETTING 5: NON-POINT SOURCES FROM URBAN AND RURAL LANDS

The projected reductions in sediment loads from each setting are shown in **Table ES-2** based on the results shown in **Table ES-1** and a GIS analysis of the land use features within each setting.

Table ES-2 Controllable Chronic Fine Sediment Loads for Zayante Area Streams

Setting	Area or Length Represented by Source	Controllable Load (tons year^{-1})	Percent of Controllable Load
Point Sources	N/A	1,470 tons yr^{-1}	5.5%
Inner Gorge Roads in sandy soils	9.7 miles	766 tons yr^{-1}	2.9%
Inner Gorge Roads outside sandy soils	52.6 miles	4,174 tons yr^{-1}	15.6%
Hillslope roads: THP, public and private	191.4 miles	7,424 tons yr^{-1}	27.8%
Urban, Rural and THP Lands	35.7 square miles	6603 tons yr^{-1}	24.7%
Concurrent treatment of mass wasting load resulting from point source, surface erosion and drainage treatments.[1]	N/A	4,425 tons yr^{-1}	16.5%
Channel and Streambank Erosion	23.5 miles	1,886 tons yr^{-1}	7.1%
Total	**N/A**	**26,747 tons yr^{-1}**	**100%**

[1] Chronic fine sediment sources from mass wasting will be decreased by improved drainage systems that reduce surface erosion. Note that only a portion of the mass wasting load is chronic fine sediment

Erosion and sediment control in the San Lorenzo River Watershed and Zayante Area is the subject of several local, state and federal regulations and programs. The erosion control recommendations stemming from this report are directed towards chronic fine sediment sources and their location relative to impaired fish habitat. There are obvious tie-ins to existing programs and an effort was made to tailor recommendations to fit and augment existing programs and not create new ones. In basic terms, the recommendations of this report are primarily directed towards the Santa Cruz County Planning Department regulatory efforts in riparian habitat management and erosion control, the Environmental Health Department in Watershed Planning and Water Quality Protection Planning, and Public Works Department in road maintenance and erosion control. Other agencies (the City of Scotts Valley, the Santa Cruz County Resource Conservation District, U.S. Department of Agriculture Natural Resources Conservation Service, California Department of Forestry, California Department of Fish and Game, National Marine Fisheries Service, Regional Water Quality Control Board) also have roles in reducing fine sediment in the Zayante Area.

The recommendations presented in **Table ES-3** focus upon reduction of chronic fine sediments generated from road networks and parcels. Obvious and known "Point Sources" of fine sediment, which should be the first priority for investigations for treatment, are called out under the appropriate recommendation category. For "non-point source" areas, further data refinements are necessary to locate and prioritize specific projects, however development and implementation of Best Management Practices (BMP's) for road maintenance could move forward immediately. The recommendations are incorporated into separate public and private road and land improvement programs and include measures addressing control of sediment during emergency repairs, funding for upgrading existing road networks and funding and implementing BMP's. It must be emphasized that future data collection through the other programs and monitoring could lead to revisions in treatment recommendation and numeric targets presented in this report.

Recommendation A **Improve Geomorphic and Hydrologic Data with Regard to Impacts to Fisheries Resources**		
A.1	Refine Geomorphic Data in Streams	A more refined erosion survey should be combined with an assessment of physical habitat and geomorphic conditions in stream channels so that sediment reduction efforts can most benefit reaches were spawning and rearing habitat occur.
A.2	Measure Streamflow	Monitoring stream flow reductions would help improve the understanding of aquatic habitat quality and whether groundwater development over the past 30 years has impacted surface flow.
A.3	Establish and Maintain Channel Monitoring Programs to Measure Sediment Impairment and the Effectiveness of Sediment Control Measures	Very little data has been collected to document geomorphic conditions that influence impairment of bed conditions by fine sediment. The Steelhead Enhancement Plan being developed through funding from the California State Coastal Conservancy and the County of Santa Cruz is setting up a network of 15 monitoring stations covering a range of stream types, locations and conditions. This network should be maintained in the future in order to assess the effectiveness of sediment reductions programs.
Recommendation B **Public Agency Measures to Reduce Sediment from Private Lands**		
B.1	Amend Santa Cruz County Erosion Control Ordinance to Improve Sediment Reduction in Sandy Soils	The Santa Cruz County erosion control ordinance should be amended to further prevent erosion and sediment delivery from land uses occurring within the area underlain by the Santa Margarita Formation. The City of Scotts Valley should also implement this ammendment as part of their standard erosion control ordinances.
B.2	Develop and Anlayze Alternatives to Hard Bank Protection Structures	Impacts from hard bank protection structures should be analyzed and non-structural solutions such as securing riparian buffers or restoring stable channel geometry should be investigated. Moneys should be made available to purchase eroding private properties in riparian corridors and an education program should be developed.
B.3	Reduce Erosion from Point Sources	Significant "point sources" of erosion from parcels identified in the study area include the Mount Hermon slide, McEnery Road, Skypark, Rancho Rio and Monte Fiore. These areas require engineering feasibility studies and projects aimed at reducing fine sediment production.
Recommendation C **Implement a Santa Cruz County Road Improvement Project to Control Sediment Loading**		
C.1	Create County Road Database to Prioritize Projects for Implementation	An erosion survey of public roads should be conducted starting with inner gorge roads in sandy soils followed by roads in other settings prioritzed by their erosion risk. The road surveys should document all road features (road cuts, drainage ditches and crossings, shoulders and surfaces) and generate data that can be used to estimate sediment yields as an index of sediment generation. This database, in combination with the proximity to sensitive stream habitat areas, should be used to develop treatment priorities.
C.2	Augment Emergency Road Repair Fund	Develop a road upgrade fund to supplement FEMA emergency repair funding or amend FEMA policies so that problem roads could be upgraded to reduce sediment loading and improve road reliability. Augmenting FEMA funding would help to implement a long-term fix instead of in-kind replacement of problem roads.
C.3	Develop a Road Maintenance BMP Program and Develop Spoils Disposal Sites	Develop road Best Management Practices (BMP's) to ensure that all feasible measures are taken to reduce erosion and prevent road maintenance sediments from entering waterways. A key component of this program would be to develop a spoils disposal site where sediment removed from roads and ditches during road maintenance can be deposited safely.

Table ES-3: Zayante Area Sediment Source Study - Controllable Load Erosion Reduction Recommendations

Recommendation D Implement a Private Roads Sediment Reduction Program		
D.1	Provide Cost Sharing for Private Road Improvement	There is little incentive for individuals and homeowner associations to improve the conditions of private roads unless a new project is proposed or an enforcement action is necessary. Developing a program to provide cost sharing for private road improvement would allow for improvements in erosion and access problems.
D.2	Develop Private Road Database, Treatment Priorities and Strategies	A inventory of private roads should be compiled including documentation of all road features (road cuts, drainage ditches and crossings, shoulders and surfaces) in order to upgrade the existing public road erosion rate database and prioritize projects.
D.3	Implement Private Road BMP's	A program of BMP's for road maintenance should be designed and implemented on private roads similar to the proposed program for public roads. The focus should be on drainage control, upgrading road surfaces, emergency repair work and spoils storage and disposal.
D.4	Implement Private Road and Land Education Program	Workshops and other methods of public outreach should be developed to educate the public about available programs and useful information on road maintenance and erosion control that would reduce sediment input into waterways.
D.5	Improve Enforcement of Erosion Control Ordinance, as needed, for Private Roads and Lands	The Santa Cruz County Erosion Control Ordinance has provisions requiring the responsible parties to repair and alleviate erosion problems that are deemed severe. Enforce provisions of the ordinance where property owners are unresponsive and provide outreach assistance and financial assistance, when feasible.
Recommendation E Improve Timber Harvest Roads		
E.1	Document and Improve THP Access Roads	Timber Harvest Plans (THP) should include information regarding harvest access routes, surfaces and mileage to the nearest paved county road along with culvert locations and a description of road conditions. This information would be valuable in assessing the overall impact a timber harvest will have on existing road networks and allow for reasonable improvements to be made to roads in substandard condition.
E.2	Surface Year-Round Access Roads	Encourage that all permanent and year-round access roads beyond the THP parcel be surfaced after harvest completion with rock, asphalt or chipseal, as appropriate.
E.3	Maintain Unsurfaced Roads and Skid Trails	Require that all unsurfaced roads and skid trails be seeded with an appropriate grass mix, slash packed, or mulched with chipped slash material following seasonal harvesting activities. Use rolling dips instead of water bars where roads are subject to trespass or regular travel.
E.4	Upgrade Stream Crossings	Stream crossings on THP parcels should be identified and mapped with the intention of replacement or removal if they cannot pass 100-year flows for Class 1 or 2 streams or 50-year flows for Class 3 streams. Culvert designs should include fail safe measures to accomodate cullvert overflow without causing massive road failures.
E.5	Extend Monitoring Period and Upgrade THP Road Maintenance after Harvests	Monitoring and maintenance plans for THP roads should be extended to 5 years to assess and repair poor road drainage conditions that may lead to increased surface erosion and/or mass wasting.
E.6	Identify and Fix Problems Associated with Legacy Roads	New THP's should identify problematic legacy roads within WLPZ's, remove them and revegetate the area with appropriate native species.
E.7	Engineering Geologist should Review Grading on Inner Gorge Slopes	A Certified Engineering Geologist should review and approve any THP plan proposed for inner gorge slopes.

Table ES-3 continued

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1.0 Introduction and Problem Statement

The San Lorenzo River **(Figure 1.1)** is identified as an impaired waterway under the Federal Clean Water Act for sediment and nutrients affecting drinking water, fisheries and recreational beneficial uses (California Regional Water Quality Control Board Basin Plan Region 3 and CWA). In order to gain compliance, the Regional Water Quality Control Boards (RWQCB) and local agencies are required to prepare and implement water quality improvement programs to meet targets for Total Maximum Daily Load (TMDL) of specific pollutants ranging from nitrates and sediment to trash.

Section 303(d) of the Clean Water Act requires that "Each state shall identify these waters within its boundaries for which effluent limitations…are not stringent enough to implement any water quality standards applicable to such waters." The CWA also requires states to establish a priority ranking for waters on the 303(d) list of impaired waters and establish Total Maximum Daily Loads (TMDL) for impaired waters. The San Lorenzo River has been identified as a sediment-impaired waterbody in the California 303(d) list. The County of Santa Cruz, the California Department of Fish and Game, and the State Water Resources Control Board have identified areas of sandy erodible soils, that comprise much of the watershed, as the most significant source of habitat impairing sediment. Both the mainstem San Lorenzo River and the tributary Lompico Creek (a subwatershed in the Zayante project area) are listed in the State 303(d) list as impaired waters for sediment/siltation (Shingle Mill Creek, Carbonera Creek and the San Lorenzo River Estuary are also listed for sediment/siltation). Other San Lorenzo River tributary streams are not called out specifically in the list, but share the same conditions that warrant 303(d) listing.

Since the 1940's, excessive sediment delivery to the San Lorenzo River has been identified as having a significant negative impact on the water supply and the quality of salmonid habitat (DWR, 1958). Several studies have found that the quantity of stream flow and excessive sediment loading are limiting factors in fisheries production (Shapavolov and Taft, 1954; Kelley and Dettman, 1981; Smith and Alley, 1982). This impairment is often attributed to extensive road building and development in the entire San Lorenzo River Drainage Basin over a terrain where natural conditions combine structurally weak geologic materials with a high level of seismic activity, steep hillslopes and high seasonal rainfall. Earlier studies have suggested that disturbance related erosion in the San Lorenzo River has increased sediment production by 2-3 fold over the past 150 years (Brown, 1973; HEA, 1980). On the eastern side of the watershed in the Zayante Area, erosion rates observed in the 1970's suggest sediment production 4-6 times historic background rates (Brown, 1973; HEA, 1980).

Added to the erosion-prone "natural" geologic conditions, recent disturbances over a legacy of late 19th century and early 20th century disturbances include extensive clear-cut

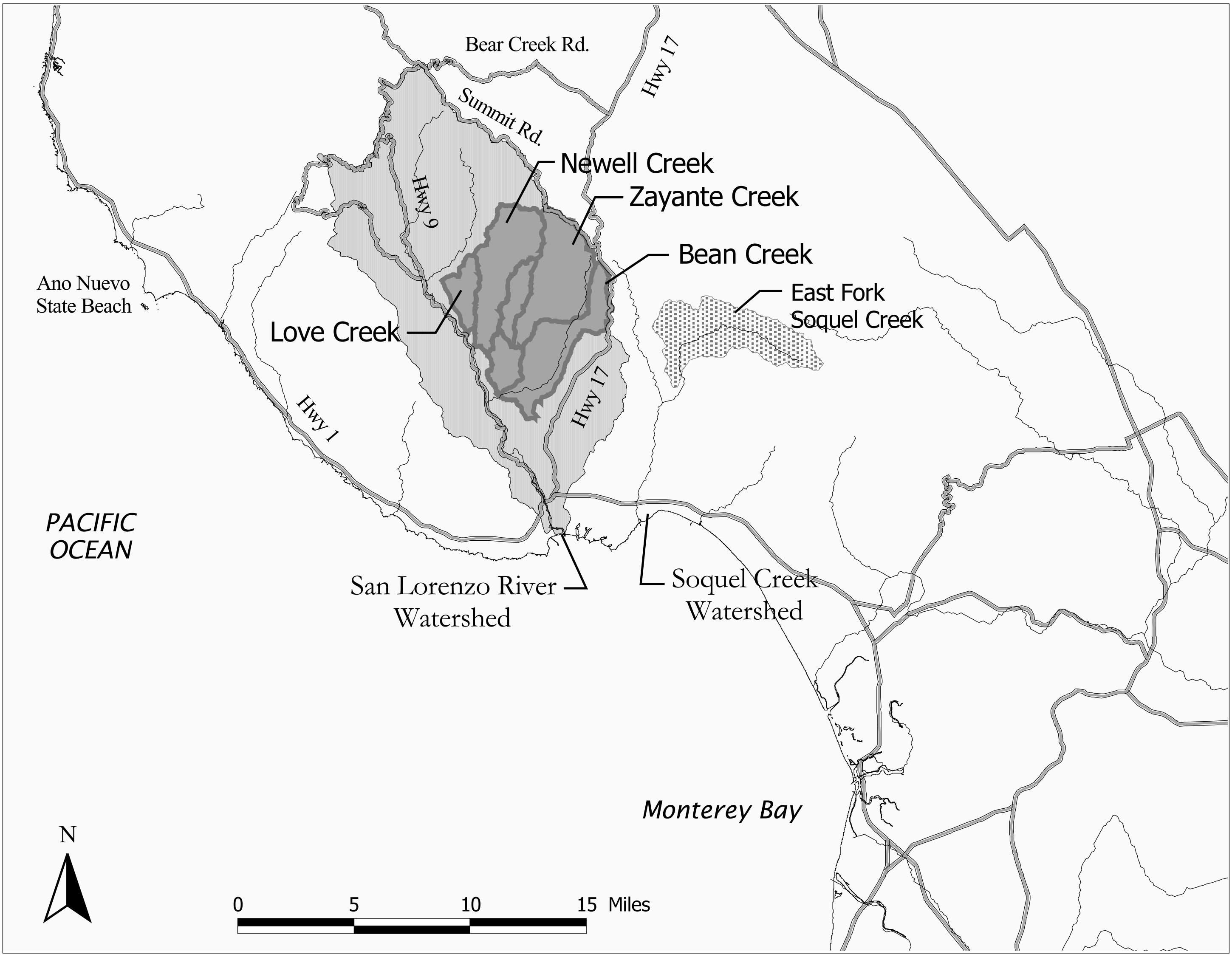
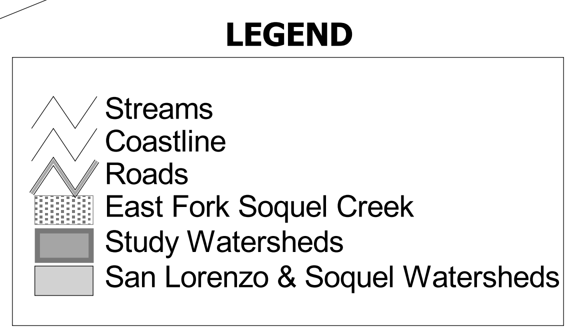


Figure 1.1: Regional location map for watershed study areas along the central California coast. San Lorenzo River and Soquel Creek watersheds on the north side of Monterey Bay are shaded gray. Detailed study areas (Love, Newell, Zayante & Bean Creeks) are darker gray. East Fork of Soquel Creek shown in black.
Wide gray lines show major roads and narrow black lines show streams.



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logging, water diversions, stream channelization and destruction of fisheries by direct dumping of sawdust, sewage and refuse into the river and streams. The history of land disturbance, interacting with natural physiographic conditions, presents a complex challenge to develop an effective sediment source reduction program and reduce sediment input to "natural" background levels. Relating the outcome of sediment reduction to biotic and ecosystem processes, with an end to improve aquatic productivity, presents further challenges that are beyond the scope of this sediment source study.

Regardless of these complexities, abundant evidence of erosion and sedimentation and a connection to the quality of physical habitat is clear. Many of the observed problems in the San Lorenzo River concur with technical literature in that chronic fine sediment sources are a significant problem to fish production and survival (Terhune, 1958; McNeil and Ahnell, 1964; Vaux, 1962; Cooper, 1965; Daykin, 1965; Wickett, 1954; Alderdice et al, 1958; Shumway et al, 1964; Brannon, 1965). The sediment impact connection to fisheries is demonstrated where large amounts of sand are delivered at point sources - such as the large slide area of Bean Creek - causing physical conditions for fish and aquatic habitat decline immediately downstream. The magnitude of excessive non-point source sediment over the entire watershed is understood when the number and density of unimproved roads criss-crossing the watershed is examined along with measurements of erosion rates from roads. These two observations cannot substitute for a fully quantified assessment of the sediment problems with a detailed data set, which unfortunately rarely exists. When considered in the face of declining fisheries, most notably endangered listings of salmonids, the conclusion must be drawn that sediment sources and erosion control must be addressed. A program to rectify sediment pollution problems must be guided by the most reasonable direction drawn from available data and success must be measured quantitatively.

1.1 Objectives of Investigation

As stated above, the designation of the San Lorenzo River as an impaired water body necessitates improvement under the Clean Water Act. For habitat impairing sediment, the TMDL process begins with identification of pollution problems (in this case sediment sources), followed by quantification of sediment sources, then design and implementation of an erosion control program to reduce sediment input and achieve "target" aquatic habitat conditions to gain "compliance". Monitoring must be provided through the implementation period to adjust management activities and to measure progress towards target goals (**Figure 1.2**). Estimates of sediment sources can also be refined as data is collected.

Due to limited funding, the geographic area for this study was confined to the Zayante Area Streams of the Newell Creek, Bean Creek, Zayante Creek, Love Creek, and Lompico Creek **(Figure 1.3)** drainage basins. These streams have been the subject of previous sediment and anadromous fisheries studies, some specifically related to the previously proposed Zayante Dam, and thus the data available is relatively abundant.

Phased TMDL Plan for Sediment

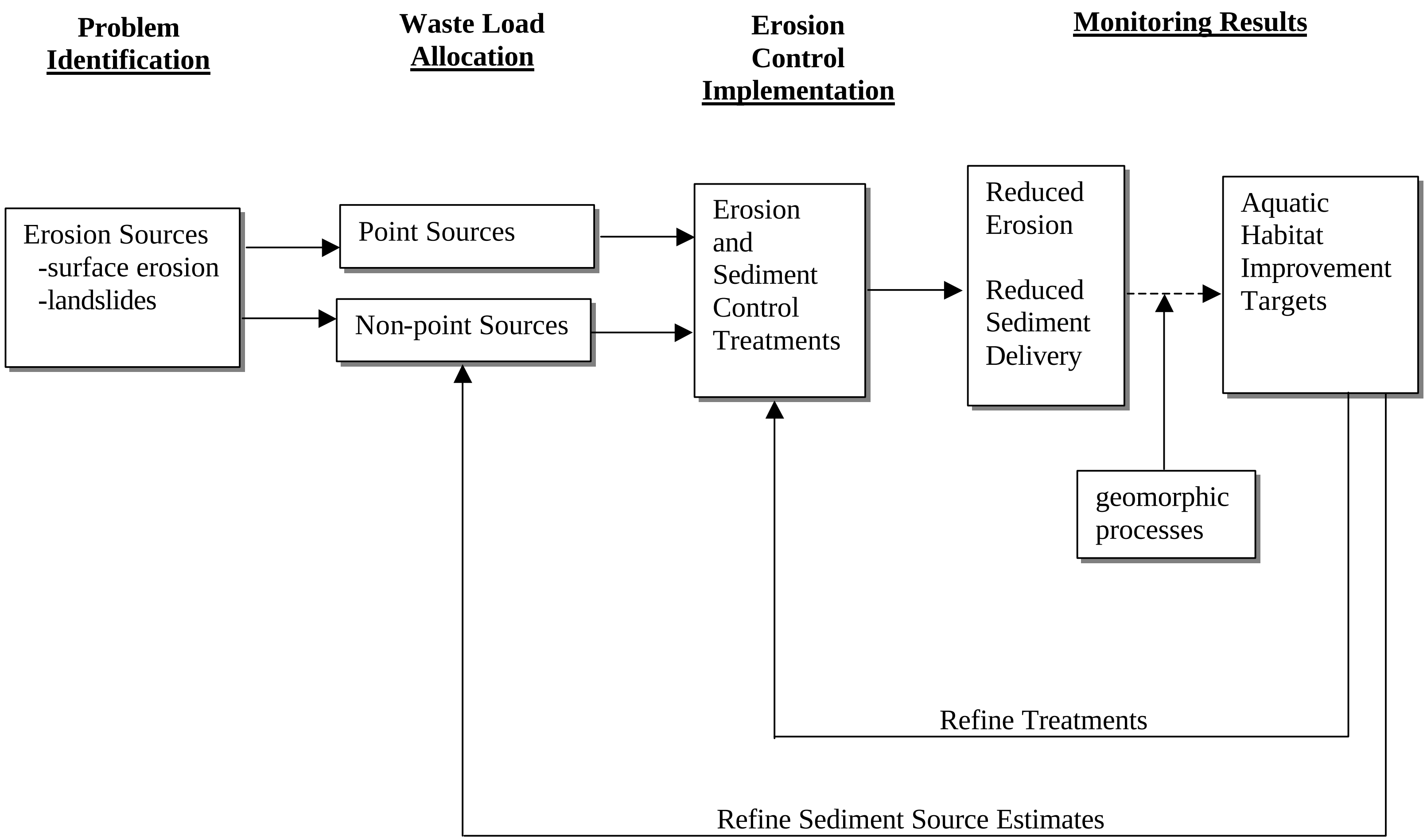

Figure 1.2: Flowchart describing the "phased" approach to a TMDL for the Zayante Study Area

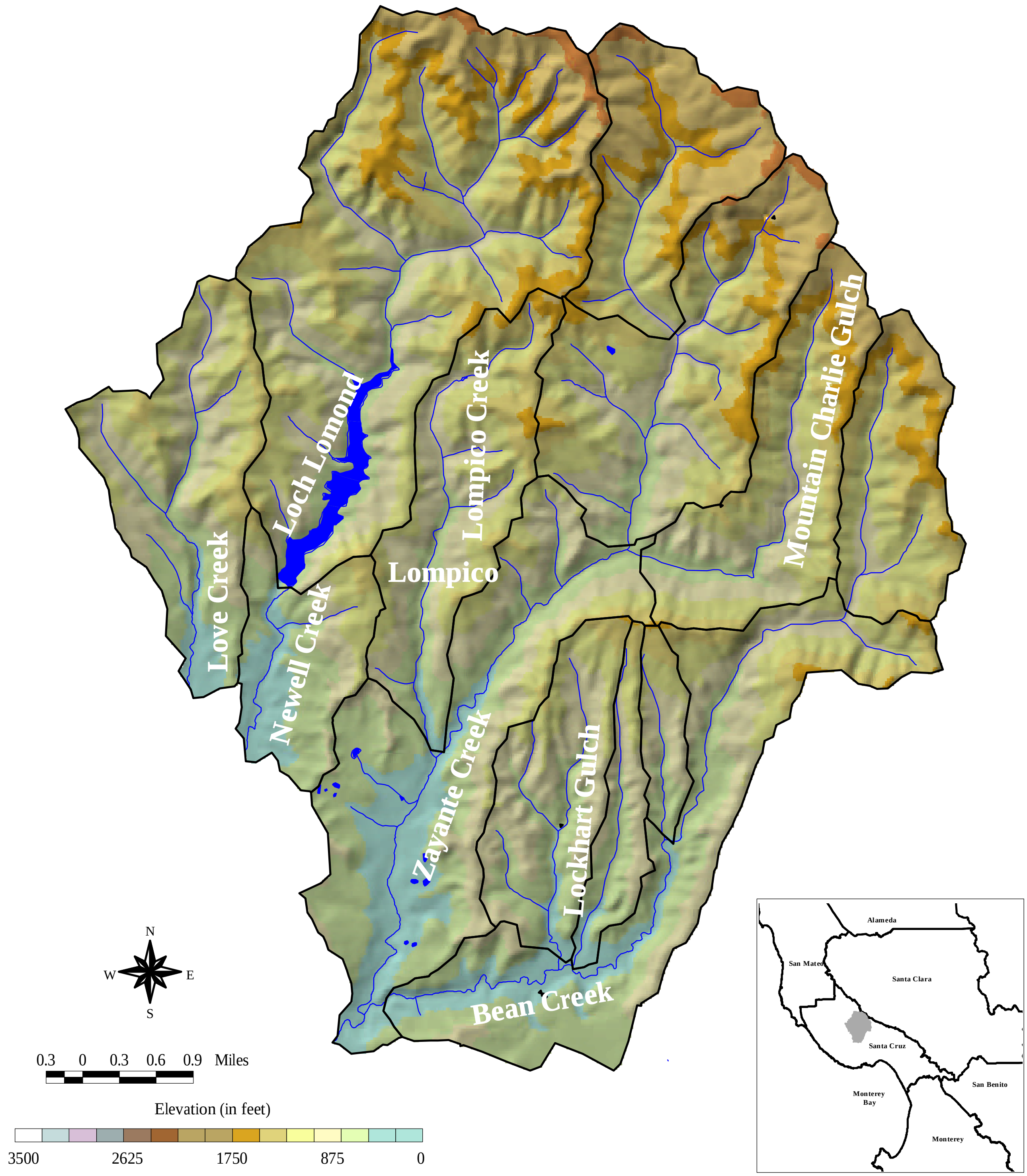

Figure 1.3: Location Map of Zayante, Newell, and Love Creeks with major subwatersheds delineated.

The Zayante Creek Watershed has been a consistent source of habitat-impairing fine sediment to the Lower San Lorenzo River (DWR, 1958; Santa Cruz County, 1979 and 1997; City of Santa Cruz Water Department, 1996). Moreover, the geologic, physiographic and land use conditions in the Zayante Area appear to be a reflective sample of the entire San Lorenzo Watershed. However, the most apparent erosive geologic formation within the watershed, the Santa Margarita Sandstone, occurs almost exclusively within the Zayante study area.

The goal of this study is to provide the following from an analysis of the Zayante Area Streams:

1) Define sediment problems through a description of the processes that generate and distribute sediment through stream systems;

2) Determine the level of disruption caused by different land uses occurring in the Zayante Area Streams;

3) Provide a context to conditions in the San Lorenzo River and implications for a watershed-wide TMDL;

4) Estimate sediment loading for the modern "impaired" watershed conditions and identify current disturbance types (roads, urbanization activities, timber harvests, horse stables, accelerated channel and bank erosion). Identify non-point and point sources of sediment by location;

5) Estimate the volume of sediment sources that are "controllable" and could be eliminated to reduce sediment loading to meet numeric targets;

6) Recommend a prioritized set of sediment reduction measures for implementation with the goal of reducing sediment input to a level that removes the sediment-related "impairments" of beneficial uses as defined by the RWQCB;

7) Develop an aquatic habitat monitoring network of selected streambed sites to characterize streambed conditions and monitor for improvements gained from future erosion control measures; and

8) Recommend a data collection program to monitor sediment related problems to measure the success of treatments and gain a better understanding of overall sediment sources.

Local agencies, watershed organizations and industry groups, including the sponsor of this study, the Santa Cruz County Environmental Health Services (EHS), are participating in developing the San Lorenzo River TMDL and this study of Zayante Area

Sediment Sources. These participants include the Santa Cruz County Resource Conservation District (SCRCD) and the Coastal Watershed Council (CWC) (a citizens group focused on water quality monitoring), who will have roles in implementing erosion control projects and monitoring their success. Representatives of the timber industry and the Santa Cruz County Public Works Department are also participating since some of their activities in the watershed could be affected. A Technical Advisory Committee (TAC) consisting of representatives of these groups is helping to design and manage this study, and foster cooperation.

This study of sediment generation in the Zayante Area Streams is also part of an overall San Lorenzo River Watershed Management Study. The collection, compilation, and analysis of technical data and preparation of this report (and technical addendum) was conducted by Swanson Hydrology and Geomorphology (SH&G) under contract with the Santa Cruz County EHS. SH&G serves as the principal scientific advisor to the TAC and oversees the work of other study participants including the Coastal Watershed Council who are separately contracted with the EHS to conduct bed conditions monitoring and portions of the public road surveys. Several UCSC interns and researchers assisted with initial road surveys, GIS dataset preparation and spatial data analysis.

1.2 Technical and Regulatory Concepts and Assumptions

Strictly speaking, the San Lorenzo River Sediment Source Study is an attempt to reduce sediment input in ways that measurably improve fisheries production by creating cleaner spawning gravels and more favorable conditions for food production and rearing. Under this premise, reducing sediment sources alone will produce more productive fisheries with improvements reflected in physical measurements of spawning gravels and pool depths (i.e. less fine sediments in spawning riffles and deeper pools). Realistically, these physical conditions are also dictated by factors other than sediment supply. Channel morphology and sediment transport hydraulics may be affected by episodic and variable sediment loading events that occur naturally. Nineteenth century land use disturbances, added to modern activities such as woody debris logjam removal or destruction of stabilizing riparian vegetation, are important influences on fisheries production, independent of sediment supply. Sediment is but one of a number of physical and biotic variables, both natural and human-induced, that influence fishery conditions.

Sediment supply is an important factor that merits attention and action. However, the resource management institutions involved in the TMDL effort should not lose sight of other short term and strategic stream channel enhancement actions that would improve channel morphology (dimensions and pattern) or enhance recruitment of instream large organic debris (i.e. large conifer logs or equivalent structures). These improvements may be as or more effective measures in improving spawning gravels and pool depths than sediment source reduction alone. Conserving existing high quality streams will prevent conditions from getting worse. These actions may produce more immediate results given that the apparent magnitude of an effective sediment reduction program will likely involve large expenditures and widespread landowner and agency cooperation. Specific studies regarding these measures are just beginning (e.g. the City of Santa Cruz San Lorenzo River Lagoon Enhancement Plan, and the San Lorenzo River Watershed Salmonid Enhancement Plan by Santa Cruz County RCD).

In the face of limited data and immense variability, quantifying sediment loading and relating it to specific land use factors must be viewed as *an index of severity* rather than an absolute statement of sediment volume. This stems largely from the variable nature of sediment transport and circumstances of available data. Sediment generation and loading to streams is subject to a high level of variability in time and space, particularly since detachment and transport is dependent upon rainfall and stream flow. The Mediterranean climate of Santa Cruz County is subject to winter season rains with a high degree of variability given the El Nino/La Nina phenomena. Quantifying specific causes and sources is fraught with difficulty and a lack of confidence in available data. Through measurement of erosional features (road cuts, rills, gullies, landslides), application of erosion rates measured in other comparable areas, and professional judgment of cause, *an index of severity* can be reasoned to prioritize projects.

Articulating a TMDL is essentially an exercise in estimating a sediment budget, an exercise that scientists approach with trepidation and caution (Reid and Dunne, 1996; EPA, 1998; EPA, 1999). As a basis of a defensible scientific assessment, the focus should be upon the portion of the sediment load that is actually important to impairment. Erosion and sedimentation were certainly part of the primordial landscape and an essential element for building alluvial valleys, beaches, spawning gravels and substrate for abundant anadromous fisheries that were recorded in early explorer's accounts. Critical distinctions must be made as to which parts of the sediment loading are important. Chronic erosion of a gully incised in sandy soil, that in every rainfall event delivers sand immediately to an adjacent stream, is probably a more significant problem than episodic landslides that occur during periods of high streamflow and deliver a supply of coarse sediments.

It is widely accepted that chronic erosion of fine sediment is damaging to salmonid habitat and that is the focus of this study.

1.3 Overview of Study Methods

Study methods are described in an abbreviated form in this section to give an overview. More detailed method discussions are provided later in this report, and in the accompanying technical addendum, to describe exactly how results of individual elements were derived through data analysis in this report.

1.3.1 Background and Problem Definition

Information and data describing the pertinent environmental conditions in the San Lorenzo River and Zayante Area Stream watersheds for this study were derived from existing reports, field observations and technical literature. Most notable of these are previous studies focused on sediment pollution in the subject streams, including the San Lorenzo River Watershed Management Plan (Santa Cruz County, 1979) and its update (Balance Hydrologics, 1998). Reports by Kelly and Dettman (1981) and Alley (1998) describe fisheries habitat conditions and were used to substantiate specific aspects of impairment. New field observations, combined with the experiences of the authors, first as students and later as consultants in the San Lorenzo River Watershed over the past 20 years, were integrated. The background and problem definition sections include descriptions of land use and land use history important to defining sediment sources for quantification and to assess the feasibility of treatment.

1.3.2 Quantification of Sediment Sources and Sediment Source Reduction Needs

The next step involves quantification of sediment sources that are leading to the impaired condition for aquatic habitat. It has been concluded in previous studies that sediment impairment for aquatic habitat is related to sediment grain sizes less than 3 mm (Koski, 1981). In this study, estimates of impaired sediment load (Load Allocation in TMDL language) were derived from a Geographic Information System (GIS) analysis of road networks, combined with field measurements using erosion rates published for roads and timber harvest plots in the nearby Soquel Demonstration Forest by the California Department of Forestry (Cafferata and Poole, 1993). Erosion from public and private roads and non-timber harvest lands were calculated using sediment yield rates from the same CDF study. Watershed sediment yields derived from stream sediment transport data measured at stream gages on the San Lorenzo River and Zayante Creek were examined against sediment yields derived from erosion rates by each source (HEA, 1980; Brown, 1973; USGS, 1970-1990).

An initial estimate of the sediment source reduction necessary to eliminate impairment was developed using field data, reports and the experiences of the consultants and agency staff. This involves implementation of a broad range of erosion control actions, from treating point and non-point sources, to implementing Best Management Practices (BMPs) for road maintenance. These projects should be designed and implemented as pilot projects by the RCD, Santa Cruz County and other agencies. The pilot projects would provide examples for implementing erosion control on private lands. Priority projects should be sited where measurable improvements in aquatic habitat will be realized. The overall program necessary to reduce the impaired sediment load to an acceptable level will not be known until available data improves through monitoring. As described above, other influences independent of sediment supply are fundamental to aquatic habitat quality.

1.3.3 EROSION CONTROL PROGRAM DEVELOPMENT, PRIORITY AND MONITORING

Successful regulatory retraction of the "impaired" designation means achievement of measurable improvements in the physical condition of aquatic habitat such as spawning gravel quality and increased pool depth. This will likely be achieved through erosion and drainage control projects on the public and private road networks that criss-cross the watershed, stabilization of large landslides in sandy parent material and development of instream structures to improve sediment sorting and encourage pool scour.

High quality spawning gravel can be defined as a large patch of gravel that remains free enough of fine sediment to successfully support egg incubation and fry emergence. Fine sediment filling the interstitial spaces between the gravel reduces oxygen flow to the eggs resulting in either suffocation or early emergence that can reduce the success of survival. Deposits of coarse gravel, cobbles and boulders provides rearing habitat, escape cover and habitat for aquatic invertebrates (a main source of food for salmonids) unless fine sediments (finer gravel and smaller sizes) fill the interstitial spaces. Pool depth and quantity are important variables in salmonid life cycles for rearing fish.

To develop criteria for monitoring success, a monitoring program was developed to measure substrate sizes and pool depths at key locations. This work, already underway and initiated by Santa Cruz County and the Coastal Watershed Council (CWC) volunteer program, was examined and modified to address "target" values for sediment load reduction. Previous work measuring and characterizing substrate in the Zayante Area streams was reviewed and incorporated as background information.

The following sections of this report include analysis, results and recommendations, and a more detailed description of methods, where appropriate. The majority of the background environmental setting, and sediment calculation methodology is included in the technical addendum.

2.0 Background, Impairment Problem Definition and Context for this Study

2.1 General Background Information

(Note: In interest of brevity, detailed information regarding watershed geology and other physiographic factors important for sediment production is found in the Technical Addendum: Appendices A, B, C and D).

2.1.1 CLIMATE

Rainfall in the San Lorenzo River Watershed averages about 45 inches per year and is highly variable, both temporally and spatially (*see Technical Addendum, Appendix A for more detail*). Two important themes in the description of sediment supply are that rainfall is the driving force for sediment production and yearly rainfall amounts are highly variable. Wet years usually include intense rainfall periods that trigger landslides and high erosion rates.

2.1.2 GEOLOGY

The San Lorenzo River Watershed is underlain by predominately marine sedimentary rocks that are deeply weathered and subject to erosion by landsliding and surface erosion. In addition, the watershed is located at the boundary of two major tectonic plates where crustal uplift, deformation, and seismic activity are high. Uplift and faulting create conditions where highly erodible rocks and soils occur on steep slopes adjacent to rapidly downcutting streams (*see Technical Addendum, Appendix A for more detail*). The Zayante Area, situated at the eastern side of the San Lorenzo River Watershed, is underlain by rocks that are prone to landsliding and, in the case of the Santa Margarita Sandstone, highly vulnerable to surface erosion. Recent alluvial and colluvial deposits are also subject to rapid surface erosion and landsliding, especially when disturbed by development.

Further discussion of geologic conditions can be found in the *Technical Addendum, Appendix A.*

2.2 Aquatic Habitat Impairment

The relationship between stream bed conditions, sediment impacts and fisheries habitat in Santa Cruz County has been examined over the last several decades by Shapavolov and Taft (1954), the California Department of Water Resources (1958), Kelley and Dettman (1981), Smith and Alley (1982) and Alley and Associates (1995, 1998). Stream surveys by the California Department of Fish and Game in the 1960's and 1970s, as well as County Watershed Staff and intern stream surveys in 1976 and 1986, have consistently noted bed-impairment due to high percentages of fine sediments in study reaches.

Fine sediment has been documented to diminish the reproductive success of salmonids by reducing the permeability of gravels, intragravel water flow, and availability of dissolved oxygen for developing embryos (Terhune, 1958; McNeil and Ahnell, 1964; Vaux, 1962; Cooper, 1965; Daykin, 1965). Several researchers have also found an inverse relationship between fine sediment and fry survival (Bjornn, 1968; Phillips et al, 1975). Fine sediment deposited on the streambed also negatively impacts aquatic macroinvertebrate survival and production, a main food source for salmonids (Williams and Mundie, 1978).

Excessive fine sediment production in a watershed can also result in filling of historically deep pools. Pool filling can result in reductions in total salmonid biomass by reducing available habitat. When sediment was experimentally added to two Idaho streams, researchers found a decrease in fish density in direct proportion to the loss in pool volume (Stuehrenberg, 1975; Klamt, 1976). Pool filling and loss of habitat can also result in changes in population and community structure of the affected stream. For example, a study conducted by Bisson (unpublished data) in two streams in western Washington found that a decrease in the amount and quality of pools caused a shift in the population from a cutthroat, coho, steelhead stream to a predominantly steelhead stream. The age structure also changed from one composed of several age classes to a system dominated by young-of-the-year steelhead. These results suggest that an increase in fine sediment load creates a homogeneous system that is poor rearing habitat.

Excessive fine sediment resulting in embedded spawning gravel (sand fills interstices), pool filling and loss of escape cover on boulder/cobble substrate has been considered a limiting factor at all life stages of anadromous fish species historically present in the drainage (Santa Cruz County Planning Department, 1979). The species of concern in the San Lorenzo River are steelhead trout (*Oncorrynchus mykiss*) and coho salmon (*Onchorrynchus kisutch*). A study by Coats et al (1985) indicated that sedimentation in the San Lorenzo River was the primary cause for the decline of steelhead and coho salmon. Studies by Kelley and Dettman, (1981) Smith and Alley (1982) and D.W. Alley and Associates (1995, 1998) imply that sediment-impaired spawning habitat is likely to be less of a limiting factor than loss of escape cover and pool depth. Escape cover and a loss of pool depth is likely due to increases in embeddedness and sediment aggradation in formerly deep pools.

D.W. Alley and Associates, in the 1998 steelhead survey for the San Lorenzo River, found evidence that a series of five peak flows late in the 1998 water year probably destroyed spawning redds by scouring and/or smothering them with sediment. Bed mobility related to the prevalence of finer particle sizes in spawning areas appears to be a significant factor in spawning success. This concept is further drawn out by the observations of several senior fisheries scientists that late run steelhead are more likely to have spawning success, although outmigration and first year growth may be adversely impacted by rapid drops in late season streamflow (Dettman, personal communication-

1995; Smith, personal communication-1998; Alley, personal communication-1999; Anderson, personal communication-1999).

Another factor contributing to a reduction of salmonid habitat is the loss of woody debris and structural elements. Channels containing stored sediment and large organic debris are more productive at every trophic level than unstable channels devoid of sediment. Structural elements in the channel result in local hydraulic variability that scours pools and provides “islands” of clean gravel, even in streams with high average fine sediment contents (Keller et al, 1981). Channel obstructions greatly diversify channel morphology and add to channel stability (Keller and Swanson, 1979). In Prairie Creek, California, 50 to 90% of pools found, were associated with woody debris (Keller and Talley, 1979).

2.3 Sediment Source Problems and The Impacts of Roads

In the late 1970’s the County of Santa Cruz developed the San Lorenzo Watershed Plan (1979). A major finding in the 1979 plan was the identification of erosion and sedimentation as a primary cause of degraded aquatic habitat and impaired water quality. In 1996 through 1998, the County of Santa Cruz Department of Environmental Health convened a Technical Advisory Committee and secured funding from the State Water Resources Control Board (Contract No-4-133-250-0) and began the process of updating the San Lorenzo Watershed Plan to assess the effectiveness of implementation measures that were put forth in the 1979 plan. This effort resulted in the production of a report titled, *An Assessment of Streambed Conditions and Erosion Control Efforts in the San Lorenzo River Watershed, Santa Cruz County, California* (Balance Hydrologics, 1998).

The same primary conclusions put forth in the 1979 San Lorenzo Watershed Plan are echoed 19 years later in the 1998 assessment by Balance Hydrologics (1998). The 1998 study found little apparent improvement in sediment control and impaired conditions. The 1998 Assessment stated that in the intervening period since 1979, it was learned that:

> **“The material which is contributing to sedimentation of the bed is primarily sand and very fine gravels. This material represents a small fraction of the total sediment conveyed through the watershed. When eroded, sandy material contributes disproportionately to bed sedimentation.”**

and

> **“Considerable portions of the watershed are underlain by sandy soils. These special soils can erode deeply, quickly, and can cause extensive and deep sedimentation of the bed. Special management practices need to be applied to areas of sandy soils, principally to promote infiltration and minimize runoff.”**

Road building is a common and often dominant theme in land use disturbance. From timber harvests to driveways and public thoroughfares, roads are required for access to nearly every land use. Roads are also by far the most destructive element in the landscape as far as excessive fine sediment generation per unit area. Roads constructed along canyon floors and steep inner gorge slopes cause channel realignment resulting in direct delivery of sediment to streams (**Figure 2.1**).

Figure 2.1. Road Shoulder and Streambank Failure in Road-confined Inner Gorge Area of Zayante Creek. (Failure is likely due to sheet flow erosion and saturation of streambank material resulting from a plugged culvert.)

Erosion from road surfaces, ditches, shoulders and other human-induced land clearing contribute mostly fine-grained sediment. Paved and unpaved roads modify local hillslope drainage patterns, concentrate flow and increase runoff rates. Runoff on roads concentrates over soils exposed on the roadbed and shoulder, drainage ditches, road cuts, sidecasts and fills (**Figures 2.2 and 2.3**). In terms of managing sediment loads to reduce aquatic habitat impairment, fine sediment source reduction from roads will be the most effective treatment.

Roads are the primary cause of human-induced or “accelerated” erosion in the San Lorenzo River Watershed. This study builds upon previous work (1979 San Lorenzo River Watershed Plan; 1998 Assessment, Balance Hydrologics) by doing a detailed assessment of road and road-related erosion impacts.

Figure 2.2. Roadcut Failure and Landslide Over East Zayante Road. Inside ditch and cross culvert are overwhelmed by the sediment load, which forces sheet flow over the road surface.

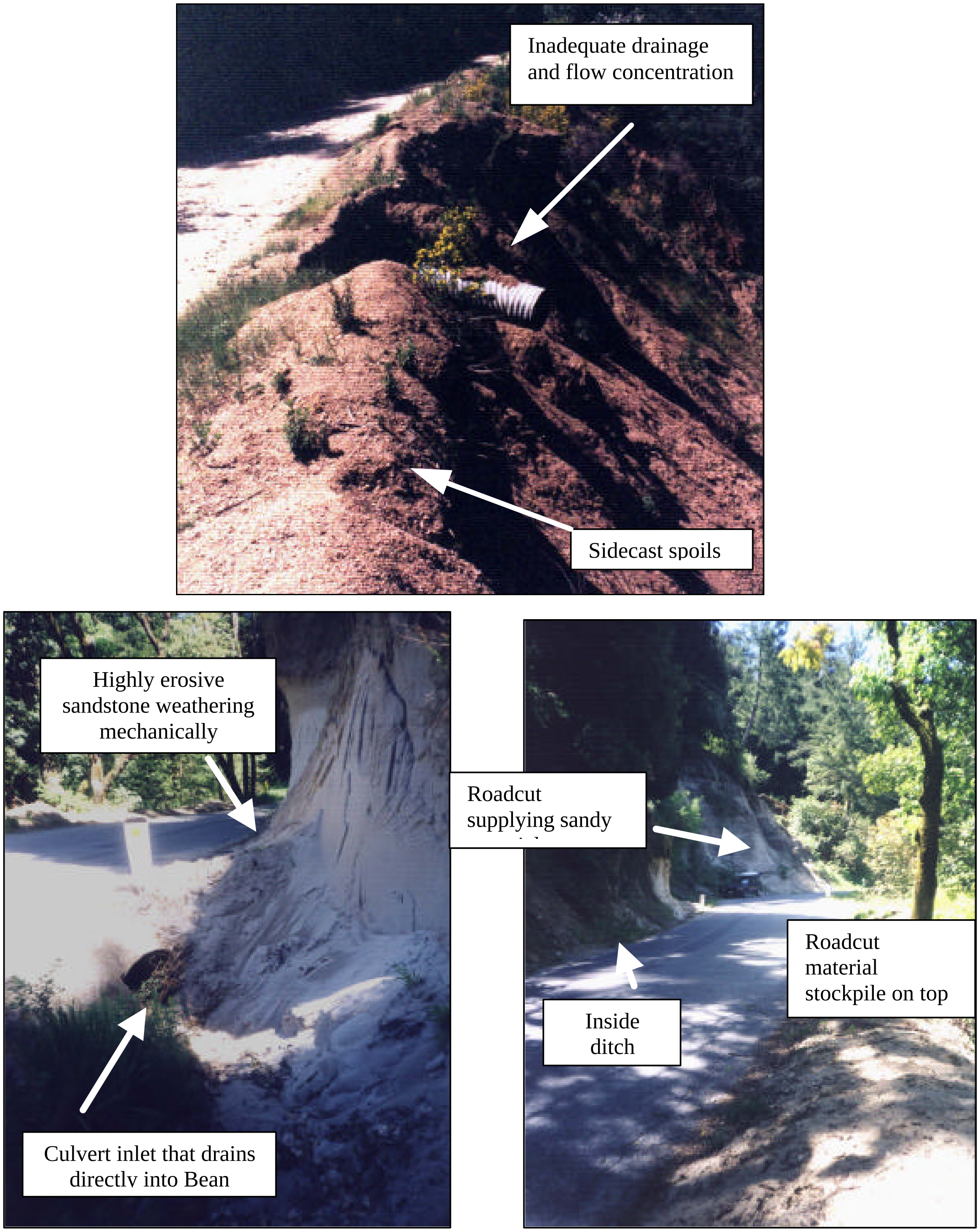

Figure 2.3. Typical plugged and failed culvert and associated slope erosion on private road in upper watershed (upper photo). Eroded roadcut in the Bean Creek subwatershed (lower left photo). Roadcut and road spoil material (lower right photo).

3.0 Field Identification of Erosion Sources

3.1 Overview

A primary objective of this study is to identify and distinguish between the contributions of various sediment sources associated with natural and human induced land disturbance. Quantifying sediment sources involves constructing a watershed sediment budget. In a sediment budget the basic relation to be solved is the sediment continuity equation:

$$O = I +/- \Delta S$$

where:

O = Sediment Outflow (tons) measured in a stream channel below a watershed

I = Sediment Inflow (tons) measured from the watershed principally from hillslopes

ΔS = Change in alluvial storage (tons) between inflow source and outflow point.

Within the framework of the sediment continuity concept, presented in greater detail, in the Technical Addendum *Appendix B*, Sediment Inflow (I) components increase when human disturbance sources are added.

This section describes the types of sediment sources, the associated geomorphic processes and their variability. Once the major sediment sources are identified, an estimate of the relative magnitude of each source to stream sedimentation can be made.

3.1.1. GEOMORPHIC PROCESSES AND SEDIMENT GENERATION

Assigning mean annual sediment yields to individual sources is contrary to the episodic nature of geomorphic processes. The discussion below attempts to describe the “reality” of actual sediment loading processes.

Rainfall is the dominant factor affecting erosion rates and sediment delivery to streams. In natural, undisturbed systems, the magnitude of sediment delivery is related to a progressive set of erosion thresholds driven by increasing rainfall period, intensity and antecedent soil moisture.

The first threshold of sediment supply and delivery is due to small and common rainfall events where sediment is mobilized from the surfaces of hillslopes in areas of weak soils and from the bed and banks of high order stream channels. With increasing rainfall, the second threshold is reached and sediments in steep tributary streams are mobilized, thereby increasing sediment delivery to high order stream. The final threshold occurs when intense and/or long duration rainfall over saturates soils and triggers landslides from hillslopes, delivering large volumes of sediment to the streams during flood stage. Depending on the size of material delivered to the streams and the steepness of the flood hydrograph, sediment can be carried long distances or remain near their source and cause local channel aggradation.

There is a spectrum of landslide types that deliver sediment to streams at different rates. Rapidly moving "debris flow" slides can instantly deliver much of a landslide mass to a stream. They are triggered by rainfall intensity that elevates soil saturation to a level that liquefies the mass and triggers abrupt and rapid movement (Benda and Dunne, 1997). Debris flows were ubiquitous within inner gorge slopes and in some cases deadly in the Santa Cruz Mountains as a result of the January 2-4, 1982 storm.

A "debris slide" is a deeper and more coherent mass that moves along a distinct failure plane; this type can also move rapidly and often with deadly consequences, such as the Love Creek Slide that occurred in 1982. Deeper "slumps" and "rotational" landslides respond to longer periods of rainfall and deep saturation. They move slowly (inches to tens of feet per day) but can deliver significant volumes of sediment when the slump toe is exposed to the stream channel or when large gullies develop in the deformed slide mass. Many large slides terminate at stream banks and feed sediment directly into the stream.

Over the past 17 years, understanding of climate patterns and cycles of intense precipitation have improved greatly, notably the identification of Surface Seawater Temperature Anomalies and El Nino/La Nina cycles. When combined with observation of sediment delivery and sediment transport mechanisms in streams and on hillslopes, a model explaining variability in sediment supply to streams emerges. Unfortunately, progress has been slow to understand the increment of human caused sediment sources above and beyond natural sources delivered in extreme events, although there are clearly impacts from these sources. Extreme events include periods of protracted high flows in streams and thus, the flushing action in channels after sediment delivery is high (e.g. Nolan et al, 1984).

Quantifying a long-term average sediment budget in coastal California rivers is difficult to undertake because year-to-year variability in rainfall intensity, sediment supply and streamflow is high. An extended recovery period may occur following one season of extreme rainfall, when large quantities of sediment are added to channel and floodplains, and subsequently flushed in normal rainfall years. This sequence would result in elevated fine sediment deposition rates at channel monitoring locations with several years of potentially poor aquatic conditions (Note: observations of the lower San Lorenzo River in 1999-2000 winter season show extensive flushing of stored sediments below Highway 1, perhaps caused by channel loading during the 1998 El Nino Floods). As a result, annualized sediment load estimates may have little meaning even if they are based upon abundant sediment transport data. Bed condition monitoring results can misrepresent sediment loading conditions from previous winter seasons. It should be noted that periods of recovery can extend further back in time to 19th century land disturbances as well as past extreme natural events spanning hundreds or perhaps thousands of years (e.g. earthquake induced landslides).

It is clear that over time, large-scale landsliding or mass wasting delivers the greatest volume of sediment to streams. However, a distinction must be made for the portion of the sediment that is causing impairment of fisheries habitat and that is chronic fine sediments eroded from surface erosion sources during small, frequent rainfall events. For the purposes of this study, observations of fresh erosion and chronic fine sediment runoff from disturbed areas under normal rainfall conditions indicate problematic chronic sources of sediment. Addressing chronic sediment sources through improved management of roads and other disturbed areas will likely help offset these impacts during extreme events.

3.2 Field Identification of Sediment Sources and Prioritization of Treatment Programs

The purpose of the field source analysis is to identify and categorize the types of sediment sources and to gain an impression of their relative contribution. This was accomplished through field surveys and review existing information in reports and technical literature.

The preliminary identification and assessment of sediment sources is based on results from the San Lorenzo Watershed Sanitary Survey (Camp, Dresser, and McKee, 1996), the 1998 Watershed Assessment by Balance Hydrologics (1998), and discussions with the San Lorenzo River Watershed Technical Advisory Committee (TAC).

Identified sediment sources can be classified into chronic non-point or acute point sources. This classification is necessary when considering the effects these sources have on stream sedimentation, biological integrity, and possible treatment methods.
Non-point sources of fine sediments include:

- Natural surface erosion and landslide background sources;
- Erosion from exposed soils along roads including surfaces, ditches, road cuts, shoulders, fill and side cast spoils;
- Surface and landslide erosion stemming from defective road drainage networks;
- Surface erosion from cleared areas including timber harvest areas, urban areas, and agricultural plots; and
- Natural and land use accelerated channel erosion of banks or streambeds.

Acute "point" sediment sources include specific landslides, quarry operations, or cleared areas that discharge sediment directly to a stream at a specific point. The distinction between point and non-point landslide sources is that point sources have known locations and a history of documented sediment discharge to streams. Non-point erosion sources are dispersed, less well-documented and comprise a cumulatively significant source for sediment, for which little data is available but delivery efficiency to streams is high.

3.3 Field Observations and Estimates of Erosion Rates

Fieldwork was directed towards identification of specific erosion sources, determination of relative contributions from each source and development of erosion control recommendations. This study was limited to one winter season and did not allow for detailed measurement of erosion rates. However, some insights gained from field surveys are important for calculating sediment yields and include the following results, discussed below.

The field inventory of sediment sources for this study was limited to publicly accessible roadways and watershed lands. Unpaved roads are more common on private lands so special attention was paid to unpaved roads that were accessible. Broader examinations of road networks and disturbances were made through interpretation of aerial photographs, analysis of GIS road networks and the timber harvest plot database. A limited survey of private timber harvest lands was made when accompanied by a Santa Cruz County Resource Planner. Field evaluations in Upper Newell Creek above Loch Lomond Reservoir were limited to verification of disturbance levels in order to place reservoir sediment yields in the context of yields for other areas of the Zayante Area Streams study area. More detailed land management information will result from a City of Santa Cruz Water Department Watershed Resources Management Study scheduled for completion in 2001.

3.3.1 ROAD SURVEYS

A general reconnaissance "windshield" survey of roads was conducted to observe erosional features in different settings. This was followed by data collection to provide a sample of representative road data for analysis. SH&G and CWC staff developed a road survey data form for collecting data. Under SH&G supervision, data collection was expanded by CWC staff, volunteers and student interns.

A road cut survey was conducted on publicly accessible roads in each subwatershed within the study area. The road cut survey consisted of collecting dimensions of each road cut (height and length), slope angle, and the percent of the road cut area that was protected from erosion by rooted vegetation. Other features such as road shoulders, ditches and sidecast spoils were not measured in order to maximize survey coverage. However, estimates of erosion from surveyed road cuts can provide the necessary information needed to infer an erosion rate for other road features.

To calculate a sediment yield from each surveyed road cut, a modified Universal Soil Loss Equation (USLE) was used that estimates sediment yield from road cuts in tons per year (USDA-NRCS, 1999) from measurements of road cut area and cut slope (**Table 3.1**). The length of road surveyed within each subwatershed was assumed to be representative of all roads in the subwatershed. Based on this assumption, the erosion rate from road cuts could be determined by dividing the yield by the total miles of roads surveyed, producing a sediment yield rate in tons mi^{-1} yr^{-1}.

The road survey sediment source data and erosion estimates are shown in **Table 3.1**. When averaged over the entire area of road cuts, the net surface erosion rate is estimated to be 0.25 inches per year. For public roads, many of which are paved, road cuts were found to represent the largest area of disturbance-related sediment sources. Road cuts occurring along steep inner gorge slopes immediately above streams appear to provide the majority of the bed impairing sediment, due to their close proximity to streams and high sediment delivery efficiency rates. Of these areas, the erosional features observed in road cuts in the highly erodible Santa Margarita Sandstone appear to contribute the highest sediment loads, especially along Bean Creek Road.

Table 3.1: Sediment Erosion from Road Cuts in the Zayante Study Area

Subwatershed	Sediment Yield from Surveyed Road Cuts using USLE Method (tons yr^{-1})	Total Survey Road Length (mi)	Sample Percent of Total Roads	Per Unit Sediment Yield (tons mi^{-1} yr^{-1})
Lower Bean	457	8.0	26%	57
Upper Bean	111	4.1	26%	27
Ruins	0	0.1	4%	0
MacKenzie	0	1.3	21%	0
Lockhart	224	2.1	17%	106
Love	72	2.9	17%	25
Lower Newell	32	3.8	34%	9
Upper Newell	0	3.0	29%	0
Lower Zayante	384	7.4	25%	52
Upper Zayante	141	6.3	25%	23
Lompico	331	7.9	34%	42
Mountain Charlie	132	3.0	25%	44
W Upper Zayante	302	4.7	30%	64
Summary	**2187**	**54.5**	**26%**	**40.1**

3.3.2 STREAM BANK EROSION ALONG BEAN CREEK AND LOCKHART GULCH

Stream bank erosion is a major concern since sources are immediately adjacent to the stream and readily available for erosion if disturbed. Bank erosion can be chronic, as well, and often involves fine grain alluvium or landslide deposits. Sediment loading from past land use activities can result in channel aggradation in high order trunk streams.

Aggraded reaches can store large quantities of sediment in floodplain areas with residence times of thousands of years (Dietrich and Dunne, 1978; Madej, 1984). Subsequent channel downcutting due to lower sediment loads, channel straightening or reduction in woody debris can result in excessive bank erosion.

Where erosion features such as unvegetated high banks are observed, fine sediments often impact downstream bed conditions. Bank stabilization is an important component of sediment control measures, though it presents many challenges ranging from private land practices to poor accessibility. Construction of treatment measures can also result in significant impacts to hillslopes and aquatic habitat. Bank erosion control projects will likely be highly scrutinized when listed endangered species are involved.

To quantify the potential sediment yield from streambank erosion within the study area, survey data, collected in 1999 by fisheries biologist Don Alley, was used. Data was collected on Bean Creek and Lockhart Gulch on the area and extent of each streambank erosion site. This data was then used to estimate a total sediment yield per year by computing the dimensions of each site and multiplying by an assumed erosion rate of 0.5 feet per year, with a bank material bulk density estimated to be 100 lbs ft^{-3}. This assumption was necessary since the streambank erosion sites were only surveyed once and the date when the initial erosion occurred was not known.

Based on the input data available for the analysis, the estimated average sediment yield contributed by bank erosion in Lower Bean, Upper Bean, and Lockhart Gulch is 240 tons mi^{-1} yr^{-1} (**Table 3.2**). These numbers suggest that bank erosion contributes a significant proportion of the total sediment load to stream channels. Smaller volumes of bank erosion sediments in the Santa Margarita Sandstone were located by Mr. Alley in less accessible reaches of Bean Creek, including channel instability resulting from fallen trees, logjams, stream bed aggradation and lateral channel migration.

Streambank failures in Lockhart Gulch appear related to road failures and erosion by concentrated drainage in tributary channels. Limited observations also suggest that the primary sources of impairing sediments occur in reaches lined with Santa Margarita Sandstone and alluvium. Logjam-related channel migration during the 1998 floods appears to be the predominant cause of bank instability in the low gradient, alluvial reaches of Bean Creek.

Little is known about the rate of channel downcutting in the Santa Cruz Mountains. Since the mountains are still uplifting at a relatively fast rate, stream channels compensate by downcutting. In addition to downcutting resulting from tectonic uplift, channel straightening and confinement can result in accelerated channel downcutting. Since no data are available on rates of channel downcutting in the Santa Cruz Mountains, it was assumed that the contribution of streambank erosion to channel erosion as a whole should represent around 60% of the total (with channel downcutting contributing 40% to the overall channel erosion sediment budget). The result is a channel erosion rate of 400 tons per mile per year (**Table 3.2**) or 240 tons per square mile per year assuming a drainage area of 39.3 square miles and a total stream mileage of 23.5.

Table 3.2: Estimated Channel Erosion on Bean Creek and Lockhart Gulch

Creek Name	Survey Bank Length (mi)	Length of Eroding Banks (both banks)	Cut Area (ft^2) (height and width of cut)	Cut Volume (ft^3) (assuming a retreat rate of 0.5 ft yr^{-1})	Streambank Erosion Rate (tons mi^{-1} yr^{-1})	Erosion Rate w/channel downcutting (tons mi^{-1} yr^{-1})	Converted to Erosion Rate per Basin Area (tons mi^{-2} yr^{-1})
Bean Creek	5.7	0.82 miles	60222	30111	264		
Lockhart Gulch	1.5	0.14 miles	8634	4317	144		
Total	**7.2**	**0.96 miles**	**68857**	**34428**	**240**	**400**	**240**

3.3.3 Estimation of Sediment Loading From Large Landslides and Mass Wasting

Three large, deep-seated landslides within the south Zayante Fault geologic unit are known to contribute substantial sediment to area streams. Two of these landslides occur within the Santa Margarita Sandstone (Bean Creek Road and Mount Hermon slides) and one within the Monterey Shale (Love Creek Slide). All three have been identified as major sediment sources contributing to aquatic habitat impairment (CDM, 1996, Hecht and Kittleson, 1998).

A field survey aimed at quantifying rates of mass wasting input to streams from these slides was made in 1999. Digital topographic surveys (including cross sections, a longitudinal profile, and topo map) and slide-creep monitoring stakes were placed on the main Bean Creek Road slide, the upper rupture zone at the Mount Hermon slide and at the toe of the Love Creek slide to provide a baseline for future monitoring.

In 1982, the toe of the Love Creek Slide completely filled the inner gorge of Love Creek and dammed the channel for several hundred yards upstream. Subsequent channel excavation and re-alignment of Love Creek Road required the placement of a large corrugated metal pipe culvert at the downstream extent of the slide zone. The channel survey and topographic maps will serve as baseline conditions for future monitoring efforts.

A sediment yield estimate from the Love Creek Slide was determined by dividing the slide into upstream and downstream sections that are bisected by a large gully that has formed below the principle drainage culvert that picks up runoff from the slide face. The slide toe in the downstream half consists of unvegetated, steep walls with an estimated erosion rate of 25 yd^3 yr^{-1}, based on an estimate of recently sloughed sediments at the toe of the slide. Using a bulk density of 85 lbs ft^{-3}, the estimated yield would be 29 tons yr^{-1}. The upstream half has more vegetation cover and the erosion rate is estimated to be 15 yd^3 yr^{-1}or 17 tons yr^{-1}. A total of 46 tons yr^{-1} is estimated from erosion off the Love Creek slide toe. Extended to the entire Love Creek watershed, the yield is 15 tons mi^{-2} yr^{-1} (**Table 3.3**).

Table 3.3: Selected Point Source Erosion Estimates

Source	Total Load (yd^3 yr^{-1})	Total Load (tons yr^{-1})
Love Creek Slide – upstream	25	29
Love Creek Slide – downstream	15	17
Total	**40**	**46**
Mt. Hermon Slide – upstream	400	459
Mt. Hermon Slide – downstream	500	574
Bean Creek Road	380	436
Total	**1280**	**1469**

At the Mt. Hermon Slide the material is a mix of weathered shale and sand, and numerous seeps emerge at the toe and along the base of gullies (**Figure 3.1**). The slide was divided into upstream and downstream sections in order to estimate a sediment yield from observational data. The sediment yield from the upstream section was estimated to be 400 yd^3 yr^{-1}, which converts to 460 tons yr^{-1} using a bulk soil density of 85 lbs ft^{-3}. The downstream section sediment yield was estimated to be 500 yd^3 yr^{-1} or 570 tons yr^{-1} for a total of 1,030 tons yr^{-1} (**Table 3.3**).

Bean Creek Road, north of Scotts Valley, features an extensive collection of eroding roadcuts in the Santa Margarita Sandstone and, to a lesser extent, the Santa Cruz Mudstone (**Figure 3.2**). This site failed massively in the high intensity rainfall event in 1982 and was subsequently treated in 1985 and 1986. Measures undertaken during that time included installation of rock toe protection, slope recontouring and revegetation. These measures have had mixed results, and have done little to reduce erosion rates on the exposed failure face. Sediment delivery was somewhat reduced through drainage management, but newly placed drainage outlets have created new gully failures both upstream and downstream of the treated failure.

SH&G conducted a topographic survey of the Bean Creek erosion site to estimate the area subject to gullying and erosion. The survey serves as the basis for material loss estimates and can be used as baseline data for any future slope stability engineering designs. Sediment yield estimates were determined through a combination of topographic surveys of the site and ground photos taken in 1985, 1995, and 1999. Estimates of erosion since 1986 were 11,400 yd^3 resulting in an estimated erosion rate of 760 yd^3 yr^{-1}. Assuming a stream delivery efficiency of 50%, the adjusted sediment yield to Bean Creek would be 380 yd^3 yr^{-1}or 440 tons yr^{-1}. When the Mount Hermon Slide and Bean Creek

Road erosion are combined, the total sediment yield is estimated to by 1,470 tons yr^{-1}. Extended to the entire Lower Bean Creek subwatershed the sediment yield estimate is 350 tons mi^{-2} yr^{-1} (**Table 3.3**).

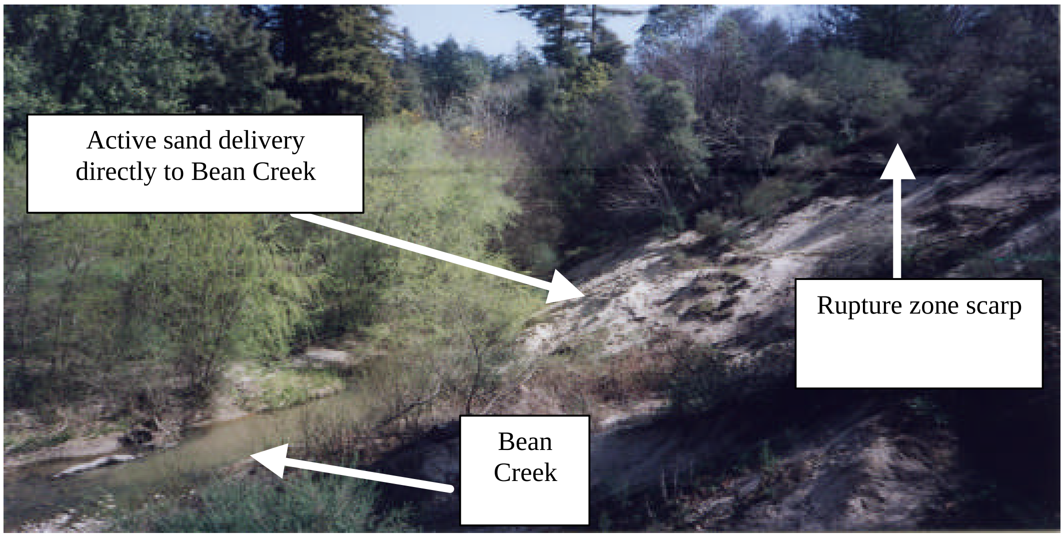

Figure 3.1: Mt. Hermon Slide and Bean Creek

Figure 3.2: Eroding Road Cuts on Bean Creek Road Within Santa Margarita Sandstone

3.3.4 OTHER "POINT" EROSION SOURCES

Other significant "point" sources of erosion were identified in the study area but were not visited frequently enough to determine a sediment erosion rate. These erosion sites are predominantly found within the Santa Margarita formation and contribute a significant amount of fine sediment to study area streams. They include developments such as Rancho Rio, Skypark, McEnery Road and Monte Fiore.

Rancho Rio Subdivision

The Rancho Rio subdivision, located in the Lower Newell subwatershed, began development in the 1970's. Exposure of the fragile Santa Margarita sandstone formation during construction resulted in extremely high erosion rates. Recent decades have seen notable reductions in sediment loads due to drainage improvements, retaining wall construction, gully stabilization projects, regeneration of riparian corridors and establishment of residential landscaping.

Excessive erosion problems still exist at Rancho Rio (**Figure 3.3**), specifically a large gully of weathered Santa Margarita sandstone in a drainage swale next to Quail Hollow Middle School. Drainage improvements to the school parking lot, playing fields and roof runoff, along with an engineering feasibility study to stabilize the large gully would be necessary to reduce this site as a significant fine sediment source.

Figure 3.3: Exposed Santa Margarita Sandstone Above Quail Hollow School

Skypark Development

The Skypark development, in the vicinity of Scotts Valley, was the former site of a sand quarry and municipal airport, resulting in exposures of Santa Margarita sandstone. Recent development has converted these previous land uses to residential and commercial uses. Residual effects of open quarry faces and older gully features have resulted in continued excessive fine sediment erosion (**Figure 3.4**). Slope stabilization and revegetation efforts have failed due to the erosiveness of the soils.

Road development along the highly erosive bluffs adjacent to the former quarries have resulted in increased gully development due to inadequate drainage infrastructure, specifically along Navigator and Coast Range Road. An engineering feasibility study needs to be conducted in the Skypark area to assess development of retaining wall structures, runoff retention basins and modification of the current drainage system.

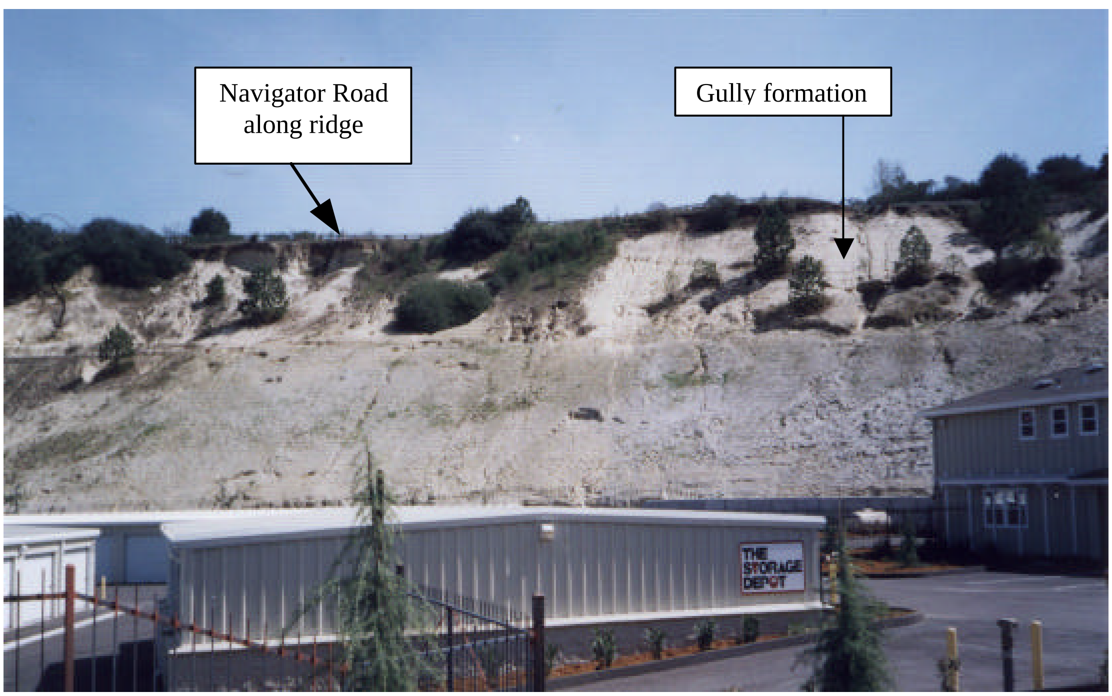

Figure 3.4: Old Sand Quarry Bluff at the Sky Park Development, Scotts Valley

McEnery Road

McEnery Road is a residential access road that drains to the mainstem of Zayante Creek between the confluences of Lompico and Bean Creek. Increased surface runoff from the road surface, poor drainage design, and increased residential and equestrian development along the road has resulted in the development of a large gully in Santa Margarita sandstone adjacent to the road (**Figure 3.5**).

An engineering feasibility study needs to be conducted to determine the best approach to manage runoff from the road and adjacent land uses. Gully stabilization and revegetation would be required to reduce the excessive fine sediment supply.

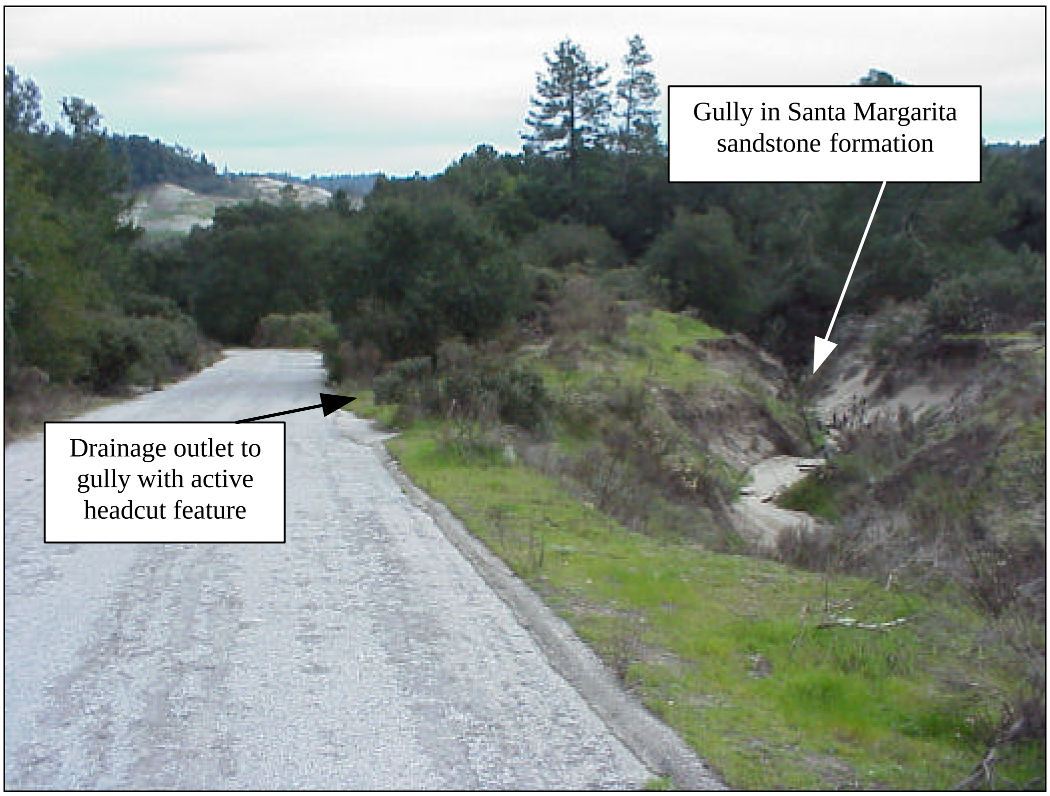

Figure 3.5: Gully Development Adjacent to McEnery Road

4.0 Sediment Yield Estimates Using GIS Model and CDF Erosion Yields

4.1 Overview and Categories of Erosion Sources

The field surveys discussed in the previous section provided information regarding the type and magnitude of the primary sources of sediment in the Zayante Area Streams. Based on these field estimates, the major sources of erosion were classified into the following categories **(Table 4.1):**

- THP roads (Hillslope and Inner Gorge) – **Figures 4.1 and 4.2**;
- Public and private roads (Hillslope and Inner Gorge) – **Figure 4.3**;
- Active and recent THP parcels **– Figure 4.4**;
- Other Urban and Rural Lands **– Figure 4.5**;
- Mass wasting – **Figure 4.1**; and
- Channel erosion – **Figure 4.6**

Table 4.1: Description of Sources of Erosion

Sediment Source Category	Source Extent	Erosion Description/Types/Sources
THP Roads THP Roads in Sandy Soils	Includes road cuts, shoulders, surfaces, sidecast spoils and ditches on permanent and seasonal roads and skid trails	Predominately surface erosion from road related activities including erosion from drainage modifications caused by roads. This category is considered to be 100% human caused. These roads can accelerate surface erosion and mass wasting off-site by altering drainage patterns.
Public and Private Roads Public and Private Roads in Sandy Soils	Includes road cuts, shoulders, surfaces, sidecast spoils and ditches on paved and dirt roads	Predominately surface erosion from road related activities including erosion from drainage modifications caused by roads. This category is assumed to be 100% human caused. These roads can accelerate surface erosion and mass wasting off-site by altering drainage patterns.
Active and Recent THP Parcels	Includes forested lands with Timber Harvest Plans generated since 1987	Includes all surface erosion including sheet erosion, rills, and gullies. This category has both human and natural components.
Other Urban and Rural Lands	Includes all forested and unforested lands outside of recent Timber Harvest Plan parcels	Includes surface erosion from sheet erosion, rills, and gullies as well as mass wasting (i.e. – landslides, debris flows). The mass wasting component was pulled out of the final numbers and put into a separate mass wasting category. This category has both human and natural components.
Mass Wasting	Includes all lands within the study area	Erosion from landslides and debris flows are included in this category along with road and disturbance related mass wasting. This category has both human and natural background components, though the available data is insufficient to determine their proportions.
Channel Erosion	Includes all stream corridors within the study area	Includes erosion of main channel, banks, and floodplain areas of the stream. Does not include landslide toes and erosion from culvert outfalls. This category is predominately natural, though rates can be accelerated by human activities.

Figure 4.1: Recently Built Timber Harvest Road in the Fritch Creek Drainage that was cited for a grading violation by Santa Cruz County.

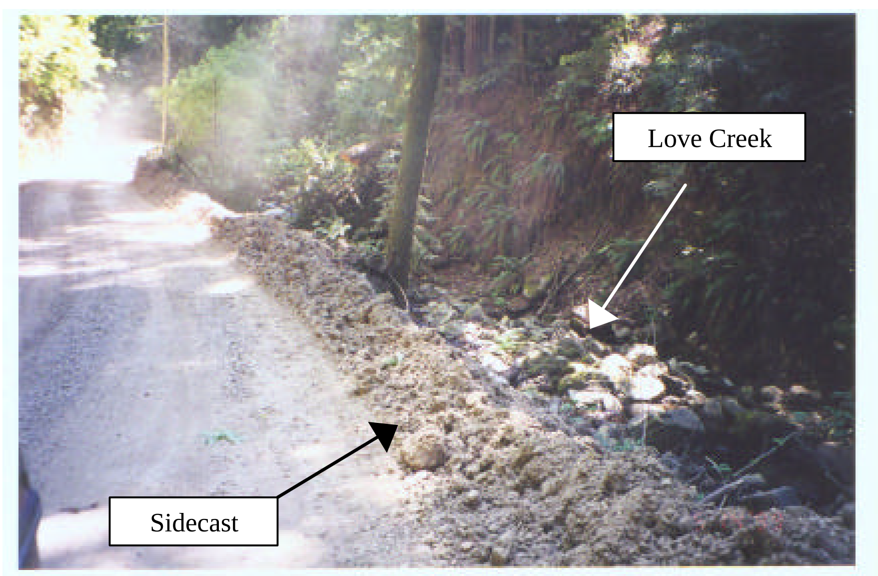

Figure 4.2: Recently Graded Road Used for Timber Harvests and Residential Access in the Inner Gorge along Love Creek that was cited for a grading violation by Santa Cruz County (Love Creek Road).

Figure 4.3: Example of a Timber Harvest Road Managed by the City of Santa Cruz in the Zayante Creek Drainage Basin.

Figure 4.4: Example of a Gravel Road Within the Inner Gorge on Kings Creek.

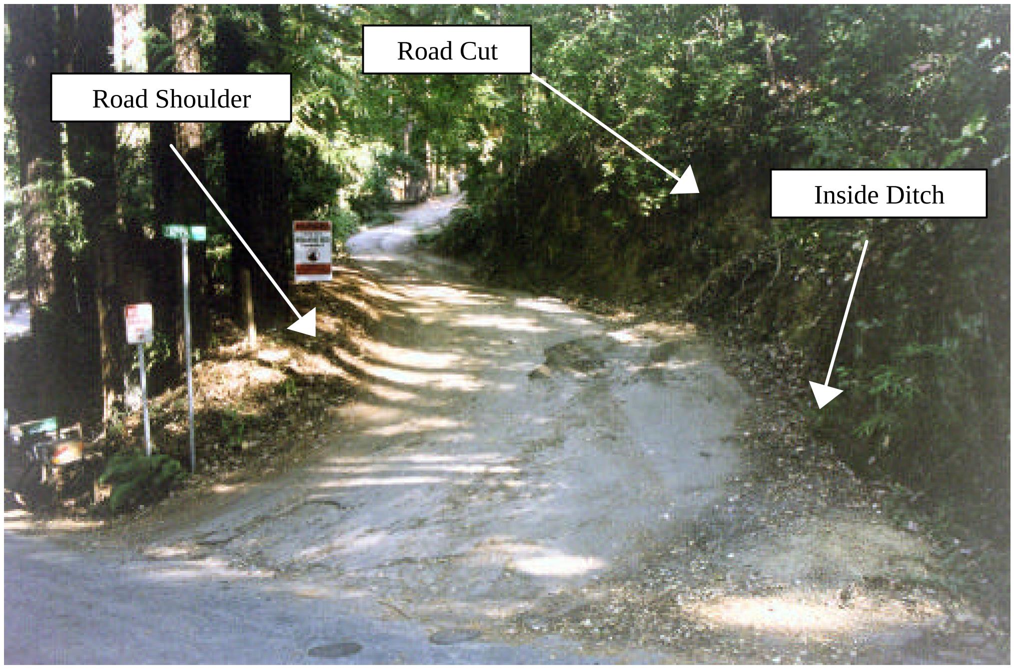

Figure 4.5: Example of Public and Private Roads in the Zayante Study Area.

Figure 4.6: Example of an Active or Recent Timber Harvest Area in the Zayante Study Area.

Figure 4.7: Example of Recent Land Clearing for Residential Development (Other Urban and Rural Lands).

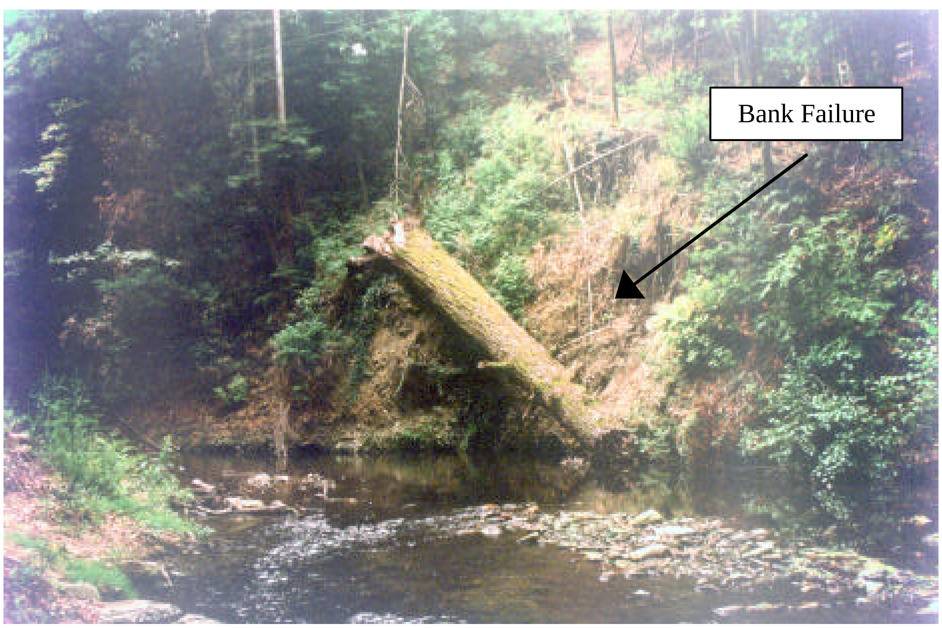

Figure 4.8: Example of Stream Bank Erosion in the Zayante Study Area.

Once identified, an attempt was made to estimate the total sediment contribution to Zayante Area Streams from each source. The sediment sources are categorized to highlight the types of disturbances present in the study area. Total erosion is estimated using a spatial GIS database and modified erosion rates developed by CDF (1993) in the nearby Soquel Creek Demonstration Forest. As mentioned above, the modified CDF erosion rates are applied to disturbance areas over each subwatershed then back-checked by comparison with sediment yields measured in streams.

The sediment load estimates are made by applying published and measured erosion rates to the disturbed and natural sediment source areas. These factors represent the sediment inflow (I) variable of the continuity equation previously referred to in Section 3.1 of this report (*see Technical Addendum, Appendix B for more detail*). Long-term change in storage (ΔS) has been assumed to be zero for calculation purposes, though short-term changes in storage do occur. Sediment outflow (O) is assumed to be measured sediment yields at discharge points; this is where verification and perhaps adjustment of erosion rates may be warranted, although the data set is limited.

4.2 Erosion Rates

Due to time and budgetary constraints associated with making direct measurements of sediment yield for a watershed of this size, previous sediment yield estimates measured for East Branch of Soquel Creek (Cafferata and Poole, 1993) were extrapolated to each subwatershed (**Table 4.2**). Though in general, land use conditions, geology and soils are comparable between Soquel Creek and the Zayante Study Area, adjustments were made to the CDF sediment yield rates to reflect some important differences. These include:

- **Geologic rock type:** The Zayante Area Streams include a significant portion of highly erodible Santa Margarita Sandstone that isn't represented in Soquel Creek. Therefore, surface erosion rates in Zayante Area are likely higher.

- **Road Networks:** A more extensive network of inner gorge public and private roads exists in the Zayante Area Streams, therefore the sediment delivery rate to streams in Zayante is higher.

- **Land Use:** Land use in the East Branch of Soquel Creek is more heavily influenced by rural, large parcel residences and timber harvests. Zayante has denser road networks and more intensive land uses.

- **Terrain:** Hillslopes in the East Branch of Soquel Creek are steep and similar to the upper watershed of the Zayante Area.

The CDF sediment yield estimates were determined for plots in the Soquel Creek Demonstration State Forest using methods developed by Rice (1993) using measured erosion values from monitored timber harvest and road plots. Land-use categories in the

CDF study were defined as timber harvest, non-timber harvest, forestry roads, and non-forestry roads. For application to the Zayante Area Streams, these categories were modified slightly and adjustments were made to the erosion rates based on field surveys described in Chapter 3 (**Table 4.2**). Hillslope and inner gorge roads were divided into separate sediment source categories to reflect the different stream delivery efficiencies from these features.

Table 4.2: Sediment Source Estimates

Sediment Source	Sediment Yield from Soquel (CDF, 1993)	Sediment Yield assuming a bulk density of 85 lbs ft^{-3} (Lane and Koezler, 1953)	Final Sediment Yield Estimate from Various Sources	Delivery Efficiency to Streams (Average Rate from CDF, 1993)	Sediment Delivery Rate
THP Plots[A]	0.28 yd^3 ac^{-1} yr^{-1}	206 tons mi^{-2} yr^{-1}	206 tons mi^{-2} yr^{-1}	42 %	87 tons mi^{-2} yr^{-1}
Other Urban and Rural Lands[B]	5.8 yd^3 ac^{-1} yr^{-1}	4260 tons mi^{-2} yr^{-}	2620 tons mi^{-2} yr^{-1}	42 %	1100 tons mi^{-2} yr^{-1}
Hillslope THP Roads[C]	360 yd^3 mi^{-1} yr^{-1}	413 tons mi^{-1} yr^{-1}	413 tons mi^{-1} yr^{-1}	42 %	173 tons mi^{-1} yr^{-1}
Inner Gorge THP Roads[D]	360 yd^3 mi^{-1} yr^{-1}	413 tons mi^{-1} yr^{-1}	413 tons mi^{-1} yr^{-1}	100 %	413 tons mi^{-1} yr^{-1}
Hillslope Public and Private Roads[E]	46.8 yd^3 mi^{-1} yr^{-1}	54 tons mi^{-1} yr^{-1}	120 tons mi^{-1} yr^{-1}	42 %	50 tons mi^{-1} yr^{-1}
Inner Gorge Public and Private Roads[F]	46.8 yd^3 mi^{-1} yr^{-1}	54 tons mi^{-1} yr^{-1}	120 tons mi^{-1} yr^{-1}	100 %	120 tons mi^{-1} yr^{-1}

**** Footnotes on Following Page***

To apply the erosion rates outlined in **Table 4.2**, Santa Cruz County Environmental Management Information System (EMIS, representing public and private roads) and Timber Harvest Plan (THP) road layers were classified as non-forestry and forestry roads, respectively. THP layers were digitized from THPs in CDF files for the period 1987-1998. Overlap that occurred between the EMIS and THP road layers was identified and removed from the THP roads layer, since they are most likely multiple use roads and therefore represent a mix of erosion sources that are not easily separated. The EMIS road layer also contains a "paper subdivision" in the vicinity of Love Creek that was also removed for the sediment yield analysis. In total, 10% of the EMIS roads were either removed, or considered multiple use roads.

Footnotes for Table 4.2

A) Rate based on CDF (1993) estimates from the East Branch of Soquel Creek for *Harvest Areas of the Last 20 Years.* The rate, in yd^3/ac was converted to tons/yr assuming a soil bulk density of 85 lbs/ft^3. The delivery efficiency to stream channels was assumed to be 42% based on an average rate determined from the Soquel Demonstration Forest.

B) The Soquel Demonstration Forest Study (CDF, 1993) reported a background erosion rate of 5.8 yd^3/ac/yr that was derived from previous studies of sedimentation in Loch Lomond. The Brown (1973) report on average sedimentation rates measured in Loch Lomond Reservoir reported rates of 1100 tons/mi^2/yr. Given the available information we were unable to back calculate and obtain equivalent values. Instead, the Brown value was used along with a delivery efficiency of 42%. Rates include erosion from all sources (surface and mass wasting).

C) Rate based on CDF (1993) estimates from the East Branch of Soquel Creek for *Forestry Roads Currently in Use.* The rate, in yd^3/ac was converted to tons/yr assuming a soil bulk density of 85 lbs/ft^3. The delivery efficiency to stream channels was assumed to be 42% based on an average rate determined from the Soquel Demonstration Forest.

D) Rate based on CDF (1993) estimates from the East Branch of Soquel Creek for *Forestry Roads Currently in Use.* The rate, in yd^3/ac was converted to tons/yr assuming a soil bulk density of 85 lbs/ft^3. The delivery efficiency to stream channels was assumed to be 100% since the estimate is for inner gorge roads.

E) The Soquel Demonstration Forest Study (CDF, 1993) reported an erosion rate from *Non-Forestry Roads* as 46.8 yd3/mi. Since the density and location of road in the Zayante Study Area does not resemble public and private road densities in the Demonstration Forest, field data collected by SH&G was used. SH&G collected information from representative road cuts throughout the Zayante Study Area and applied a USDA-NRCS erosion yield methodology. The result was an erosion rate of approximately 40 tons/mi/yr from road cuts. To account for erosion from inside ditches, road shoulders and the road surface, this value was tripled. A sediment delivery efficiency of 42% was used for hillslope roads.

F) The Soquel Demonstration Forest Study (CDF, 1993) reported an erosion rate from *Non-Forestry Roads* as 46.8 yd3/mi. Since the density and location of road in the Zayante Study Area does not resemble public and private road densities in the Demonstration Forest, field data collected by SH&G was used. SH&G collected information from representative road cuts throughout the Zayante Study Area and applied a USDA-NRCS erosion yield methodology. The result was an erosion rate of approximately 40 tons/mi/yr from road cuts. To account for erosion from inside ditches, road shoulders and the road surface, this value was tripled. A sediment delivery efficiency of 100% was used for hillslope roads.

An assessment was also made to determine the comparability between the CDF study area and our study area regarding the percent of non-forestry roads that were paved versus unpaved. For the CDF study plots, 59% percent of the roads were unpaved and 41% were paved. In general, this matched the ratio for our study area except at the subwatershed level. At the subwatershed level, Lower Bean was over-represented by paved roads while Mackenzie, Lockhart, Love, and Upper Newell were over-represented by unpaved roads (**see Table C-2, Appendix C of Technical Addendum**).

Land-use data distinguishing timber harvest and non-timber harvest areas of each subwatershed was also available from CDF Timber Harvest Plan maps digitized by SH&G staff. Subwatersheds with significant land under timber harvest plans are Upper Newell, Mountain Charlie, Upper Zayante, West Upper Zayante, Lower Zayante, and Lockhart Gulch.

The erosion and sedimentation rates described in **Table 4.2** were then applied to the corresponding features in the Zayante Study Area producing a sediment yield by subwatershed (**Table 4.3**). For this part of the analysis, mass wasting is only included implicitly in the *Other Urban and Rural Lands* since the erosion rate from this category is based on sedimentation in Loch Lomond Reservoir (Brown, 1973). The channel erosion category was excluded due to the lack of definable erosion rates at the subwatershed level. Based on these categories the estimated total erosion for all subwatersheds combined is 139,000 tons yr^{-1}. When divided by the drainage area the estimated total erosion rate is 3,550 tons mi^{-2} yr^{-1}. When sediment delivery efficiency for each category is considered, the resulting total estimated sediment yield for all subwatersheds combined is 64,111 tons yr^{-1}or 1,632 tons mi^{-2} yr^{-1}.

To develop a final sediment yield estimate for the Zayante Study Area, determinations of erosion from mass wasting and channel erosion needed to be made. Since the *Other Urban and Rural Lands* category includes a component of mass wasting, 50% of this category was moved into the Mass Wasting category based on the assumption that half of the erosion is from a surface erosion component and the other half is from mass failures. An additional amount was also added to the mass wasting category to reflect known contributing point sources (Mt Hermon Slide and Love Creek Slide), debris flows, and road induced landslides (episodic) not accounted for in CDF study plots. Sediment yield rates from channel and bank erosion were estimated from Don Alley's streambank erosion estimates (**Table 3.2**) with an additional 40 percent added to account for channel downcutting.

The final sediment yields integrated over all subwatersheds within the Zayante Study Area are shown in **Table 4.4**. The resulting sediment yield from all categories combined is 115,116 tons yr^{-1}. When divided by the drainage area the estimated sediment yield rate

Erosion			Hillslope THP Roads (tons/yr)	Inner Gorge THP Roads (tons/yr)	Hillslope Public and Private Roads (tons/yr)	Inner Gorge Public and Private Roads (tons/yr)	Active and Recent THP Parcels (tons/yr)	Other Urban and Rural Lands (tons/yr)	Estimated Total (tons/yr)	Estimated Total (tons/mi^2/yr)
Watershed	Subwatershed	Area (mi^2)	at a rate of 413 tons/mi/yr	at a rate of 413 tons/mi/yr	at a rate of 120 tons/mi/yr	at a rate of 120 tons/mi/yr	at a rate of 206 tons/mi^2/yr	at a rate of 2620 tons/mi^2/yr		
Bean	Lower Bean	4.2	620	0	1956	588	14	13155	16333	3921
Bean	Upper Bean	1.9	83	124	1416	444	13	4855	6934	3622
Bean	Ruins	0.5	0	0	189	112	0	1402	1703	3183
Bean	MacKenzie	0.8	0	0	459	288	0	2147	2894	3531
Bean	Lockhart	2.0	909	496	927	585	65	4537	7518	3674
Love	Love	3.0	1446	661	1308	720	104	6541	10780	3588
Newell	Lower Newell	1.6	1080	266	1092	252	7	4215	6913	4205
Newell	Upper Newell	8.3	5164	1157	936	276	269	18264	26065	3148
Zayante	Lower Zayante	4.9	2099	91	2196	1392	89	11575	17441	3596
Zayante	Upper Zayante	4.0	1115	0	2532	516	108	9105	13376	3344
Zayante	Lompico	2.8	1546	118	2038	758	51	6598	11109	4017
Zayante	Mountain Charlie	2.8	2263	92	1178	5	126	5819	9482	3348
Zayante	W Upper Zayante	2.4	1363	372	1166	417	88	5255	8661	3556
Total		39.3	17687	3377	17393	6353	934	93466	139209	3543
	Percent of Total Yield		12.7%	2.4%	12.5%	4.6%	0.7%	67.1%		

Sediment Delivery			Hillslope THP Roads (tons/yr)	Inner Gorge THP Roads (tons/yr)	Hillslope Public and Private Roads (tons/yr)	Inner Gorge Public and Private Roads (tons/yr)	Active and Recent THP Parcels (tons/yr)	Other Urban and Rural Lands (tons/yr)	Estimated Total (tons/yr)	Estimated Total (tons/mi^2/yr)
Watershed	Subwatershed	Area (mi^2)	at a rate of 173 tons/mi/yr	at a rate of 413 tons/mi/yr	at a rate of 50 tons/mi/yr	at a rate of 120 tons/mi/yr	at a rate of 87 tons/mi^2/yr	at a rate of 1100 tons/mi^2/yr		
Bean	Lower Bean	4.2	260	0	822	588	6	5525	7201	1729
Bean	Upper Bean	1.9	35	124	595	444	5	2039	3242	1693
Bean	Ruins	0.5	0	0	80	112	0	589	780	1458
Bean	MacKenzie	0.8	0	0	193	288	0	902	1382	1687
Bean	Lockhart	2.0	382	496	389	585	27	1905	3785	1849
Love	Love	3.0	607	661	549	720	44	2747	5328	1774
Newell	Lower Newell	1.6	454	266	459	252	3	1770	3204	1949
Newell	Upper Newell	8.3	2169	1157	393	276	113	7671	11778	1422
Zayante	Lower Zayante	4.9	881	91	922	1392	37	4861	8185	1688
Zayante	Upper Zayante	4.0	468	0	1063	516	45	3824	5917	1479
Zayante	Lompico	2.8	649	118	856	758	21	2771	5174	1871
Zayante	Mountain Charlie	2.8	950	92	495	5	53	2444	4039	1426
Zayante	W Upper Zayante	2.4	573	372	490	417	37	2207	4095	1681
Total		39.3	7428	3377	7305	6353	392	39256	64111	1632
	Percent of Total Yield		11.6%	5.3%	11.4%	9.9%	0.6%	61.2%		

Table 4.3: Calculated erosion and sediment delivery by subwatershed. All yields were calculated using adjusted CDF (1983) rates from the East Branch of Soquel Creek for all erosion source categories except mass wasting and channel erosion.

Sediment Source	Area or Length Represented by Source (inner gorge length)	Erosion Rate	Delivery Efficiency	Sediment Delivery Rate to Streams	Sediment Yield (tons/yr)	Percent Controllable	Controllable Load (tons/yr)	Percent of Total Controllable Load	Remaining Load/Allocation (tons/yr)
Hillslope THP Roads and Skid Trails [1]	42.9 miles	413 tons/mi/yr	42%	173 tons/mi/yr	7422	50%	3711	13.9%	3711
Inner Gorge THP Roads and Skid Trails [2]	8.2 miles	413 tons/mi/yr	100%	413 tons/mi/yr	3387	50%	1694	6.3%	1694
Hillslope Public and Private Roads [3]	148.5 miles	120 tons/mi/yr	42%	50 tons/mi/yr	7425	50%	3713	13.9%	3713
Inner Gorge Public and Private Roads [4]	54.1 miles	120 tons/mi/yr	100%	120 tons/mi/yr	6492	50%	3246	12.1%	3246
Active and Recent THP Parcels [5]	4.5 square miles	206 tons/mi^2/yr	42%	87 tons/mi^2/yr	393	30%	118	0.4%	275
Other Urban and Rural Lands [6]	35.7 square miles	1310 tons/mi^2/yr (50% classified as mass wasting)	42%	550 tons/mi^2/yr (50% classified as mass wasting)	21615	30%	6485	24.2%	15131
Mass Wasting (Natural and Human Caused) [7]	39.3 square miles	3570 tons/mi^2/yr	42%	1500 tons/mi^2/yr	58950	10%	5895	22.0%	53055
Channel Erosion [8]	23.5 miles	400 tons/mi/yr	100%	400 tons/mi/yr	9432	20%	1886	7.1%	7546
Estimated Total					**115116**	**23%**	**26747**	**100%**	**88369**

Measured Sediment Yield @ Zayante Gage (tons/mi^2/yr)	**5400** [9]
Estimated Sediment Yield for Study Area (in tons/mi^2/yr)	**2930**
Expected Sediment Yield after Erosion Control Treatments (in tons/mi^2/yr)	**2249**

Table 4.4: Sediment Yield and Source Load Allocation for the Zayante Study Area. Sediment yields were generated from values averaged over each subwatershed (Table 4.3) and adjustments based on known sediment sources and best professional estimates. Percent controllable was based on BMP's and current sediment source control methods. Since length or area measurements are rounded, calculations may not produce exact values.

**** Footnotes on Following Page***

Footnotes for Table 4.4

1) Erosion rates from Hillslope and Ridge THP Roads and Skid Trails is taken from CDF (1993) estimates for Forestry Roads Currently in Use with a delivery efficiency assumed to be 42%. Soil bulk density was assumed to be 85 lbs/ft^3.

2) Erosion rates from Inner Gorge THP Roads and Skid Trails is taken from CDF (1993) estimates for Forestry Roads Currently in Use with a delivery efficiency assumed to be 100%. Soil bulk density was assumed to be 85 lbs/ft^3.

3) Erosion rate from Hillslope and Ridge Public and Private Roads was estimated using a combination of road surveys conducted by SH&G and CDF(1993) estimates for Non-Forestry Roads with a delivery efficiency assumed to be 42%. SH&G estimated erosion rates from road cuts using a USDA-NRCS method. This rate was then tripled to account for erosion from road surfaces, inside ditches and road shoulders producing an erosion rate of 120 tons/mi/yr, which was comparable to the CDF rate.

4) Erosion rate from Inner Gorge Public and Private Roads was estimated using a combination of road surveys conducted by SH&G (see Footnote #3) and CDF(1993) estimates for Non-Forestry Roads with a delivery efficiency assumed to be 100%.

5) Erosion from THP lands taken from CDF (1993) estimates of 0.28 yd3/ac/yr, which converts to a sedimentation rate of 87 tons/mi2/yr (assuming 42% delivery efficiency). This estimate was assumed to only include surface erosion features such as rilling, gullying and sheetwash. Soil bulk density was assumed to be 85 lbs/ft^3.

6) Erosion rates from Other Urban and Rural Lands were estimated from sedimentation rates in Loch Lomond Reservoir (Brown, 1973). This estimate was assumed to include surface erosion features as well as erosion from mass wasting from an assortment of land uses including urban and rural residential and timber harvests. Therefore, 50% of the estimated value was subtracted from this category and added to the mass-wasting category.

7) Sediment Yield from Mass Wasting was estimated by taking 50% of the value from Other Urban and Rural Lands and adding estimated erosion rates from known active landslides in the project area. An additional amount was also added to account for unknown mass wasting sources. This category also accounts for mass wasting from timber lands and roads that was not accounted for in Categories 1-5.

8) Sediment Yield from Channel Erosion is assumed to come from two sources, bank erosion (assumed to be 60% of the process) and channel downcutting (assumed to be 40% of the process). Bank erosion was estimated based on field surveys conducted by Don Alley. The total cut area for the survey was calculated and multiplied by an assumed retreat rate of 0.5 feet per year. The volume was then divided by the total stream mileage surveyed to produce a sediment yield per mile of stream. Since no data are available for rates of channel downcutting in the Santa Cruz Mountains, channel downcutting was assumed to amount to 40% of the Channel Erosion sediment yield. The combined value of bank erosion and channel downcutting was converted to tons/mi^2/yr by multiplying by the stream mileage in the studied watersheds and dividing by the total drainage area. Soil bulk density was assumed to be 100 lbs/ft^3.

9) Based on average annual synthetic suspended sediment load estimate from Zayante Creek, based on data collected in the early 1970's, plus an additional 10% to account for bedload (see Appendix C in Technical Addendum).

is 2,930 tons mi^{-2} yr^{-1}. This can be compared to the extrapolated sediment yield developed from sediment transport estimates taken at the Zayante Creek at Zayante gage. The gage data shows a sediment yield of 5,400 tons mi^{-2} yr^{-1} when 10% is added to the suspended sediment yield results to account for bedload. Though the estimated sediment yield value is substantially lower than gage estimates from Zayante Creek, this lower value makes sense when considering factors such as the trapping efficiency of Loch Lomond reservoir and sediment reduction efforts in recent decades.

As part of a TMDL, estimates of the percent “controllable load” and “remaining load” allocation need to be made for each sediment source category. In general, these estimates represent a judgment similar to those made in previous investigations from other sediment TMDLs that have been approved by the USEPA (Redwood Creek, 1998; Protocol for Developing Sediment TMDLs, 1999). The “controllable load ” reflects a number of qualitative and quantitative factors, including the effectiveness of past erosion control and drainage projects.

Estimates for controllable loads in the Zayante Area Watershed were made considering technical and logistical issues including: geologic stability, access to lands, costs, and potential hydrologic impacts. The reasoning behind the percent controllable load for individual sediment source is as follows:

- **Hillslope THP Roads and Skid Trails (50%):** Reduction of sediment loads from THP roads and skid trails on hillslopes will largely depend upon cooperation with landowners, monitoring and maintenance of roads beyond the period required by CDF and additional expenditure. Sediment load reductions from existing roads could be tied to future timber harvest proposals (See THP recommendations). For these reasons, it was assumed that only a 50 percent reduction could be achieved.

- **Inner Gorge THP roads and Skid Trails (50%):** Inner gorge THP roads and skid trails typically occur within a geologically unstable area, reducing the potential effectiveness of treatments. For this reason in addition to the reasons cited above for hillslope THP roads and skid trails, only a 50 percent reduction is assumed.

- **Hillslope Public and Private Roads (50%):** Hillslope erosion control will largely depend upon the cooperation of multiple landowners for private roads and Santa Cruz County for public roads. This will be especially important to create systematically continuous drainage systems. Treatment of hillslope drainage should result in a beneficial reduction in mass wasting and concentration of flow in the inner gorge slopes. Although geologically more stable than inner gorge slopes**,** landownership is predominately private. For these reasons, a 50 percent reduction in supplies was assumed.

- **Inner Gorge Public and Private Roads (50%):** Inner gorge roads are largely publicly owned and assumed accessible. Private inner gorge roads may have limited accessibility depending upon landowner cooperation. Treatment success may be difficult due to unstable geologic setting and steep terrain. For these reasons, the controllable load has been set to 50 percent.

- **Active and Recent THP parcels (30%):** Similar to THP roads and skid trails, cooperation with landowners will be the key to treatment and sediment reduction. Incentives to treat past harvest plots may only arise with future timber harvests on the same or nearby parcels. THP parcels in recent years have occurred in steeper terrain and some parcels are within inner gorge slopes. For these reasons, it is assumed that sediment loads can only be reduced by 30 percent.

- **Other Urban and Rural Lands (30%):** Other urban and rural lands are a mix of public and private ownerships, thus limiting factors are funding resources and landowner (private or agency) cooperation. For these reasons a 30 percent reduction has been assumed.

- **Mass Wasting (Natural and Human Caused) 10%:** Mass wasting in this sediment load allocation is the episodic and non-point source component, rather than known point sources (note: point sources of chronic fine sediments such as Mount Hermon Slide are addressed separately from the "controllable non-point sources"). The "human caused" component results from excessive grading and/or poor drainage conditions on roads and development on hillslopes and in the inner gorge. Direct treatment of landslides is usually difficult and expensive and in many cases requires access to private lands. However, proper treatment of surface drainage and erosion problems within the categories listed above should help reduce human caused mass wasting. The 30% reduction is assumed to be an ancillary benefit to treatment of surface erosion problems.

- **Channel Erosion (20%):** Treatment of channel erosion problems is difficult due to lack of construction access and geologic instability. Bank erosion problems are often expensive to treat and are usually not undertaken unless valuable property or structures are at risk. In addition, installation of bank control structures may cause more bank erosion thereby undoing benefits. For these reasons, sediment reduction at channel erosion sites is assumed to be 20 percent.

In this "phased approach" to determine sediment sources and yields, estimates of controllable load have been made for each sediment source based on the proposed application of typical and suggested Best Management Practices appropriate for local conditions (discussed further in Chapter 5). For each sediment source load category, suggested reductions reflect an aggressive approach to watershed improvements and project implementation. The timeline for implementation of suggested management measures is 25 years. Within this period, it is anticipated that the proposed sediment source reduction program will result in substantial instream habitat improvements, while acknowledging that within this period, extreme storms and episodic sediment loading will occur.

The remaining load allocations for the Zayante Study Area, if sediment source reductions are achieved, result in a total sediment yield of 88,400 tons yr^{-1}or 2,250 tons mi^{-2} yr^{-1}. If the reductions are met, fine sediment loading would be reduced to a level 1/2-1/3 of the sediment yield rate measured at Zayante Creek in the 1970's.

5.0 Objectives for Aquatic Habitat Improvement - Numeric Targets

For sediment impairment in the San Lorenzo River and Zayante Area Streams, the strategy is to reduce chronic fine sediment input through implementation of erosion control measures (described in Chapter 6) and to monitor aquatic habitat conditions in substrate quality and pool development. This chapter describes the goals of erosion control projects and ***numeric targets*** for improvement in streambed substrate quality to a level that removes the impaired condition.

The freshwater lifecycle for salmonids require coarse substrate and appropriate hydraulic conditions for successful reproduction and rearing of young fish. Spawning occurs within gravel deposits situated at the end or tail of pools and head of riffles. When females dig a nest or *redd* in the gravel, significant clearing of fine sediment in the gravel deposits occurs (Cordone and Kelley, 1961). The incubation period for salmonid eggs may take up to three months and during that time there must be adequate water circulation to oxygenate the eggs. When hatched, the fish remain in the gravel as *sac fry* and have very limited mobility within the gravel deposits. After growing and emerging from gravel the juvenile fish become very active in swimming to avoid being swept downstream, to seek refuge from predators and to find food for growth.

The quality of streambed habitat for these life cycle stages can become seriously disrupted by influx of fine sediments. Coarse substrate and redds can be buried by influxes of fine sediments that move along the bed even during summer low flow periods. Fine sediments can clog redds, reduce water circulation and kill or force early emergence of sac fry thereby decreasing the chances of survival. Fine sediments can also significantly reduce rearing habitat and escape cover for fry and juveniles by burying gravel, cobble and boulder areas on the streambed; lack of escape cover has been cited as a limiting factor for salmonid production in the streams of the Zayante Study Area and in the San Lorenzo River Watershed (Alley, 1999).

The amount of impairing fine sediments in streambed substrate can be assessed through physical measurements of bed particle sizes. The best measure of escape cover quality and excess fine sediments is particle *embeddedness.* Embeddedness is the percent of particles greater than 16 mm that are buried in fine sediments. Generally, particles buried more than 25 percent have significantly less quality as escape cover.

A second measure of habitat impairment is the percent of fine sediment less than 4 mm found within a sample of bed substrate. Generally, fine sediment content in excess of 30 percent has been found detrimental to spawning success and primary benthic invertebrate productivity (Koski, 1975). The percent fines can be measured from surface measurements or *pebble counts*, or by a sieving analysis of a dried bulk sample removed from the streambed, usually from a riffle. Embeddedness is a simpler and more direct measure of escape cover quality than pebble counts. Bulk sampling is labor intensive and its statistical significance is highly dependent upon numerous samples.

For these reasons ***embeddedness*** and ***percent fine sediment less than 4 mm*** were chosen as the numeric targets to eliminate the impaired condition. The target for embeddedness was set at 25%. The percent fine sediment target was set at 30%. For embeddedness, the minimum sample size of 16 mm represents an explicit Margin of Safety (MOS). Research in Zayante Area streams has found that cobble and boulder sizes typically greater than 64 mm are more closely associated with escape cover. Using 16 mm particles expands the numeric target requirement to a more extensive sample of the bed substrate conditions and more thoroughly addresses spawning gravel quality and aquatic food production. The targets can be modified in the future as new data is developed.

In the future, numeric targets should be developed for pool depth and habitat quality (see monitoring recommendations below).

5.1 1999 Streambed Conditions and Bed Census Assessment

To gain a preliminary understanding of current streambed conditions, measurements of bed substrate were conducted during low flow conditions at the 14 locations shown in **Figure 5.1 and Table 5.1**. The instream monitoring and surveying was conducted collaboratively by SH&G and CWC staff and volunteers. Monitoring sites included surface pebble counts, embeddedness measurements, and subsurface particle size distributions. Some measurements were taken at locations of previous surveys conducted in 1996 and 1978.

Table 5.1: Bed Census Monitoring Sites

Creek Name	Location	Sample Dates
Zayante Creek	Graham Hill Road	1996,1999
	above Woodwardia Weir	1996, 1999
	at Zayante Store	1999
	below Cobble Creek @ scour logs	1999
	above Mountain Charlie Gulch	1978, 1999
Mountain Charlie Gulch	at confluence with Zayante Creek	1978, 1999
Bean Creek	below Mount Hermon Slide	1999
	above Mount Hermon Slide	1999
	at 1958 DWR Site	1996, 1999
	below Lockhart Gulch confluence	1996,1999
Newell Creek	upstream of Steel Bridge	1999
	upstream of Glen Arbor Bridge	1999
Love Creek	Downstream of Love Creek Slide	1999
Lompico Creek	at Road Mile 0.32	1999

Surface pebble counts were taken by random walk technique developed by Wolman (1954). Samples were taken below bankfull along a pool/riffle/pool sequence and the diameter of individual particles were measured along their intermediate axis and tallied within size classes (e.g. less than 2mm, 4mm, 8mm, 16mm, etc). Over 100 particles were measured at each monitoring site. The data was compiled and reduced to yield statistical sediment size distributions including the mean size (labeled D_{50} or the particle size

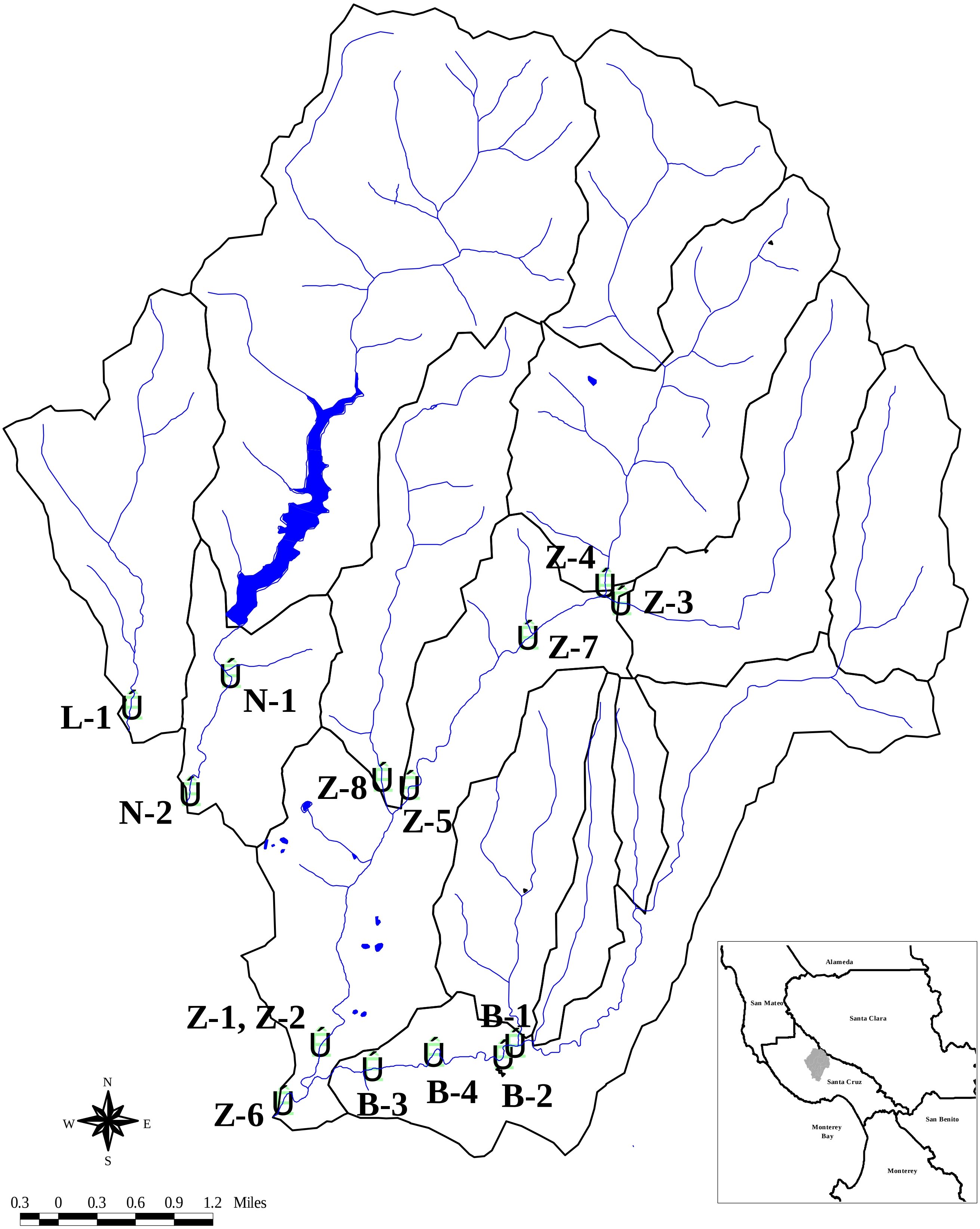

Figure 5.1: Surface pebble count monitoring locations from 1999 surveys

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that is larger than 50 percent of the total sample), and the end points of the sample standard deviation (D_{16} is the lower end of the sample sediment size being larger than 16 percent of the total sample while D_{84} represents the sample size that is 84 percent larger than the entire sample). This statistical data describes the mean size and the range of sizes within the sample, as well as the percent of fine sediments. The results of pebble counts are shown in **Figure 5.2**.

Particle embeddedness was measured in the pebble counts for grain sizes over 16mm, which was the minimum grain size measured in earlier studies (HEA, 1980). Visually, the embedded portion of a particle appears cleaner than the algae stained unembedded portion, particularly in summer low flow conditions. **Table 5.2** summarizes the measured bed conditions at each monitoring site along with recommended numeric targets. The target reduction in embeddedness is consistent with samples of good quality substrate escape cover measured by Alley (1998), although particles Alley measured were greater than 64 mm.

Table 5.3 summarizes the results from 1978 to 1999 for the repeated sampling locations. In general, there appears to be an increase in sand from 1996 to 1999 at monitoring sites on Zayante and Bean Creeks. The increase in sand in Lower Zayante and Bean Creeks is consistent with an increase in erosion documented in 1998 and 1999 stream surveys (Alley 1998; Don Alley - Personal Communication, 1999). The heavy rains of February 1998 triggered landslides and bank erosion within the riparian corridors of Bean Creek, Lockhart Gulch, and lowermost Zayante Creek.

Table 5.3: Comparison of pebble count sediment size distributions for repeated monitoring sites

Stream	Station	Date	Grain Size Distribution (in mm)			
			D_{50}	D_{16}	D_{84}	% < 4 mm
Zayante	Riffle above Graham Hill Road	4/5/79	69	23	180	8
		3/21/80	111	37	200	31
		10/24/96	40	12	128	7
		6/26/99	53	16	120	16
Zayante	Riffle above Woodwardia Weir	2/9/79	78	27	220	6
		4/5/79	86	38	304	2
		3/22/80	86	31	227	2
		10/24/96	66	26	125	4
		5/22/99	21	8	71	36
		5/22/99	46	8	148	41
Zayante	Above Mountain Charlie Gulch	12/12/78	87	20	236	4
		6/22/99	38	11	222	11
M.C. Gulch	At Confluence w/ Zayante Creek	12/12/78	100	27	228	12
		6/22/78	12	4	182	38
Bean	Riffle at 1958 DWR Site	8/8/96	40	19	81	4
		7/30/99	25	10	57	23
Bean	First Riffle below Lockhart Gulch	2/9/79	44	27	72	0
		8/8/96	29	12	50	0
		6/5/99	24	7	55	42

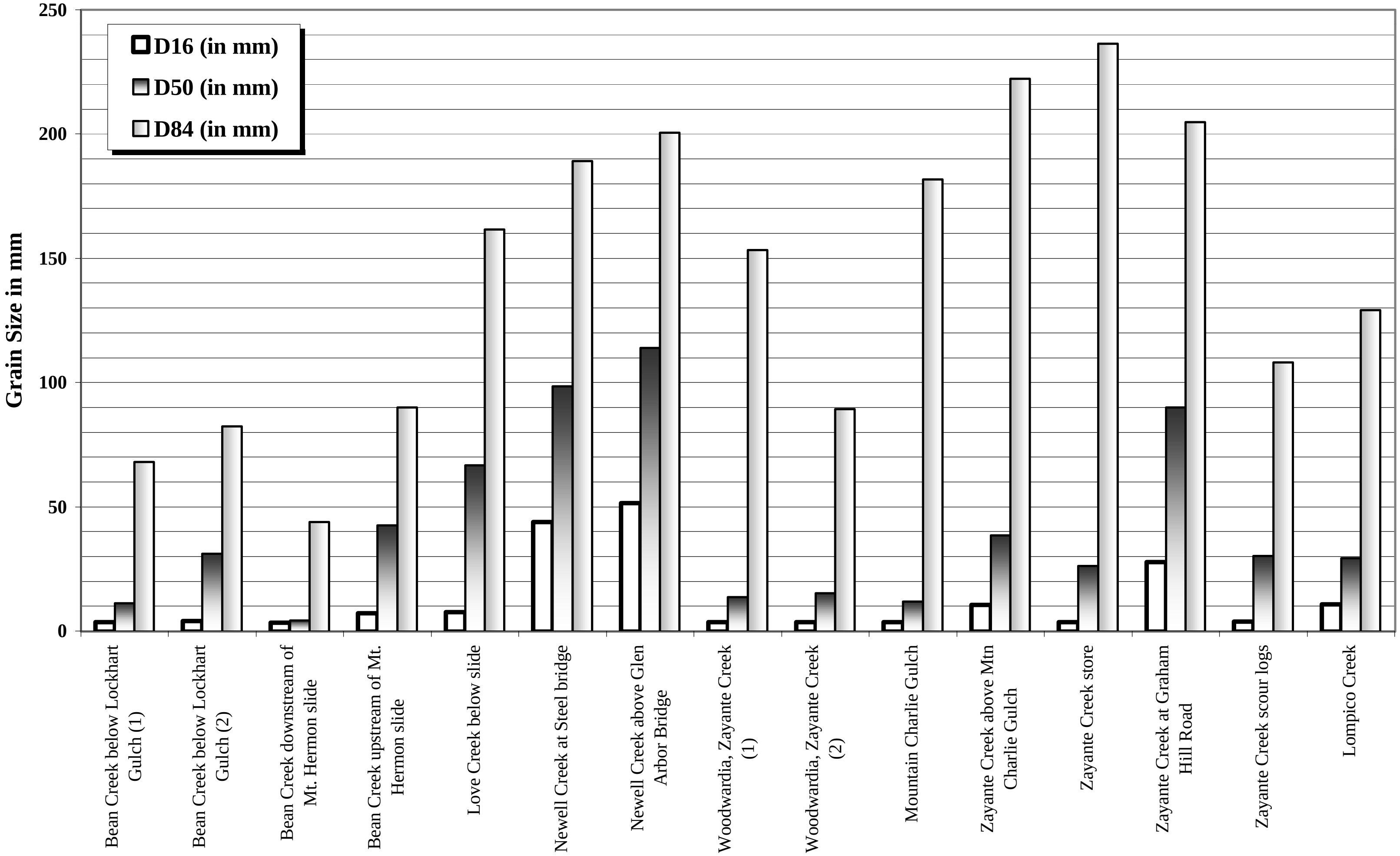

Figure 5.2: Particle size distribution for pebble count sample locations from 1999 by Swanson Hydrology & Geomorphology and Coastal Watershed Council.

Sample ID		Date	Location Description	< 4mm	Pebble Count Embeddedness (particles > 16 mm)
Current Condition	B-1	6/5/99	Bean Creek below Lockhart Gulch	42%	52%
			Proposed Target	**30%**	**25%**
Current Condition	B-2	7/30/99	Bean Creek at 1958 DWR site	23%	50%
			Proposed Target	**30%**	**25%**
Current Condition	B-3	7/10/99	Bean Creek downstream of Mt. Hermon slide	55%	60%
			Proposed Target	**30%**	**25%**
Current Condition	B-4	7/24/99	Bean Creek upstream of Mt. Hermon slide	15%	49%
			Proposed Target	**30%**	**25%**
Current Condition	L-1	9/18/99	Love Creek below slide	12%	44%
			Proposed Target	**30%**	**25%**
Current Condition	N-1	6/19/99	Newell Creek at Steel bridge	1%	23%
			Proposed Target	**30%**	**25%**
Current Condition	N-2	6/19/99	Newell Creek above Glen Arbor Bridge	4%	22%
			Proposed Target	**30%**	**25%**
Current Condition	Z-1	10/21/99	Woodwardia, Zayante Creek	38%	54%
			Proposed Target	**30%**	**25%**
Current Condition	Z-2	5/22/99	Woodwardia, Zayante Creek	34%	47%
			Proposed Target	**30%**	**25%**
Current Condition	Z-3	6/12/99	Mountain Charlie Gulch	38%	24%
			Proposed Target	**30%**	**25%**
Current Condition	Z-4	6/22/99	Zayante Creek above Mtn Charlie Gulch	11%	39%
			Proposed Target	**30%**	**25%**
Current Condition	Z-5	6/19/99	Zayante Creek store	27%	42%
			Proposed Target	**30%**	**25%**
Current Condition	Z-6	6/26/99	Zayante Creek at Graham Hill Road	16%	46%
			Proposed Target	**30%**	**25%**
Current Condition	Z-7	6/12/99	Zayante Creek scour logs	28%	25%
			Proposed Target	**30%**	**25%**
Current Condition	Z-8	11/14/99	Lompico Creek	6%	48%
			Proposed Target	**30%**	**25%**

Table 5.2: Surface pebble count and embeddedness results from the 1999 surveys and proposed targets for each bed census monitoring site.

6.0 SEDIMENT REDUCTION IMPLEMENTATION PROGRAM AND RECOMMENDATIONS

6.1 EXISTING PROGRAM S AND IMPLEMENTATION STRATEGY

Erosion and sediment control in the San Lorenzo River Watershed and Zayante Area is the subject of several local, state and federal regulations and programs. The objective of chronic fine sediment reduction strategy is to direct recommendations for removing sediment impairments to the appropriate existing programs. In basic terms, the recommendations of this report are primarily directed towards the Santa Cruz County Planning Department regulatory efforts in riparian habitat management and erosion control, the Environmental Health Department in Watershed Planning and Water Quality Protection Planning, and Public Works Department in road maintenance and erosion control. Other agencies (the City of Scotts Valley, the Santa Cruz County Resource Conservation District, U.S. Department of Agriculture Natural Resources Conservation Service, California Department of Forestry, California Department of Fish and Game, National Marine Fisheries Service, Regional Water Quality Control Board) also have roles in reducing fine sediment in the Zayante Area.

Coordination among the various groups conducting watershed planning and projects is essential for to avoid duplication of effort and/or working at cross-purposes. The following is a description of existing programs related to sediment and water quality management.

One purpose of local sediment control efforts is to meet the requirements of the Federal Clean Water Act and State authority over its implementation. Federal Regulations require that states identify measures needed to implement a TMDL in the state water quality management plan (40 CFR 130.6). The U.S Environmental Protection Agency (EPA) has established policies that emphasize the importance of timely implementation of non-point source control measures. EPA expects that the state will incorporate the TMDL (in this case the overall San Lorenzo TMDL, yet to be developed by RWCQB) upon approval by EPA, as required by 40 CFR 130.6. Other federal regulations concern the impacts of federal activities, most notably any activity within waters of the United States (section 404 of the Clean Water Act for wetlands protection) or within areas where Endangered Species occur (Endangered Species Act). The ESA provides for development of a "recovery plan" and designation of critical habitat for listed species; in this regard the listing of anadromous fish (Steelhead and Coho Salmon) and the California Red Legged Frog require an effort to improve habitat conditions and expand populations to sustaining levels. The U.S. Environmental Protection Agency (EPA) is involved in wetlands regulatory issues and in providing grant money to conduct water quality studies and development of watershed plans.

The California Department of Fish and Game (CDFG) and the Regional Water Quality Control Board (RWQCB) largely carry out California regulations governing sediment, erosion and aquatic habitat in streams. The RWQCB is primarily responsible for implementing CWA measures as discussed above. CDFG regulates activities within stream zones through the section 1600 regulations. CDFG also provides grant monies and technical assistance for implementing wildlife and fisheries habitat improvement projects.

Santa Cruz County has several water quality protection programs in place addressing sediment, nitrates and pathogens. Sediment and erosion control is regulated under the grading ordinance and the Erosion Control Ordinance (ECO) that addresses problems associated new development and existing erosion problems. The ECO limits grading activities on steep slopes and requires runoff control and soil stabilization measures to address short-term and long-term problems. The Riparian Protection Ordinance limits activities that occur and affect riparian vegetation and habitat, a factor important for stream bank stability.

Santa Cruz County actively participates outside of regulation in areas of project development and implementation for erosion control and stream habitat enhancement. The San Lorenzo River Watershed Management Plan was prepared in 1979 and has guided the water quality and habitat protection efforts. As part of the a current Watershed Plan update process, Santa Cruz County with funding from the California State Coastal Conservancy is developing a specific Steelhead Enhancement Plan for the San Lorenzo River, including provisions for monitoring substrate conditions relevant to TMDL monitoring of fine sediment in substrate. The Santa Cruz County Public Works Department is developing a public roads stream-crossing database for fish habitat enhancement projects and erosion and drainage control.

Other important programs include efforts by the City of Santa Cruz (an owner of 3,800 acres of watershed lands in the San Lorenzo River Watershed), the Santa Cruz County Resource Conservation District (SCCRCD) and the Coastal Watershed Council (CWC). The City of Santa Cruz is in the initial process of preparing a Habitat Conservation Plan (HCP) for all city activities affecting endangered species habitat, including anadromous fish and red-legged frog. The City is also preparing a watershed resource management plan for lands in the Newell Creek and Zayante Creek watersheds.

The SCCRCD programs include efforts to implement erosion control projects (recently under EPA 319 grants), develop plans and public education targeted towards specific activities (e.g. road maintenance and improvement, manure management and sediment in agricultural runoff) and develop watershed-level plans. The Coastal Watershed Council (CWC) provides important public education and participation functions for community awareness and involvement. Moreover, CWC provides data on stream habitat quality and water quality in a variety of streams.

The erosion control recommendations stemming from this report are directed towards chronic fine sediment sources and their location relative to impaired fish habitat. There are obvious tie-ins to the existing programs described above and an effort was made to tailor recommendations to fit and augment existing programs and not create new ones.

The recommendations presented below focus upon reduction of chronic fine sediments generated from road networks and parcels. Obvious and known "Point Sources" of fine sediment, which should be the first priority for investigations for treatment, are called out under the appropriate recommendation category. For "non-point source" areas, further data refinements are necessary to locate and prioritize specific projects, however development and implementation of Best Management Practices (BMP's) for road maintenance could move forward immediately. The recommendations are incorporated into separate public and private road and land improvement programs and include measures addressing control of sediment during emergency repairs, funding for upgrading existing road networks and funding and implementing BMP's. It must be emphasized that future data collection through the other programs and monitoring could lead to revisions in treatment recommendation and numeric targets presented in this report.

6.2 EFFECTIVENESS OF PAST SEDIMENT REDUCTION PROJECTS AND PRACTICES IN THE STUDY AREA

To place the proposed sediment reduction programs in perspective, it is instructive to review the sediment control measures implemented over the past 20 plus years since the completion of the San Lorenzo River Watershed Management Plan in 1979 and implementation of the Forest Practice Rules in 1973.

6.2.1 COUNTY SEDIMENT CONTROL PROJECTS

Sediment control efforts in the Zayante Area have focused on areas south of the Zayante Fault in sandy soils of the Santa Margarita Formation. Example projects include surface erosion stabilization on roads and in recent residential developments. These efforts include timber slough /retaining walls on road cuts, check dams on gully channels and installation of adequate road drainage systems that account for phenomena such as debris clogging. Information compiled in this and other studies shows that erosion in sandy Santa Margarita soils can persist for many years following the initial disturbance. Approximately five to ten years after a residential development of about 50 homes was completed in the Lower Newell Creek Watershed, erosion and sediment delivery to streams from roadcuts and the drainage system was still very high. Santa Cruz County received a $600,000 grant from the California Department of Fish and Game to construct twenty gabion check dams in incised gully channels, install retaining walls to support failing roadcuts, renovate and reconstruct a sediment retention basin on Marion Avenue and revegetate barren areas surrounding Quail Hollow School.

These efforts were partly successful, serving to trap perhaps 70 percent of eroded sediments, based on visual observation (no actual data exists to evaluate effectiveness). All but the revegetation effort worked reasonably well to offset continued accelerated erosion. Revegetation efforts on exposed sandy slopes at Quail Hollow Middle School have been less successful, both in terms of sediment reduction and restoration of vegetation to protect unstable slopes; this is largely due to the dry sandy terrain and the physical impacts of kids playing on the revegetated slopes. Field reconnaissance of these and other sandy soil-dominated residential areas found that well engineered retaining walls supported by deep concrete caissons, buttressed over-steepened embankments and caught eroded sediments that in some cases became stabilized by vegetation **(Figure 6.1).** The estimated minimum cost, in sandy soils, to make land development and watershed uses compatible, was approximately $6,000 per home (Hecht, 1984).

6.2.2 Erosion Control Ordinance

Santa Cruz County has enforced an Erosion Control Ordinance (ECO) after the San Lorenzo River Watershed Management Plan was completed in 1979. ECO regulates land disturbance for new development requiring specific erosion control measures and restrictions on activities during the rainy season. This has led to substantial improvements in erosion from new development according to county staff that witnessed activities prior to the ECO enforcement. ECO is primarily applied to new land disturbance activities and existing problems have been difficult to address.

6.2.3 Forest Practice Rules

Timber harvest activities on private and public land in California are presently governed by Timber Harvest Rules that were initiated by the Z'berg-Nejedly Forest Practice Act of 1973. The California Department of Forestry (CDF) administers the rules for timber harvests plan permits. Prior to 1973, little control over grading activities or consideration of aquatic habitat issues was associated with carrying out a timber harvest plan. After 1973, the requirements for Timber Harvest Plans have steadily increased and include that erosion control and stream protection measures be developed, documented, reviewed and carried out. Often, experts are brought in to address issues ranging from geological stability and engineering designs to specific cultural resources and biological issues. Since 1973, many additions and modifications have been added to the rules governing timber harvest. However, the findings of the Scientific Review Panel report (1999) found that the FPR did not protect endangered salmonid habitat. SRP recommendations have been applied by the State Board of Forestry as an interim measure prior to development of site-specific watershed plans that will eventually guide timber harvest.

Under current conditions in the San Lorenzo River Watershed, timber harvest management of roads generally exceeds the attention given to some privately held roads for the period required under the THP rules (2-years). In some cases, drainage and erosion control improvements on private roads that access THP lands is achieved through harvest activities. However, the fact remains that timber harvest does open up new roads and skid trails, or reactivates older roads and trails that were constructed prior to the timber harvest rules and do not meet current standards. Timber roads are often eventually or concurrently used for residential purposes even though they do not have to meet the standards required for residential roads under County policies and ordinances. After the harvest period, trespass or residential use can induce erosion from timber roads.

6.3 PROPOSED SEDIMENT REDUCTION MEASURES

6.3.1 OVERALL APPROACH

The overall goal of the sediment reduction recommendations is to reduce chronic fine sediment inflow streams to a level that removes aquatic habitat impairment. The priorities for chronic fine sediment reduction should be guided by the severity of chronic erosion sites, their proximity to watercourses, the efficiency of sediment delivery to streams and the cost-effectiveness of control efforts. **Table 6.1** shows the estimated sediment reductions anticipated from implementation of the proposed measures. The projected reductions are not designed to address the episodic large storm events that trigger landslides (i.e. 1982, 1998).

Table 6.1 Controllable Chronic Fine Sediment Loads for Zayante Area Streams

Setting	Area or Length Represented by Source	Controllable Load (tons year^{-1})	Percent of Controllable Load
Point Sources	N/A	1,470 tons yr^{-1}	5.5%
Inner Gorge Roads in sandy soils	9.7 miles	766 tons yr^{-1}	2.9%
Inner Gorge Roads outside sandy soils	52.6 miles	4,174 tons yr^{-1}	15.6%
Hillslope roads: THP, public and private	191.4 miles	7,424 tons yr^{-1}	27.8%
Urban, Rural and THP Lands	35.7 square miles	6603 tons yr^{-1}	24.7%
Concurrent treatment of mass wasting load resulting from point source, surface erosion and drainage treatments.[1]	N/A	4,425 tons yr^{-1}	16.5%
Channel and Streambank Erosion	23.5 miles	1,886 tons yr^{-1}	7.1%
Total	**N/A**	**26,747 tons yr^{-1}**	**100%**

[1] Chronic fine sediment sources from mass wasting will be decreased by improved drainage systems that reduce surface erosion. Note that only a portion of mass wasting load is chronic fine sediment.

The proposed treatment measures described below are presented at a conceptual level; site-specific assessments must be made to determine the appropriate treatment at a specific site. Treatment measures in this report are distinguished as two specific types: 1) Best Management Practices (BMPs) for routine activities involving road clearing, ditch maintenance and spoils management; and 2) BMP projects are defined permanent or semi-permanent features such as drainage structures, culverts, retaining walls, pavement, curb and gutter systems, and sediment retention basins.

Table 6.2 shows results from technical literature that significant decreases in sediment production result from implementing various BMPs. The applications of these measures are common and in general apply to the Zayante Area and San Lorenzo River Watershed Streams. **Table 6.3** shows the types of measures that can be applied in the San Lorenzo River Watershed given parcel and road disturbances in either inner gorge or hillslope setting. The measures are based upon strategies of drainage control and energy dissipation, soil stabilization measures and sediment retention. The application of these measures may be difficult in some areas of the San Lorenzo River watershed where flow and sediment volumes are high and the terrain is steep. However, the strategies and measures provide a basis for innovation to meet the need for cost effective techniques that reduce erosion and sediment generation.

Table 6.2: Examples of various Road Surface Projects in Forested Settings and examples of sediment reductions resulting from Best Management Practices for road cuts and fill slopes

Stabilization Measure	Area Treated	Percent Decrease in Erosion	Reference
Tree planting	Fill Slope	50	Megahan, 1974b (cited in Megahan 1987, 1980)
Straw mulch	Fill Slope	72	Bethlahmy and Kidd, 1966
Wood chip mulch	Fill Slope	61	Bethlahmy and Kidd, 1966
Straw mulch, netting and planted trees	Fill Slope	98	Megahan, 1974b (cited in Megahan 1987, 1980)
Straw mulch and netting	Fill Slope	99	Bethlahmy and Kidd, 1966
Grass and legume seeding	Road cuts	71	Dyrness, 1970
Terracing	Cut slope	86	Unpub. Data Intermountain Forest and Range Experiment Station, Boise
Straw Mulch	Cut slope	32-47	King 1984
Gravel Surface	Road Tread	70	Burroughs and King (cited in Megahan, 1987 and 1980)
Dust Oil	Road Tread	85	Ibid
Bituminous Surfacing (asphalt seal)[1]	Road Tread	99	Ibid

[1] According to the Santa Cruz County Road Department (Bill Williamson, Public Works) significant erosion problems commonly occur where private paved roads are installed without a proper drainage system and uncontrolled discharge onto public roads, especially in the inner gorge slopes. He suggests that a compacted gravel road may be superior to asphalt paving where a drainage system is absent. Compacted gravel could have roughness to reduce runoff velocity and at least some infiltration capaicty. In addition, any sediments delivered to streams would not be saturated in toxic bituminous substances, a potentially significant water quality contaminant.

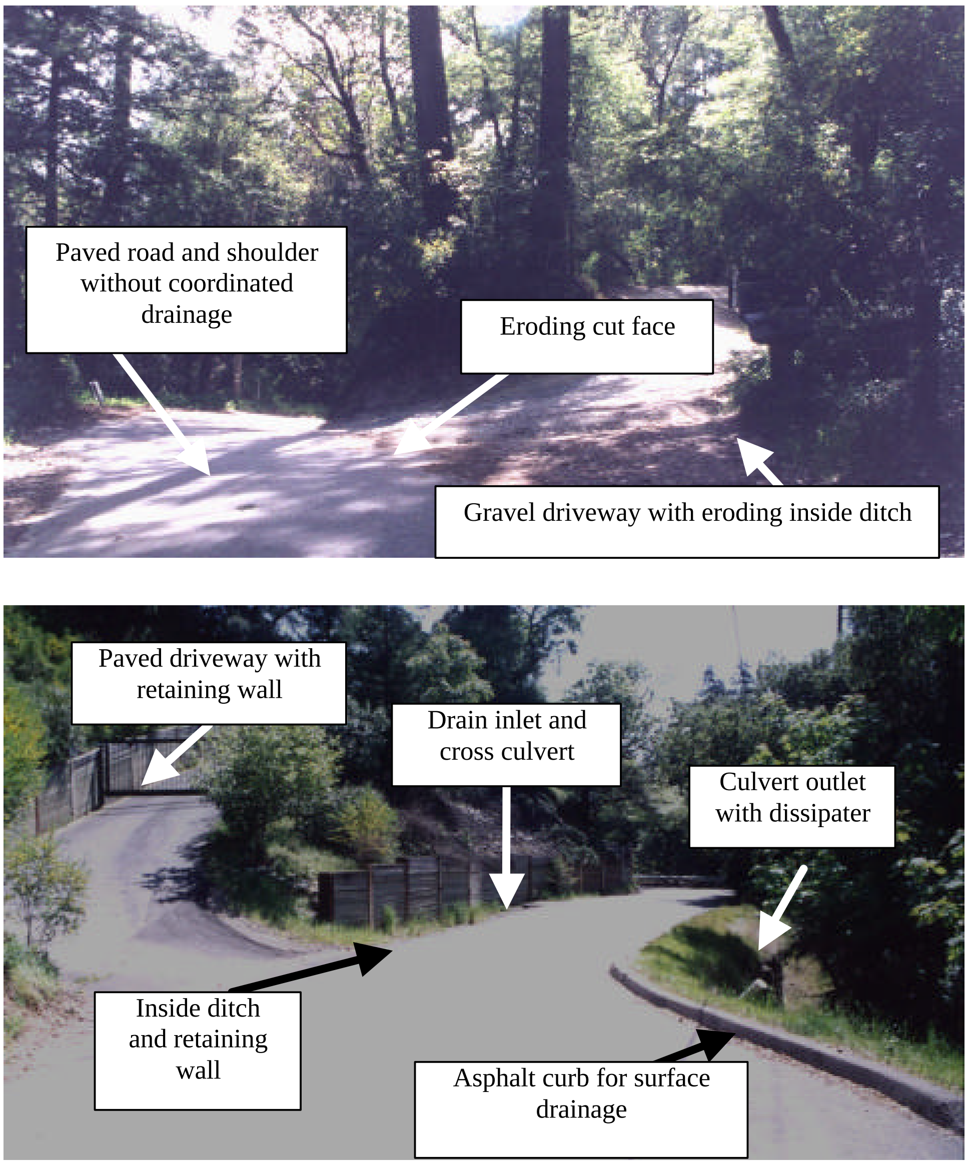

Figure 6.1: Example of Public and Private Mountain Roads in the Zayante Area With (bottom photo) and Without (top photo) Erosion Control Measures in Place.

Table 6.3: Available Strategies and Measures to reduce erosion and chronic sediment fine sediment for sites situated in inner gorge and hillslope settings.

SITE LAND USE	***TREATMENT STRATEGY***	***TREATMENT MEASURE***	***NOTES***
Roads	**Drainage Control**		
	Disperse/Slow Runoff	Grass-lined Swales	Application May be limited due to steep slopes
		Infiltration Trenches	May be limited due to saturated conditions
		Rolling Dips + Water Bars	Works well on unpaved roads and small paved roads in many terrains; must be installed correctly and maintained
		Outslope roads	Can be effective but reduces roads safety; should be applied to seasonal roads only.
		Pave roads with compacted gravel/decomposed Granite	Requires periodic replacement, re-compaction and Maintenance
	Control Concentrated Runoff	Place flow in culverts	Must be sized appropriately for runoff volume.
		Extend culvert outlets Fit with energy dissipaters	
		Use curbs to direct runoff on paved roads	
	Sediment/Erosion Control		
	Soil Stabilization	Pave road surfaces with asphalt	Must install drainage control systems to handle increases in concentrates runoff volume and peak flow
		Pave roads with compacted gravel/decomposed Granite	Requires periodic re-compaction/ Maintenance
		Rock line open drainage ditches	
		Install retaining/slough walls to stabilize road cuts and trap sediments.	Slough walls require periodic cleaning.
		Stabilize roadcuts and sidecast with vegetation	Should choose appropriate plant species and avoid exotic invasive plants.
	Sediment Retention	Install staged catch basins	Can handle only small volumes of sediment and runoff
		Install vegetated filter strips	May have limited application due to plant growth conditions
		Install organic debris filters.	May be difficult to hold in place; decays over time
		Install sediment retention basins	May have limited application due to steep terrain
Developed Parcels	**Drainage Control**		
	Control runoff from impervious surfaces	Install roof gutter and downspout systems and control discharge in pipe	
		Install pipe extensions and energy dissipaters to safe outlet	
	Disperse runoff	Direct runoff to infiltration trenches	Application may be limited in areas of high saturation; may create landslide hazard.
		Direct runoff into grass lined swales and/or open flat vegetated areas	Application may be limited due to steep terrain
	Sediment/Erosion Control		
	Soil Stabilization	Mulch and plant vegetation on exposed soils	
		Install retaining structures to support fill slopes	
		Install retaining / slough walls on cut slopes	
	Sediment Retention	Install vegetated filter strips in drainage paths and/or in flow dispersion areas	Application may be limited due to steep terrain
		Install catch basins at inlets or culvert discharge points, control outflow by dispersion and/or energy dissipation.	

Stream bank erosion management is an important area of concern in the sediment reduction program. Treatment techniques include traditional structures most commonly rip rap, bioengineered or biotechnical structures that incorporate vegetation in rip rap of other hard structures. Acquisition of easements to restore natural geomorphic processes and for allow erosion and riparian vegetation colonization to occur naturally is a possibility that should be explored. Application of low-cost approaches may be useful in some circumstances. All of these measures usually involve intensive engineering, consideration of liability on private lands and difficult construction access. Great care must be taken to offset the effects of hardening one bank that could amplify erosive energy on adjacent banks and lead to greater erosion. More scrutiny of bank protection projects by regulatory agencies has increased the complexity of designing and implementing bank protection projects. In sum, bank protection projects are usually expensive and should be carefully planned to meet specific objectives. Completing Recommendation A.1 below, geomorphic assessment should provide direction for reducing fine sediment input from channel banks.

6.3.2 RECOMMENDATIONS TO ACHIEVE SEDIMENT REDUCTION TO REMOVE IMPAIRMENT

RECOMMENDATION A.1: REFINE GEOMORPHIC DATA IN STREAMS

A more refined erosion survey should be combined with an assessment of physical habitat and geomorphic conditions in stream channels so that sediment reduction efforts can most benefit reaches where spawning and rearing habitats occur. The geomorphic survey would supplement fish habitat surveys and include quantified channel dimensions, channel pattern, local hydraulic conditions, and stream bank stability factors. An inventory of landslide and stream bank failures would help refine the sediment budget for in-channel sources, a major weakness in the current database. The geomorphic surveys could reveal other effective measures, not involving sediment control on roads, to improve aquatic habitat immediately in streams. For example, installing instream cover and hydraulic elements to improve fine sediment flushing or expanding the area for active channel processes can greatly improve habitat conditions. Based upon limited observations, there appear to be many opportunities for instream improvements. Typical costs for geomorphic surveys are about $1,000 per stream mile. Approximately 15 miles of surveys would be required on the mainstem and tributaries of the San Lorenzo River.

RECOMMENDATION A.2: MEASURE STREAMFLOW

Infilling stream beds with fine sediments and streamflow reductions are the most significant factors affecting fish habitat. Stream flow monitoring would help improve the understanding of aquatic habitat quality and whether groundwater development over the past 30 years has impacted surface flow. This would be conducted by "synoptic" or same time streamflow measurements at key locations to track groundwater loss and gain. These measurements would be conducted at a set of stations along each stream over spring to fall seasons. Low cost water level recorders ($800 per unit plus installation, maintenance and gaging costs) could provide a continuous record of flow.

RECOMMENDATION A.3: ESTABLISH AND MAINTAIN CHANNEL MONITORING PROGRAMS TO MEASURE SEDIMENT IMPAIRMENT AND THE EFFECTIVENESS OF SEDIMENT COTROL MEASURES.

Stream channel conditions have a great influence over habitat quality and impairment by fine sediment. The key habitat factors are: streamflow, sediment, nutrients and riparian corridor quality and these are interrelated (e.g. riparian vegetation influences bank erosion and stream temperature). Much data has been collected to document fish habitat quality in the Zayante Area, yet little has been completed to document geomorphic conditions that influence impairment of bed conditions by fine sediment. Geomorphic analysis and measurement of streamflow should provide a greater understanding of the physical factors in streams that influence habitat quality.

A well documented and justified set of measures to control fine sediment loading along stream channels should be developed through more detailed data collection and analysis of erosion sites. This to a great extent will be addressed in an upcoming project by Santa Cruz County and the California State Coastal Conservancy to develop a Steelhead Enhancement Program for the San Lorenzo River. However, the optimization of erosion control projects to balance best return on the expenditure of available resources has not been completed. The present database has been improved by use of the GIS based analysis of roads, however a complete understanding requires better mapping details.

As a part of the implementation program, channel monitoring should be conducted to document changes in fine sediments in the streambed and the relationship to habitat quality and fish populations. The Steelhead Enhancement Program described above is setting up a network of 15 monitoring stations covering a range of stream types, locations and conditions. This network should be maintained in the future in order to assess the effectiveness of sediment reduction programs.

RECOMMENDATION B: PUBLIC AGENCY MEASURES TO REDUCE SEDIMENT FROM PRIVATE LANDS

A common non-point source of fine sediments results from drainage modifications and/or soil disturbances on private lands. Parcel development often involves removal of stabilizing vegetation, grading and exposure of soils, increased runoff rates from impervious cover (i.e. roofs, roads, etc.) and concentration of runoff in efficient drainage collection systems (roof gutters, curbs street gutters and culverts). Storm runoff on private parcels is often discharged into private and/or public road drainage systems, which, in combination with steep terrain and high rainfall, often creates significant challenges for road agencies to control drainage and erosion.

RECOMMENDATION B.1: AMEND SANTA CRUZ COUNTY EROSION CONTROL ORDINANCE TO IMPROVE SEDIMENT REDUCTION IN SANDY SOILS

The Santa Cruz County erosion control ordinance should be amended to further prevent erosion and sediment delivery from land uses occurring within the area underlain by the Santa Margarita Sandstone Formation as depicted on the USGS Geology Map (**Figure A-4**). The City of Scotts Valley should also implement this amendment as part of their standard erosion control ordinances.

This study and others have identified land use disturbance in the Santa Margarita Formation as a significant source of chronic fine sediments. Visual evidence of chronic erosion in road cuts, graded and denuded areas and gully development is abundant. Data on stream habitat quality strongly suggests a link to habitat degradation from erosion in disturbed areas of Santa Margarita Formation. Moreover, some of the most challenging existing erosion sites occur along inner gorge slopes of disturbed Santa Margarita Formation. For these reasons, it is important not to create new problems. Therefore, activities should be regulated more intensively through an amended Erosion Control Ordinance as recommended below.

For new development in the designated Santa Margarita Sandstone areas, temporary and permanent erosion, and drainage and sediment control structures shall be designed, constructed and maintained to eliminate erosion and delivery of sediment offsite. Runoff from designated sites shall not increase in volume or flow rate and shall not concentrate runoff offsite for events up to the 50-year design storm as calculated by Santa Cruz County drainage design manual. It is fundamentally important that offsite runoff be safely conveyed to primary receiving waters without causing significant erosion, therefore engineering studies must demonstrate safe conveyance from project discharge point(s) through drainage ways to the primary receiving waters.

Erosion control structures could include retaining walls and revegetation on road cuts and shoulders, sediment retention basins, stormwater detention basins, extended culverts and energy dissipaters and armoring of ditches and channels. The structures shall also address other factors such as prevention of landslides and loss of groundwater recharge.

RECOMMENDATION B.2: DEVELOP AND ANALYZE ALTERNATIVES TO HARD BANK PROTECTION STRUCTURES

Bank erosion is often difficult and expensive to fix in the Santa Cruz Mountains. Often, installing new bank protection structures that are hard (e.g. rip rap, gabions, walls etc.) may cause more erosion when flow energy reflects to an unprotected bank. In many cases, structural bank erosion fixes address the eroding bank and do not consider the reach hydraulics or geomorphic stability. Hard structures alone can lead to more erosion.

A primary example of hardened bank impacts is the bank protection structure opposite the Mount Hermon Landslide, a well-known "Point Source". The toe of the Mount Hermon Slide is actively moving unconsolidated Santa Margarita Sands directly into the inner gorge and channel of Bean Creek. Typically, a landslide toe pushes the stream towards the opposite bank and apparently this was the case before bank protection was installed. Hardening the bank at this location exacerbates erosion of the landslide toe, which further undermines the Slide causing more earth movement and fine sediment loading into Bean Creek. This structure should be investigated as part of the recommended Mount Hermon Slide engineering feasibility study previously described in Recommendation B.3 below.

Recommendation B.2 seeks to analyze bank protection structure impacts and investigate whether non-structural solutions such as securing riparian buffers or restoring stable channel geometry and using re-vegetation are applicable. The County should develop a property easement acquisition fund and acquire grant monies to purchase eroding private properties in riparian corridors through a buyout program. Provide public and agency education and alternatives for streamside landowners to prevent accelerated erosion due to placement of hard structures along banks. Incorporate “bioengineering” into bank protection structures to address wildlife habitat issues.

RECOMMENDATION B.3: REDUCE EROSION FROM POINT SOURCES

Significant "Point Sources" of erosion from parcels identified in the study area include: The Mount Hermon Slide, McEnery Road, Skypark, Rancho Rio and Monte Fiore. These areas require immediate engineering feasibility studies aimed at reducing fine sediment production.

The Mount Hermon Slide has been a well-known "Point Source" of fine sediment for over 20 years. The Slide is mostly privately held with the predominate use being a sand quarry and sand processing. No work has been conducted to determine what, if anything can be done to reduce erosion along the slide toe. An engineering investigation should be conducted to determine what could be done, including an assessment of bank protection hardening along Bean Creek opposite the slide toe.

Excessive erosion problems or Point Sources also exist at Rancho Rio, a site underlain by Santa Margarita Sandstone. This site should also be investigated for engineering feasibility. This area will likely require drainage improvements to the Quail Hollow School parking lot, playing fields and building roofs. A project is needed to stabilize a large gully at this site.

An engineering feasibility study is also needed in the Skypark area to assess whether retaining walls, runoff retention basins and modifications to the current drainage system can be cost effective in reducing sediment loads. Similarly, an engineering feasibility is needed for managing runoff in the McEnery Road area and adjacent land uses; gully stabilization and revegetation are likely required to reduce excessive fine sediment supply.

RECOMMENDATION C: IMPLEMENT A SANTA CRUZ COUNTY ROAD IMPROVEMENT PROJECT TO CONTROL SEDIMENT LOADING

RECOMMENDATION C.1: CREATE COUNTY ROAD DATABASE TO PRIORITIZE PROJECTS FOR IMPLEMENTATION

The first priority should be to conduct a public road survey beginning with inner gorge roads in sandy soils followed by roads in other settings. A road survey should consistently document all road features (road cuts, drainage ditches and crossings, shoulders and surfaces) and generate data that can be used to calculate sediment yields (using the NRCS method used in this study to assess erosion from road cuts (USDA-NRCS, 1999)) as an index of sediment generation. This data base, in combination with the proximity to sensitive streams habitat areas, should be used to develop treatment priorities.

Upgrading the GIS topographic base from 30-meter to 10-meter resolution or finer would be a good improvement to identify hillslope drainage areas, road crossings and potential problem areas. Affordable 1-meter resolution may be available within the next several years and that should be integrated into a GIS system when available. Culvert data should be integrated into the GIS database by use of Global Positioning Systems (GPS) measurements, or where GPS is not practical through use of high-resolution aerial photographs. All data collection on roads should embrace a format that allows for efficient and reliable input to the GIS database.

As part of the road database development, an engineering investigation of a well-known Point Source of fine sediment, Lower Bean Creek Road, should be conducted. The segment of Lower Bean Creek Road that failed on a massive scale in the 1982 storm was repaired and widened in 1986. Since the repair, most of the road cuts and slide face areas have continued to erode and provide a chronic supply of fine sediments to Bean Creek. This may partially be the result of the severe storms of 1995 and 1998. Gullies have formed at drainage outlets and little vegetation has colonized the slide face. The stream bank and the base of the slide are eroding, although dense growth of willows and alders now buffers the stream somewhat. An engineering study should be undertaken to determine potential stabilization efforts and whether they would be cost effective. Less expensive options such as drainage modifications, revegetation, or timber slough/retaining walls should be considered since they may reduce chronic sediment input even if they fail in large events. If a long-term fix is prohibitively expensive, funds should be set aside now to supplement future FEMA emergency repair funding.

After the road database is compiled an implementation program can be developed to target priority improvement projects.

RECOMMENDATION C.2: AUGMENT EMERGENCY ROAD REPAIR FUNDS

Santa Cruz County should develop a road upgrade fund to supplement FEMA emergency repair funding so that problem roads could be upgraded to reduce sediment loading and improve road reliability. There are many instances where roads are recurrently damaged and FEMA will only provide funding to replace without betterment. This results in chronically unreliable roads and emergency repairs that become chronic sediment sources for years to follow. Augmented funding would help to implement a long-term fix and benefit access reliability and water quality. The County should seek amendment of FEMA policies to allow improvements that prevent erosion and failure, particularly in watersheds with endangered salmonid habitat.

RECOMMENDATION C.3: DEVELOP A ROAD MAINTENANCE BMP PROGRAM AND DEVELOP SPOILS DISPOSAL SITES

Road maintenance on public (and private) roads often involves removing sediment from the road surfaces and ditches and placing in areas where it is susceptible to erosion and delivery to a waterway. The objective of the Public Road BMP Program is to ensure that all feasible measures are taken to reduce erosion and prevent road maintenance sediments from entering waterways.

A common source of fine sediments found along roads are the spoils generated during emergency repairs or normal maintenance grading found throughout the Zayante Area. This sediment is often placed on the road shoulder or in a sidecast area where it is susceptible to erosion and delivery to a waterway. Spoils often remain barren of stabilizing vegetation cover and persist for many years after placement. Many exist within inner gorge slopes where they are efficiently delivered to streams.

Recommendation C.3 is to develop road maintenance Best Management Practices (BMPs), and emergency and permanent spoil disposal sites for road maintenance work to stabilize, store or otherwise contain fine sediments permanently and prevent erosion and delivery to waterways. This recommendation seeks to incorporate BMPs into regular maintenance activities with emergency work and development of spoils disposal sites that service both activities.

To initiate a BMP program, Santa Cruz County's practices, equipment, and techniques should be examined and compared to those conducted during a construction project that involving earth grading under an established construction sediment control program such as a Storm Water Pollution Prevention Plan (SWPPP). Any resource gaps in terms of personnel, equipment, training, spoils storage and disposal, and revegetation needs should be addressed in a BMP program document, the guide for implementation.

A first order BMP would be to move excavated spoils material to safe, long-term disposal sites. The County should acquire suitable disposal sites such as old quarry pits. During winter emergencies or as part of the practicality of operations, immediate delivery of spoils to a permanent disposal site may be difficult to accomplish giving the priority of opening roads. For emergency work, interim safe storage practices should be employed such as installing runoff detention swales, straw bales and/or mulching, etc. to temporarily stored spoils. Other possible BMP's would include spreading, mulching and seedling spoils.

RECOMMENDATION D: IMPLEMENT A PRIVATE ROADS SEDIMENT REDUCTION PROGRAM

The program for reducing erosion on private roads is designed to exhaust cooperative efforts before taking enforcement actions. Improving private roads to reduce erosion could also greatly improve their reliability that may be sufficient incentive for private landowner participation.

RECOMMENDATION D.1: PROVIDE COST SHARING FOR PRIVATE ROAD IMPROVEMENT

Many of the roads contributing chronic fine sediments are privately owned. Often, there is little incentive to reduce erosion unless a new project is proposed and the Erosion Control Ordinance is enforced. In catastrophic failures, emergency repairs are completed with little design work or long-term sediment reduction in mind. This recommendation is designed to assist private road owners and private associations to upgrade their roads and reduce erosion.

Recommendation D.1 is to develop a private road improvement fund to share costs and encourage private road associations to upgrade poorly constructed private roads.

RECOMMENDATION D.2: DEVELOP PRIVATE ROAD DATABASE, TREATMENT PRIORITIES AND STRATEGIES

A private road databases should be developed using a standard methodology in parallel with the recommended public roads program discussed above in Recommendation C. The new survey should document all roads features (road cuts, drainage ditches and crossings, shoulders and surfaces), apply erosion rates then compile onto a GIS database. The first roads surveyed should be those already known by county staff, agency personnel and professionals conducting geologic assessments to be large sediment sources in the inner gorge setting. From this database and consideration of other factors such as funding and road association/owner cooperation, a specific program and priority for treatments should emerge.

In addition, similar data could be collected as part of fire equipment access surveys of private roads; the private road data should be used as a resource to develop strategies for cost sharing and programmatic reduction of non-point source sediments, and if necessary for development of enforcement actions.

Private roads meriting Point Source investigations in the Zayante Area include: Lompico Road, Love Creek Road, Fitch Creek Road and Araqi Road (Bear Canyon Road located in the Bear Creek / San Lorenzo River Watershed is also cited as a source problem).

RECOMMENDATION D.3: IMPLEMENT PRIVATE ROAD BMP'S

A program of Best Management Practices for road maintenance should be designed and implemented on private roads similar to the proposed program for public roads. The focus should be on drainage control, upgrading road surfaces, emergency repair work and spoils storage and disposal. A cost-effective method in cases of unpaved road is to upgrade water bars to larger rolling dips and to mulch sidecast spoils and other bare surfaces. The road BMP program should also be viewed as an opportunity to upgrade the reliability of roads and public education should be an initial focus for cooperation. Use of supplemental grant monies should be considered. Involvement and coordination by cooperative agencies such as the Santa Cruz County RCD is crucial.

RECOMMENDATION D.4: IMPLEMENT PRIVATE ROAD EDUCATION PROGRAM

The sediment reduction program for private roads should have a stratified approach beginning with cooperative efforts, public education, BMP implementation and cost sharing but followed by enforcement if these initial efforts fail. It should be a priority for the county and cooperative agencies to initially focus on projects that demonstrate success through cooperation (such as RCD Trinkling Creek Road improvement Project). The Santa Cruz County RCD already holds workshops and provides public education and grant assistance. This effort should be focused upon the private parties responsible for specific roads prioritized for treatment (Recommendation D.2).

RECOMMENDATION D.5: IMPROVE ENFORCEMENT OF EROSION CONTROL ORDINANCE FOR PRIVATE ROADS

The Santa Cruz County Erosion Control Ordinance has provisions requiring the responsible parties to repair and alleviate erosion problems that are deemed severe. Professionals and County staff believe that the ordinance is not being enforced to the degree that it could to cite violators and solve erosion problems. The reasons are a lack of an effective outreach program and limited technical and financial resources for landowner compliance. There is a lack of trained staff assigned specifically to erosion control. Staff is needed to notify property owners of the needs and methods to control potential erosion problems before they become major sediment sources requiring enforcement actions.

The program described in Recommendation D is to initially promote cooperation and cost sharing to solve problems. Enforcement has a role whenever a gross violation that immediately threatens water quality has occurred (such as grading sidecast into a waterway) and must be corrected. It also has a role when all cooperative efforts to fix problems have failed. Part of the economic incentive for cooperation by landowners should be the economic advantages of avoiding citation and enforcement actions. However, if the ordinance is not being enforced for chronic erosion problems, then other landowners and their peers have little incentive to cooperate.

The Santa Cruz County Planning Department should create new erosion control staff positions to help coordinate the county's cooperative efforts, but also to conduct inspections and enforcement actions as necessary. The number of erosion control specialist positions created and staffed should be driven by a realistic view of gaining cooperation and success for the target reduction in chronic fine sediment generation. This will emerge from the private road survey recommended above.

RECOMMENDATION E: IMPROVE TIMBER HARVEST ROADS

Timber harvest comprises a significant portion of roads in the Zayante Area. The activities involve construction of new roads, use and sometimes improvement of existing multiple use roads, grading new skid trails and grading within the inner gorge slopes in steep terrain. The standards used for road construction and maintenance can often exceed that utilized by some private landowners on existing private roads. However, the standards for a new timber road are less than those applied through the grading ordinance for private roads. Sometimes there is an opportunity to improve the conditions of existing roads when it is proposed for use as a timber harvest road.

The California Resources Agency and The National Marine Fisheries Service convened a Scientific Review Panel (SRP) to interview various parties about the California Forest Practice Rules and their effect on salmonid habitat for the coastal watershed region between the Russian River and the California / Oregon Border (Watershed Protection and Restoration Council, 1999). Information was collected as far south as Santa Cruz and is considered relevant to the Zayante Area. The State Board of Forestry has adopted the recommendations of the SRP statewide as an interim measure until specific watershed plans are developed to guide timber harvests.

In order to reduce sediment generation from THP-related sources the following measures are recommended.

RECOMMENDATION E.1: DOCUMENT AND IMPROVE THP ACCESS ROADS

Submission of a Timber Harvest Plan (THP) provides an opportunity to document private access road conditions and to plan for erosion control during and after a harvest. THP maps should include a THP parcel access road map that details the road access routes, surfaces and mileage to the nearest paved county road. Pre-harvest appurtenant road surfaces and conditions, culvert locations, sizes and other drainage features should be mapped and described. An assessment of erosion and drainage of the access road should be made in conjunction with the private road association or public entity to determine its condition and the repairs necessary to reduce erosion. This would result in a road improvement plan that could be implemented through multiple resources (proposed County cost share fund recommendation B.4, Federal 319 monies through RCD, or as part of THP road maintenance obligations).

The use of existing multiple use roads to access THP parcels is common. This presents an opportunity to document existing conditions on private roads to improve the road database and for upgrading deficient roads. Recommendations C.1 and C.2 are aimed to help improve these access roads.

RECOMMENDATION E.2 SURFACE YEAR-ROUND ACCESS ROAD

Encourage that all permanent and year-round access roads beyond the THP parcel be surfaced after harvest completion with base rock and road gravel, asphalt or chipseal, as appropriate.

RECOMMENDATION E.3 MAINTAIN UNSURFACED ROADS AND SKID TRAILS

Require that all unsurfaced roads and skid trails be seeded with an appropriate grass mix, slash packed, or mulched with chipped slash material following seasonal harvesting activities. Use rolling dips instead of water bars where roads are subject to trespass or regular travel.

RECOMMENDATION E.4: UPGRADE STREAM CROSSINGS

Stream crossings (culverts, bridges, seasonal crossings) on THP parcels should be identified and mapped with the intention of replacement or removal if they cannot pass 100-year flows for Class 1 and 2 streams or 50-year flows for Class 3 streams. Calculations of flow regimes and culvert sizing should be outlined in the THP document. The feasibility of achieving the target capacities should be addressed with regard to site-specific conditions. Consideration should be given to the implications of culvert/road fill failure and how to reduce or eliminate delivery of sediment to waterways. Design should include fail safe measures to accommodate culvert overflow without causing massive road fill failures.

RECOMMENDATION E.5: EXTEND MONITORING PERIOD AND UPGRADE THP ROAD MAINTENANCE AFTER HARVESTS

Monitoring and maintenance plans for THP roads should be extended to 5 years to assess and repair poor road drainage conditions that may lead to increased surface erosion and/or mass wasting. Particular attention should be paid to maintenance of trespass barriers and application of appropriate measures to the type of road (i.e. removal seasonal crossings, water bars/rolling dips, etc.). Rolling dips should be utilized instead of water bars where trespass is likely.

RECOMMENDATION E.6: IDENTIFY AND FIX PROBLEMS ASSOCIATED WITH LEGACY ROADS

New THPs should identify problematic legacy roads within WLPZs, remove them and revegetate the area with appropriate native species.

RECOMMENDATION E.7: ENGINEERING GEOLOGIST SHOULD REVIEW GRADING ON INNER GORGE SLOPES

A Certified Engineering Geologist should review and approve any THP plan proposed for inner gorge slopes.

Cited References

Alderdice, D. F., Wickett, W.P. and Brett, J.R. 1958. *Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs*. J. Fish. Res. Board Can. 15:229-250.

Alley, D.W. 1995. *Comparison of juvenile steelhead densities in 1981, 1994 and 1995 with an estimate of juvenile population size in the mainstem San Lorenzo River, with expected numbers of adults returning from juveniles reared in the mainstem river, Santa Cruz County, California*. A report to the City of Santa Cruz Water Department and the San Lorenzo Valley Water District. 67 pp.

Alley, D.W. 1998. *Comparison of juvenile steelhead densities in 1981 and 1994-7 in the San Lorenzo River and Its Tributaries, Santa Cruz County, California, with an estimate of juvenile population size in the mainstem river and expected adult returns from that productions*. A report to the City of Santa Cruz Water Department and the San Lorenzo Valley Water District.

Aston, R., and J. Ricker. 1979. *Water quality technical section, San Lorenzo River watershed management plan*. A report to the Santa Cruz County Planning Department.

Benda, L. and T. Dunne. 1997. *Stochastic forcing of sediment routing and storage in channel networks*. Water Resources Research, Vol. 33, No. 12, pp 2865-2880.

Benda, L. and T. Dunne. 1997. *Stochastic forcing of sediment supply to channel networks from landsliding and debris flow*. Water Resources Research, Vol. 33, No. 12, pp 2849-2863.

Benkman, B. 1976. *Report on the Fishery of the San Lorenzo River,* Santa Cruz County Planning Department. 75 pp.

Berglund, E.R. 1978. *Seeding to Control Erosion Along Forest Roads*. Oregon State University Extension Service, Extension Circular 885.

Bethlahmy, N., and Kidd, W.J. 1966. *Controlling Soil Movement from Steep Road Fills*. USDA Forest Service Research Note INT-45.

Bjornn, T. 1968. Survival and emergence of trout and salmon in various gravel-sand mixtures. *In* Proceedings, Forum on the Relation Between Logging and Salmon, pp. 80-88. American Institute of Fisheriy Research Biologists and Alaska Department of Fish and Game, Juneau.

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. Klamt, C. Chaco, and C. Schaye. 1977. *Transport of granitic sediment in streams and its effects on insects and fish*. University of Idaho College of Forestry, Wildlife and Range Sciences. Bulletin No. 17. 43 pp.

Brabb, E.E.. 1997. *Geologic map of Santa Cruz County, California: A digital datab*ase. U.S. Geological Survey Open File Report 97-489.

Brannon, E. L. 1965. *The influence of physical factors on the development and weight of sockeye salmon embryos and alevins*. Int. Pac. Salmon Fish Comm. Prog. Rep. 12. 26 pp.

Brown, W.M. III and L.E. Jackson, Jr. 1973. *Erosion and depositional provinces and sediment transport in the south and central part of the San Francisco Bay region, California*. U.S. Geological Survey Map MF-515. 21 pp + 4 sheets.

Brown, W.M.III. 1973. *Erosion processes, fluvial sediment transport and reservoir sedimentation in a part of the Newell and Zayante Creek basins, Santa Cruz County, California.* U.S. Geological Survey Open File Report. Menlo Park, California. 31 pp.

Butler, T. and the Office of Watershed management staff. 1981. *Inventory of erosion problems in Santa Cruz County*. Environmental Planning Section, Santa Cruz County Planning Department. 24 pp. + app.

Cafferata, P.H. and C. Poole. 1993. *Watershed Assessment of the East Branch of Soquel Cree*k. California Department of Forestry and Fire Prevention. 54 pp.

California Department of Fish and Game. 1996. Draft California Endangered Species Act Biological Opinion Issued to the California Department of Forestry and Fire Protection for review and approval of timber harvest plans and timber operations within range of coho salmon south of San Francisco Bay. 22 pp.

California Department of Forestry and Fire Protection. 1991. *California Forest Practice Rules*.

California Department of Water Resources, 1966. *San Lorenzo River watershed water quality investigation*. California Department of Water Resources Bulletin No. 143-1. 180 pp.

California Department of Water Resources. 1958. *Sedimentation Studies-Zayante and Bean Creeks, Tributaries to San Lorenzo River, Santa Cruz County*. Project No. 58-3-4. Report to Central Coast Regional Water Pollution Board. 15 pp + app.

California State Water Resources Control Board. 1982. Draft staff report for fact finding hearing-Zayante/Lower San Lorenzo River and the Upper San Loenzo River Instream Beneficial Use Program. 59 pp + app.

Camp, Dresser and McKee, Inc., Balance Hydrologics, Inc., and Archibald and Wallberg, 1995. Santa Cruz Water Department Watershed Field Survey Technical Memorandum. 27 pp.

Camp, Dresser and McKee, Inc., Balance Hydrologics, Inc., and Archibald and Wallberg, 1996. Santa Cruz Water Department Watershed Sanitary Survey. Watershed Management and Applicable Policies Memorandum. 15 pp.

Clark, J.C, 1981. *Stratigraphy, paleontology, and geology of the Central Santa Cruz Mountains, California Coast Ranges.* U.S. Geological Survey Professional Paper 1168. 51pp.

Coats, R., L. Collins, J. Florsheim, and D. Kaufman. 1982. *Landsliding channel change, and sediment transport in Zayante Creek and the lower San Lorenzo River, 1982 water year, and implications for management of the stream resource*. A Report to the State Water Resources Control Board. 123 pp.

Cooper Clark and Associates. 1974. *Preliminary map of landslide deposits in Santa Cruz County, California.*

Cooper, A.C. 1965. *The effect of transported stream sediments on the survival of pink salmon at spawning and incubation in the Fraser River system*. Int. Pac. Salmon Fish. Comm. Bull. 18. 71pp.

Copeland, R.R. 1986. *San Lorenzo River sedimentation study: Final Report.* Department of the Army, Waterways Experiment Station. Corps of Engineers Technical Report HL-86-10. 47 pp. + plates.

Corbett, E.S., Lynch, and J.A. 1985. *Management of Streamside Zones on Municipal Watersheds. In Conference on Riparian Ecosystems and their Management: Reconciling Conflicting Uses, April 16-18, Tucson, Arizona*, pp. 187-190.

Cordone, A. and Kelley, D. 1961. The influence of inorganic sediment on the aquatic life of streans, California Dept. Fish and Game 47(2):189-228.
Daykin, P. N. 1965. Application of mass transfer theory to the problem of respiration of fish eggs. J. Fish. Res. Board Can. 22(1):159-171.

Dyrness, C.T. 1970. *Stabilization of Newly Constructed Road Backslopes by Mulch and Grass-Legume Treatments*. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. PNW-123.

Dietrich, W. E. and Dunne, T. 1978. *Sediment budget for small catchment in mountainous terrain*, Z. Geomorph. Suppl., 29, 191-206.

Ellen, S.D. and G.F. Wiecozorek. 1988. *Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region.* U.S. Geological Survey Professional Paper 1434. 310 pp.

Esmaili, H.G. and Associates, Inc. 1980. *San Lorenzo River reconnaissance study, supplemental data appendix.* Prepared for Jone-Tillson and Associates.

Fogelman, R.P., and K. Johnson. 1985. *Capacity and sedimentation of Loch Lomond Reservoir, Santa Cruz County, California*. U.S. Geological Survey Open File Report 85-485. 24 pp.

Furniss, M.J., Roelofs, T.D., and Yee, C.S. 1991. Road Construction and Maintenance. *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats.* American Fisheries Society Special Publication 19, pp. 297-324.

Hecht, B, and G. Kittleson. 1998. An Assessment of Streambed Conditions and Erosion Control Efforts in the San Lorenzo River Watershed, Santa Cruz County, California. A report prepared for the Santa Cruz County Department of Environmental Health in support of the San Lorenzo Watershed Plan Update.

Hecht, B. 1984. Task Report C: Analysis of resource problems. North Central Santa Cruz County Water Supply Master Plan Study. HEA, a division of Kleinfelder and Associates report to the North Central Santa Cruz County Water Policy Planning Task Force. 63 pp.

Hecht, B. and R. Enkeboll. 1980. Channel and substrate conditions, sediment transport,and alternative approaches for sediment management in Zayante Creek below proposed Zayante Dam. Esmaili, H.G. & Associates, Inc. (HEA) Draft Report submitted to D.W. Kelley. 93 pp.

Johansen, R.R. 1975 San Lorenzo River (Santa Cruz County) Winter Steelhead and Salmon Fishery, 1971-72 and 1972-73 Seasons. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 75-6. 14 pp.

Jones and Stokes Associates, Inc. 1995. Draft Environmental Impact Report for the Soquel Demonstration Forest: General Forest Management Plan. Prepared for the California Department of Forestry and fire Protection.

Jones and Stokes Associates, Inc. 1996. Final Environmental Impact Report for the Soquel Demonstration Forest: General Forest Management Plan. Prepared for the California Department of Forestry and fire Protection.

Keller, E. A and Talley, T. 1979. Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. In D. D. Rhodes and G.P. Williams (eds.) Adjustments of the fluvial system, p. 169-197. Proceedings, Tenth Annual Geomorphology Symposium. State University of New York, Binghamton. Kendall/Hunt Publishing Co. Dubuque, Iowa.

Keller, E. A. and Swanson, F. J. 1979. Effects of large organic material on channel form and fluvial process. Earth Surfaces Processes 4:361-380.

Keller, E. A., MacDonald, A., and Tally, T. 1981. Streams in the coastal redwood environment: The role of large organic debris. In R. N. Coates (ed.) Proceedings of a Symposium on Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas, p. 167-176. Center for Natural Resource Studies, John Muir Institute, Inc.

Kelley, D.W. and D.H. Dettman. 1980. Relationships between stream flow, rearing habitat, substrate conditions, and juvenile steelhead populations in Lagunitas Creek, Marin County, 1979. A report prepared for the Marin Municipal Water District. 23 pp.

Kelley, D.W. and D.H. Dettman. 1981. Zayante Dam Project measures to make it compatible with fish and wildlife resources. In cooperation with H. Esmaili and Associates, Inc., Jones and Stokes Associates, Inc., and Linsley Krager and Associates.

Klamt, R. R. 1976. The effects of coarse granite sand on the distribution and abundance of salmonids in the Central Idaho batholith. M.S. thesis, Oregon State University, Corvallis. 84 pp.

Knott, J. M. 1973. The effects of urbanization on sedimentation and floodflows in the Colma Creek basin California. USGS Water Resources Division Open File Report 3018-14. 54 pp.

Knott, J. M. 1976. Sediment Dischareg in th Upper Arroyo Grande and Santa Rita Creek Basins, San Luis Obispo County, California. USGS Water-Resources Investigations 76-64. 29 pp.

Koski, K. 1975. The survival and fitness of two stocks of chum salmon from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Ph.D. thesis, University of Washington, Seattle. 212 pp.

Koski, K. V. 1981. The survival and quality of two stocks of chum salmon (Oncorhynchus keta) from egg deposition to emergence. Rapp. P.-V. Reun. Cons. Int. Explor. Mer. 178:330-333.

Lantz, R.L. 1971. *Guidelines for Stream Protection in Logging Operations.* Oregon State Game Commission.

Larse, R.W. 1971. Prevention and Control of Erosion and Stream Sedimentation from Forest Roads. In *Proceedings of the Symposium of Forest Land Uses and the Stream Environment*, pp. 76-83. Oregon State University.

Leopold, L.B. 1970. An Improved method for size distribution of stream gravels. Water Resources Research, Volume 6, 1970, pp. 1357-1366.

MacPherson, K. R. and Harmon, J. G. 2000. Storage Capacity and Sedimentation of Loch Lomond Reservoir, Santa Cruz County, California, 1998. USGS Water Resources Investigations Report 00-4016.

Madej, M. 1984. Recent changes in channel-stored sediment. Tech Rep. 11. Redwood National Park, Arcata, California. 54 pp.

Mangelsdorf, A. and Lundborg, H. 1997. Proposed Garcia River Watershed Water Quality Attainment Startegy for Sediment. Prepared for California Regional Water Quality Control Board, North Coast Region. 192 pp.

McNeil, W.J., and Ahnell, W.H. 1964. Success of Pink Salmon spawning relative to size of spawning bed materials. USFWS Special Scientific Report. Fish. 469, 15 pp.

Megahan, W.F. 1980. Nonpoint Source Pollution from Forestry Activities in the Western United States: Results of Recent Research and Research Needs. In *U.S. Forestry and Water Quality: What Course in the 80s?, Proceedings of the Water Pollution Control Federation Seminar, Richmond, VA, June 19, 1980*, pp. 92-151.

Megahan, W.F. 1981. Effects of Silvicultural Practices on Erosion and Sedimentation in the Interior West A Case for Sediment Budgeting. In *Interior West Watershed Management Symposium Proceedings*, ed. D.M Baumgartner. Washington State University, Cooperative Extension, pp. 169-182.

Megahan, W.F. 1983. Appendix C: Guidelines for Reducing Negative Impacts of Logging. In: *Tropical Watersheds: Hydrologic and Soils Response to Major Uses or Conversions,* ed. L.S. Hamilton and P.N. King. Westview Press, Boulder, CO, pp. 143-154.

Megahan, W.F. 1986. Recent Studies on Erosion and Its Control on Forest Lands in the United States. In: , pp. 178-189.

Megahan, W.F. 1987. Effects of Forest Roads on Watershed Function in Mountainous Areas. In *Environmental Geotechnics and Problematic Soils and Rocks,* ed. Balasubramaniam et al. pp. 335-348.

Mount. J.F. 1977. The Erosion Hazard Potential of the San Lorenzo River Watershed. A report and maps prepared for the Santa Cruz County Office of Watershed Management. 54 pp.

Nelson J. and P. Anderson. 1996. Stream-specific coho habitat deficiencies and limitations; coastal streams of San Mateo and Santa Cruz counties currently supporting coho salmon or under consideration for coho recovery efforts. California Department of Fish and Game, Region 3 (Monterey). Report to J. Steele, Environmental Services Division, Sacramento, California.

Nolan, K.M., D.C. Marron, and L.M. Collins. 1993. Stream channel response to the January 3-5, 1982 storm in the Santa Cruz Mountains, West Central California. U.S. Geological Survey Open File Report. 54 pp. + photos.

Phillips, R. W., Lantz, R. L., Claire, E. W., and Moring, J. R. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104(3):461-466.

Rantz, S.E. 1971. Precipitation depth-duration-frequency relations of the San Francisco Bay Region. U.S. Geological Survey, San Francisco Bay Region Environment and Resources Planning Study, Basic Data Contribution 25. Open File Report 3019-12.

Reid, L. M. and Dunne, T. 1996. Rapid construction of sediment budgets for drainage basins. Catena-Verlag, Cremlingen, Germany. 160 pp.

Rice, R.M., J.S. Rothacher, and W.F. Megahan. 1972. Erosional Consequences of Timber Harvesting: An Appraisal. In *Watersheds in Transition Symposium Proceedings*, AWRA, Urbana, IL, pp. 321-329.

Rice, R. 1993. A guide to data collection and analysis in support of an appraisal of cumulative watershed effects in California forests. Unpublish report. 36 pp.

Ricker, J. 1979. San Lorenzo River Watershed Management Plan. Hydrology Technical Section. Santa Cruz County Community Resources Agency, Watershed Management Section.

Ricker, J. and J. F. Mount. 1979. San Lorenzo Watershed Management Plan. Physiography-Geology and Erosion and Sediment Transport Technical Sections. Santa Cruz County Community Resources Agency.

Roberts, S. and Barron, A. D. 1998. Digital Compilation of "Preliminary Map of Landslide deposits in Santa Cruz County, California, by Cooper-Clark and Associates, 1975": A digital map database. USGS Open File Report 98-792.

San Lorenzo Valley and North Coast Watersheds Sanitary Survey Final Report. Consulting report prepared for the City of Santa Cruz Water Department, San Lorenzo Valley Water District and other water purveyors.

Santa Cruz County Planning Department. 1979. The San Lorenzo River Watershed Management Plan. Santa Cruz County Planning Department and the State of California Resources Agency. 235 pp.

Scott, K. and Williams, R. P. 1978. Erosion and Sediment Yields in the Transverse Ranges, Southern California. Geological Survey Professional Paper. 38 pp.

Shapovalov, L. and Taft, A. 1954. The life histories of the steelhead rainbow trout and silver salmon with special reference to Waddell Creek, CA and regarding their management. California Department of Fish and and Game Fish Bulletin 98, 375.

Shumway, D. L., Warren, E. C. and Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Am. Fish. Soc. 93:342-356.

Smith, J.J. and D.W. Alley. 1982 Fish habitat Assessments for Santa Cruz County streams. Harvey and Stanley Associates. Report to the Santa Cruz County Planning Department. 59 pp.

Stuehrenberg, L. C. 1975. The effects of granite sand on the distribution and abundance of salmonids in Idaho streams. M.S. thesis, University of Idaho, Moscow. 490 pp.

Swift, L.W., Jr. 1984a. Gravel and Grass Surfacing Reduces Soil Loss from Mountain Roads. *Forest Science*, 30(3):657-670.

Swift, L.W., Jr. 1988. Forest Access Roads: Design, Maintenance, and Soil Loss. In *Forest Hydrology and Ecology at Coweeta*, Chapter 23, ed. W.T. Swank and D.A. Crossley, Jr., pp. 313-324. Springer-Verlag, New York, NY.

Sylvester, M. and K. Covay. 1978. Stream quality in the San Lorenzo River basin, Santa Cruz County, California. U.S. Geological Survey Water Resources Investigation 78-19. 61 pp.

Terhune, L.D.B. 1958. The MARK VI groundwater standpipe for measurinf seepage through salmon spawning gravel. J. Fish. Res. Board Can. 15(5):1027-1063.

USDA Soil Conservation Service (S.C.S.). 1979. San Lorenzo River Watershed Field Tour Paper

USEPA (Redwood Creek, 1998; Protocol for Developing Sediment TMDLs, 1999).

USEPA. 1992a. *Managing Nonpoint Source Pollution, Final Report to Congress on Section 319 of the Clean Water Act (1989)*. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-506/9-90.

USEPA Region 9. 1998. Total Maximum Daily Load for Sediment, Redwood Creek, California. 71 pp.

Vaux, W.G. 1962. Interchange of stream and intergravel water in a salmon spawning riffle. USFWS Special Scientific Report. Fish. 405. 11 pp.

Watershed Protection and Restoration Council, 1999: Report of the Scientific Review Panel on California Forest Practices Rules and Salmonid Habitat, unpublished report prepared for the Resources Agency of California and the National Marine Fisheries Service, June 1999, 92 pages.

Weitzman, S., and G.R. Trimble, Jr. 1952. Skid-road Erosion Can Be Reduced. *Journal of Soil and Water Conservation*, 7:122-124.

Wickett, W.P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Board Can. 11(6):933-953.

Williams, D. D, and Mundie, J. H. 1978. Substrate size selection by stream invertebrates and the influence of sand. Limn. Oceanogr. 23(5):1020-1033.

Wolman, M.G. 1954. A method for sampling coarse river bed material. In American Geophysical Union Transactions

Yee, C.S., and T.D. Roelofs. 1980. *Planning Forest Roads to Protect Salmonid Habitat.* USDA Forest Service. General Techical Report PNW-109.