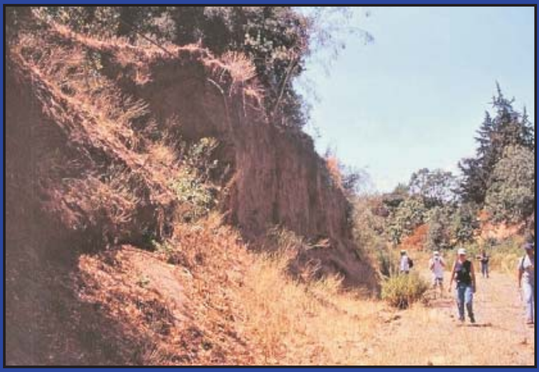

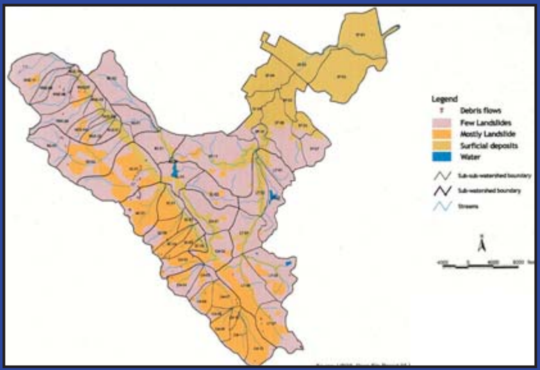

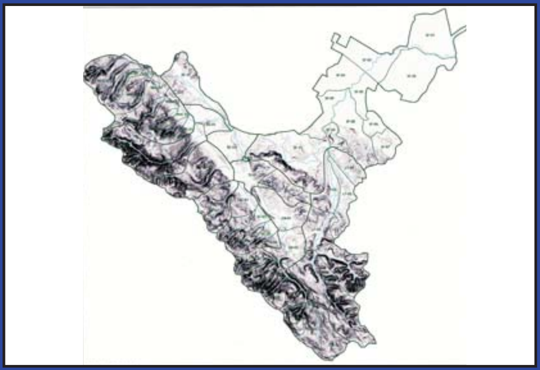

May 2004

San Francisquito Creek Watershed Analysis and Sediment Reduction Plan

FINAL REPORT

Prepared for:

San Francisquito Creek Joint Powers Authority

Prepared by:

nhc northwest hydraulic consultants

Leaders in water resource technology

Jones & Stokes

San Francisquito Creek

Watershed Analysis and Sediment Reduction Plan

Final Report
May 2004

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San Francisquito Creek
Joint Powers Authority

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EXECUTIVE SUMMARY

The first objective of the project was to understand the erosion, transport, and deposition of sediment in the San Francisquito Creek watershed, focusing on human-related activities that modify hydrology, alter erosion rates, or trap sediment. Once complete, the second objective was to review existing management policies and regulations in the context of the erosion, transport and deposition of sediment and recommend management measures and specific practices to effectively reduce erosion and sediment transport in San Francisquito Creek and its tributaries.

The project proceeded by preparing draft memoranda on specific tasks, submitting these for review by the Technical Advisory Committee (TAC), and then submitting final memoranda to the Joint Powers Authority. This report includes some of the analyses and data from the previous memoranda and develops the sediment reduction plan. The previous memoranda are on the JPA website (http://www.cityofpaloalto.org/jpa/). The analysis relied on existing digital databases, reports, maps, and other information on San Francisquito Creek, an identification of data gaps during early tasks, and additional analyses to address these gaps, where feasible and necessary to achieve project goals. San Francisquito Creek has been extensively studied by various agencies and other groups and the reports from these studies formed the core of the analysis.

Erosion, transport and deposition were examined through sediment budgets constructed for four subwatersheds – Searsville Lake, Los Trancos, Bear and San Francisquito. The budgets identified the major natural and man-made sediment sources, where they occurred, and the volume of sediment contributed to streams, stored or deposited and transported from the subwatersheds. The main erosion process in the Santa Cruz Mountains was landsliding, with significant contributions from bank erosion and surface erosion, particularly from roads. Human impacts on erosion occurred primarily through urban development and hydromodification, both from indirect impacts resulting from peak flows increased by impervious area, and direct modifications of streams, stream banks, and riparian corridors.

The Searsville Dam on Corte Madera Creek is one of the most important human modifications in the watershed. For the past century, its reservoir has intercepted nearly all of the sediment transported from the Searsville Lake watershed. Trapping has reduced coarse sediment transport in San Francisquito Creek by two-thirds, resulting in erosion and other changes to the stream, and reduced fine sediment transport by one half.

The administration of the San Francisquito Watershed is complex as it lies partly in Santa Clara but mostly in San Mateo County and East Palo Alto, Palo Alto, Menlo Park, Woodside and Portola Valley also have jurisdiction over development. Much of the upper watershed lies in the Midpeninsula Regional Open Space District, San Mateo County Parks, Palo Alto Open Spaces or other preserves, parks or recreation areas. Most of the existing policies and regulations for sediment management focus on managing new private and public development, particularly on grading and erosion and sediment control

for construction. Few jurisdictions have policies that address watershed based planning, management of impervious area, or creek setback ordinances or buffers.

Policies and regulations to manage new development are important to control sediment contributions to streams; however, the legacy of existing development is expected to continue to be the more significant contributor to erosion.

The report recommends management measures to address urban development and hydromodification. The most important measures for new development are integrated watershed planning that address the cumulative hydrologic impacts of development, and adoption of stream buffers or setbacks for new development. Watershed planning requires continuous hydrologic simulation modeling and collaborative efforts between agencies or organizations with subwatersheds, or an overall agency that coordinates efforts. Policies that minimize or eliminate native or gravel surfaced roads, improved design practices for stream crossings, and inventories of erosion sources are also thought to be important measures.

The most important measure for addressing existing development is to rehabilitate the existing network of unpaved roads and trails and paved roads crossing steep terrain. The roads are important contributors to human-related landslides and provide chronic surface erosion. The next most important measure is to adopt bank stabilization and revegetation programs to address the legacy of eroding banks in developed areas. Such programs are underway for San Francisquito Creek and Corte Madera Creek through Portola Valley. Similar programs are recommended for Corte Madera Creek in San Mateo County and Bear and Union Creeks through Woodside.

Continued sediment data collection and sediment source analysis will be important aspects of sediment reduction plans, both to confirm the benefits of the plans and to address gaps in our understanding that may affect implementation of the plans.

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1. INTRODUCTION

1.1. Background and Purpose

The San Francisquito Watershed has an area of about 47 square miles, extending from Skyline Boulevard in the Santa Cruz Mountains (elevation 2,200 feet) to San Francisco Bay (Figure 1). The watershed includes open space preserves, the cities of East Palo Alto, Menlo Park, and Palo Alto, the towns of Portola Valley and Woodside, unincorporated areas of San Mateo and Santa Clara counties, and Stanford University.

San Francisquito Creek starts at the base of Searsville Dam in Stanford University's Jasper Ridge Biological Preserve, is fed by tributary creeks from the upper watershed, and flows into San Francisco Bay about 2.5 miles south of the Dumbarton Bridge. The three largest tributaries are Bear, Corte Madera, and Los Trancos creeks. San Francisquito Creek forms the boundary between San Mateo and Santa Clara counties in the lower watershed.

San Francisquito Creek supports a steelhead trout population. Declining population numbers have earned local steelhead a place on the list of threatened species. Two other listed species that have a low potential to occur in the creek include the federally threatened Coho salmon and the federally and State endangered winter-run Chinook salmon. San Francisquito Creek and its tributaries support native fish species such as California roach, Sacramento sucker, threespine stickleback, and prickly sculpin. California red-legged frog and western pond turtle, also listed as threatened, are found in the watershed.

A variety of factors have contributed to the decline of aquatic species populations but changes in the watershed, such as dam construction, water use, urban and rural development and stream modifications are thought to have been particularly significant. San Francisquito Creek is listed as impaired by sedimentation under Section 303(d) of the Clean Water Act, requiring the development of a Total Maximum Daily Load (TMDL) for sediment. This project addresses part of the TMDL, namely developing a watershed-based plan that describes nonpoint source sediment and provides measures to reduce sediment pollution.

1.2. Project Organization and Disclosure

The San Francisquito Creek Joint Powers Authority (JPA) is responsible for the San Francisquito Creek Watershed Analysis and Sediment Reduction Plan. The Plan partially fulfills NPDES permit provisions that require the co-permittees of the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and the San Mateo Countywide Stormwater Pollution Prevention Program (SM-STOPPP) within the San Francisquito Creek watershed to assess and implement sediment management measures in the watershed. The Plan has been prepared through a contract between the JPA and Northwest Hydraulic Consultants Inc and Jones & Stokes Associates.

Funding for this project has been provided in full or in part through a contract with the State Water Resources Control Board (SWRCB) pursuant to the Costa-Machado Water Act of 2000 (Proposition 13) and any amendments thereto for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the SWRCB, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

1.3. Project Objectives and Organization

The first objective of the project was to understand the erosion, transport, and deposition of sediment in the San Francisquito Creek watershed, focusing on human-related activities that modify hydrology, alter erosion rates, or trap sediment. Once complete, the second objective was to review existing management policies and regulations in the context of the erosion, transport and deposition of sediment and recommend management measures and specific practices to effectively reduce erosion and sediment transport in San Francisquito Creek and its tributaries. This is seen as an important step in restoring or improving stream and aquatic habitats and populations of aquatic species.

The project proceeded by preparing draft memoranda on specific tasks, submitting these for review by the Technical Advisory Committee (TAC), and then submitting final memoranda to the Joint Powers Authority. The specific tasks completed were:

- *Landowner Notification:* Advised landowners of the project scope and funding source and requested permission for access to San Francisquito Creek and its tributaries.
- *Historic Conditions Analysis:* Analyzed historic conditions in San Francisquito Watershed, particularly sediment supply, transport, and deposition as they relate to stream and water quality character.
- *Existing Conditions Analysis:* Analyzed land use, biological resources, stream management and maintenance and designated beneficial uses.
- *Watershed Sediment Analysis:* Developed a rapid sediment budget, detailing sediment sources, sediment sizes, storage and sediment yield.
- *Assessment of Existing Management Practices:* Assessed existing policies and regulations that provide erosion control or channel protection, identified deficiencies and recommended improvements.
- *Watershed Analysis and Sediment Reduction Management Plan:* Developed from the previous memoranda, as described in this report.

This report includes some of the analyses and data from the above memoranda, and updates and corrects the memoranda where required. Where this report differs from the memoranda, new information or revised analyses have corrected the earlier memoranda.

The text provides references to the memoranda for detailed information, where suitable. Please refer to the specific memoranda for methods and for a complete summary of their results. They are available on the JPA website (http://www.cityofpaloalto.org/jpa/).

1.4. Project Approach

The project relied on existing digital databases, reports, maps, and other information on San Francisquito Creek, an identification of data gaps during early tasks, and additional analyses to address these gaps, where feasible and necessary to achieve project goals. San Francisquito Creek has been extensively studied by various agencies and other groups and the reports from these studies formed the core of the analysis. However, field visits verified existing reports, aided air photo interpretation, and examined specific watershed features that were not included in existing information. The Historic and Existing Conditions Memoranda provide details on the review of background information and other memoranda provide details on field visits, methods and analysis.

1.5. GIS Databases and Other Information Sources

The information reviewed for this project included historic maps and air photos, GIS data, reports, maintenance records, and flow and sediment gage records. The Geological Survey was a key source of information, providing maps, digital orthophotos, GIS layers, and maps and reports describing geology and erosion history in the watershed.

The Geological Survey's Western Region Geoscience Center has constructed a GIS database that inventories physical and cultural features in the watershed (USGS 2003). Layers in their GIS provide watershed and sub-watershed delineations, faults and fault traces, landslides, digital elevation data, city limits, and other cultural features such as roads and trails. Cultural features are current to 1991-97, the dates of the most recent Geological Survey quadrangle maps. The On-line Digital Geologic Map Database (USGS 2003) also includes elevation, slope, stream network and geologic maps. All of this information was incorporated into the GIS of the San Francisquito Watershed utilized in this project.

The USGS also provides generalized digital maps of landslide and debris flow susceptibility that show historic slope failures in San Mateo and Santa Clara Counties (Wentworth *et al* 1997; Ellen *et al* 1997). These maps were developed as part of the Landslide Folio prepared by the San Francisco Bay Landslide Mapping Team, are incorporated in the GIS, and are discussed further in Section 4.

We adopted the boundaries for the San Francisquito Watershed provided by the Geological Survey in their GIS database. They delineated major subwatersheds for the large tributaries to San Francisquito Creek and further sub-divided the tributary subwatersheds into sub-subwatershed. San Francisquito Creek watershed is composed of 10 subwatersheds: San Francisquito, Corte Madera, Los Trancos, Alambique, Martin, Sausal, Westridge, Bear, Bear Gulch, and West Union creeks. Figure 2 shows the various boundaries; The Historic Conditions Memorandum summarizes the characteristics of the subwatersheds and their sub-subwatersheds. We corrected the sub-subwatershed boundaries and codes provided by the USGS, where required.

Watershed boundaries along the lower, urbanized section of San Francisquito Creek, where natural drainage has been altered by urban development, have changed over time.

The boundaries shown along San Francisquito Creek include the watersheds of small tributaries to the creek and contributing areas from storm drains. The boundaries from Junipero Serra Boulevard to San Francisco Bay are currently being revised by the Santa Clara Valley Water District (SCVWD) to account for changes in storm water drainage. Their work is expected to slightly change some of these sub-subwatershed boundaries.

The Santa Clara Basin Watershed Management Initiative (SCBWMI) metadata repository at the Palo Alto RWQCP was also an important source of information, as were reports and information provided by the JPA and the Technical Advisory Committee. The SCBWMI provides an annual summary or inventory of studies and projects undertaken on streams in the Santa Clara Basin. EOA (2003) provides the most up-to-date version.

1.6. Organization of the Report

The Draft Watershed Analysis and Sediment Reduction Plan is organized into the following chapters:

- Chapter 1: Introduction
- Chapter 2: Geology and Hydrology
- Chapter 3: Land Use and Watershed Resources
- Chapter 4: Erosion, Transport and Deposition
- Chapter 5: Subwatershed Sediment Budgets
- Chapter 6: San Francisquito Creek Sediment Budget
- Chapter 7: Existing Management Policies and Practices
- Chapter 8: Sediment Reduction Plan
- Chapter 9: Summary and Conclusions

Technical appendices to the main report provide details on specific issues or provide summaries of significant databases or other information.

1.7. Technical Terms and Their Definitions

Technical terms are defined where they are first encountered.

2. GEOLOGY AND HYDROLOGY

2.1. Background

Physiography, including elevation, stream and valley slopes, geology, and stream networks, plays a key role in determining where sediment is eroded and where it is deposited. As such, understanding and characterizing watershed physiography is an important part of both sediment budgets and sediment reduction plans.

2.2. Physiography and Geology

The San Francisquito Creek watershed has an area of about 47 mi^2, most of which lies in the Santa Cruz Mountains southwest of Palo Alto. The overall watershed has been divided into 10 subwatersheds – San Francisquito, Corte Madera, Los Trancos, Alambique, Martin, Sausal, Westridge, Bear, Bear Gulch, and West Union creeks – and 55 sub-subwatersheds (Figure 2). The Historic Conditions Analysis Memorandum summarizes areas, stream lengths, average slopes, elevations, lengths of roads and geologic formations for each subwatershed and sub-subwatershed.

The San Andreas Fault Zone (SAFZ) is the most prominent feature in the San Francisquito Creek watershed, bisecting the watershed along a northwest-southeast direction (Figure 1). The steep, upper watershed lies southwest of the SAFZ in the northern Santa Cruz Mountains, whereas more gradually sloping areas lie to the northeast (Figure 3). Unstable slopes and active landsliding are predominantly found southwest of the SAFZ (Wentworth *et al* 1997). This area corresponds to the Santa Cruz Mountain Upland erosional and depositional province of Brown and Jackson (1973).

The upper San Francisquito watershed lies east of the crest of the northern Santa Cruz Mountains and southwest of the SAFZ. The geologic formations in this part of the northern Santa Cruz Mountains consist of Tertiary sedimentary rocks, primarily sandstone, mudstone and shale, with poorly indurated Quaternary-Tertiary sedimentary rocks (Santa Cruz Formation) and Holocene stream and fan deposits found along the SAFZ (Figure 4; Brabb *et al* 2000). The various formations differ in their resistance to erosion and their importance to sediment production, as is discussed further in Chapter 4.

The northern Santa Cruz Mountains have had an average uplift rate of about 0.1 to 0.4 mm/year during the Quaternary, significantly less than the southern Santa Cruz Mountains but still active (see Burgmann *et al* 1994; Anderson 1994). Stream incision into bedrock has been an important component of the development of these mountains and the broad alluvial fans and alluvial plain deposited along the shore of San Francisco Bay provide a record of the considerable erosion that has occurred (Anderson 1994).

Tertiary sedimentary rocks and the Franciscan Complex underlie the foothills northeast of the SAFZ. Large areas of greenstone and mélange, part of the Franciscan complex, underlie the southern part of the Los Trancos watershed (Figure 4). This area corresponds to the Bay Hills and Foothills erosional and depositional provinces of Brown and Jackson (1973).

The boundary or contact between the bedrock in the upper watershed and the unconsolidated materials around San Francisco Bay lies close to Alameda de Las Pulgas Road, along the Pulgas Fault (Fio and Leighton 1995; Metzger 2002). The unconsolidated material is an alluvial apron, consisting of coalesced sediments from the tributaries draining to San Francisco Bay that was deposited during the Pleistocene and Holocene epochs. It is thick near San Francisquito Creek (more than 1,000 feet) and includes lenses or layers of Bay Muds deposited during marine transgressions. San Francisquito Creek is well incised into the alluvial apron deposits (Helley *et al* 1979).

Pleistocene and Holocene stream and fan deposits fill the broad valleys along the SAFZ in the upper watershed, through Portola Valley and Woodside; Los Trancos Creek flows through coarse Pleistocene fan and stream terrace deposits along much of its course, as does upper San Francisquito Creek (Helley *et al* 1979; see also Figure 4). Upper Corte Madera Creek flows through the poorly consolidated Santa Clara formation, consisting of late Tertiary and Pleistocene lacustrine and alluvial gravel and sand deposits.

Metzger (2002) prepared a geological section of the San Francisquito fan downstream of Alameda de Las Pulgas Road. It shows a thick layer of coarse stream deposits near the head of the fan that thin and disappear by Middlefield Road. The coarse material overlies a medium-grained alluvium (fine sand and silt) that continues beneath the creek from Middlefield Road to the Palo Alto Municipal Golf Course, where Bay sediments cover it. A thick layer of bay sediments with lenses of alluvium extends at depth beneath the sand upstream to about San Mateo Drive forming a shallow aquifer beneath the fan (Metzger 2002). These bay sediments are underlain at depth by older, more consolidated alluvium.

2.3. The Stream Network

DATA SOURCES

The stream network for San Francisquito Creek watershed was adopted from the USGS GIS database, as shown on the most recent 1:24,000 quadrangles (Figure 1). The digital network includes the larger tributaries to Corte Madera, Bear, Los Trancos and San Francisquito Creek but does not include gullies, zero-order channels, or swales that are visible on large-scale maps or that can be identified during field inspections. The overall drainage density for the stream network is 1.7/mi. Adjustments to drainage density to include gullies and zero-order channels are discussed in Appendix C.

Few studies have examined long-term changes in alignment of streams in the upper San Francisquito Creek watershed that may have resulted from lateral movement along the SAFZ, although Smith and Harden (2002) note abandonment of the course of lower Bear Gulch and discuss some of the other effects of movement along the San Andreas Fault Zone on streams and fish habitat. Away from the SAFZ, streams are deeply incised over most of their courses.

Detailed studies of historic stream channel shifting are limited to San Francisquito Creek downstream of Searsville dam (Royston Hanamoto Alley and Abey (RHAA) *et al* 2000; **nhc** *et al* 2002). These reports examined historic changes in channel alignment by comparing USGS maps and old (1894) surveys. Both studies concluded that San Francisquito Creek has remained in about the same course, but has shifted and eroded its bank, particularly on the outside of bends. San Francisquito Creek appears to be most stable upstream of Sand Hill Road where it has incised into local bedrock.

STREAM REACHES

The stream reach or smallest stream unit for analysis consisted of the length of stream that lay within a particular sub-subwatershed.

STREAM CLASSIFICATION

After a review of existing stream classifications, the Montgomery and Buffington (1993) system was adopted to characterize and classify the streams in the San Francisquito Watershed. Key advantages of the method are:

- It was developed for mountainous watersheds of the Pacific Coastal Ecoregion, an area that covers approximately 2,300 miles along the western edge of North America, from the Santa Cruz Mountains to Anchorage, Alaska.
- It was designed for forested mountain watersheds where there is a significant large woody debris (LWD) component to stream morphology.
- It can be applied at a reconnaissance level using aerial photos and topographic maps. Although preferred, field surveys are not required for application to stream networks.
- It is a process-based approach designed for application in watershed-based studies of channel form and its response to natural and human disturbance.

The Montgomery-Buffington system identifies three main morphologic scales; the watershed, the valley segment and the channel reach. Watersheds are divided into hillslope and valley segments; valley segments are then divided into colluvial, bedrock and alluvial types. Colluvial segments store sediment derived from hillslopes by creep, tree throw and slope failure, occur in upper watersheds, and are often dominated by debris flow or landslide processes. Sediment transport capacity generally exceeds sediment supply in bedrock segments, exposing bedrock along the channel bed. Alluvial segments are those where streams flow in a self-formed channel through their own deposits.

Colluvial and alluvial valley segments are characterized by a range of stream types that change in a consistent manner with distance downstream providing a stable morphology for the given valley characteristics, sediment supply and sediment transport. Table 2-1 describes the different stream types. Note that gradient boundaries between types are not fixed and may vary with sediment supply and transport capacity.

Figure 5 classifies the streams channels in GIS database into the different Montgomery-Buffington types based on channel slope and stream observations from other report and field visits. The Existing Conditions Memorandum provides further details on the classification method and the correspondence between the predicted classes and the observed stream morphology.

Table 2-1: Summary of Valley Segment and Reach Types in the Montgomery Buffington Method

Valley Segment Type	Reach Type	Location in Watershed	Typical Slope Range	Primary Sediment Process	Instream Sediment Storage	Notes
Colluvial	Unchanneled (Hollow)	Upper	S > 0.2	Supply	N/A	Sediment accumulates in hollows over years or decades and, during infrequent large storm or seismic events, debris flows and landslides convey this sediment into the drainage network. The cycle begins again with the hollow gradually refilling with sediment.
Colluvial	Channeled	Upper / Middle	S > 0.2	Supply	High	These stream channels occur in the upper watershed, where. Landslides, debris flows, and soil creep are common. Sediment supply is abundant and sediment throughput is transport limited. Bed material is typically unsorted, containing abundant fine-grained material due to limited stream flows.
Alluvial	Cascade	Upper	0.3 > S > 0.1	Transport	Very Low	Cascade channels are very steep with very coarse bed material. High flows appear as white-water, tumbling around large boulders. Sediment storage is very limited and restricted to low-velocity areas in small pools or behind debris jams. These channels can maintain their configuration for decades, until very large storms re-mobilize the stream bed.
Alluvial	Step-Pool	Middle	0.1 > S > 0.03	Transport	Low / Medium	Step-pool channels exhibit alternating pools and steps (steep, often vertical, drops usually located near a bed control such as a very large boulder or a debris jam). Steps typically contain very coarse bed material whereas pools allow finer material to accumulate, providing some sediment storage.
Alluvial	Plane-Bed	Middle	0.03 > S > 0.01	Transport	Low / Medium	Plane-bed channels exhibit a relatively flat bed that lacks significant variability and has few bedforms. Occasional steps, pools, or rapids may form but are infrequent or absent. Bed material is typically coarse and the bed is armored. Plane-bed channels may be either supply or transport limited.
Alluvial	Pool-Riffle	Middle / Lower	0.02 > S 0.001	Transport / Deposition	Medium / High	In pool-riffle channels, the bed alternates between steeper riffles with coarse bed material and less steep pools where fine sediments accumulate and are stored until the next high flow. Regular bars store additional sediment. Pool-riffle channels are considered to be transport limited.
Alluvial	Regime	Lower	S < 0.001	Deposition	High	Regime channels are characterized by low-slope environments and predominantly sand bed material. Channel roughness is low and sediment is transport limited at all flow stages.
Bedrock	Bedrock	Upper / Middle	0.30 > S > 0.001	Transport	Low	Bedrock channels are largely devoid of bed material. They have high transport capacities and, other than local pockets of sediment accumulation, are scoured to bedrock of all available sediment.

STREAM INSPECTIONS

As part of the Watershed Sediment Analysis, we visited streams reaches in the San Francisquito Watershed that had not been described in detail in previous reports. The site visits addressed the following issues:

- Described channel morphology as part of verifying the Montgomery-Buffington method described in the previous section
- Measured surface bed material size distributions at three selected sites
- Described channel characteristics and evidence of recent bank erosion, channel incision and in-stream sediment storage
- Photographed the channel to document current characteristics

Appendix A provides a map showing the sites that were visited, a summary of the observations at each site, and photographs of stream reaches.

2.4. Hydrology

STREAM GAUGING RECORDS

The "San Francisquito Creek at Stanford University (11164500)" gage, located on the Stanford Golf Course upstream of Junipero Serra Boulevard, provides the best long-term record of flow in San Francisquito Creek with measurements from 1931 to 1941 and then from 1951 to present. This gage has a watershed area of 37.5 mi^2 and measures the flow from the Santa Cruz Mountains and Bay Foothills erosion provinces.

The stream gages that have been operated on San Francisquito Creek and its tributaries by the USGS are summarized in Table 2-2.

Table 2-2: USGS Stream Gages on San Francisquito Creek and Tributaries

Gage Name	*Gage Number*	*Period of Record*	*Area (mi^2)*	*River Mile* [1]
At Searsville Dam (staff gage on spillway crest)	None	1892-1913	–	12.7
At Stanford University	11164500	1931-41; 1950 to present	37.5	7.6
At Menlo Park	11165000	1931-1941	38.3	5.4
At Palo Alto	11165500	1934-36	38.4	4.6
Los Trancos Ck near Stanford University	11163000	1930-41	–	–
Los Trancos Tributary near Stanford University	11163200	1958-66	0.42	–
Los Trancos Ck at Stanford University	11163500	1930-41	7.46	–

1. River mileage along San Francisquito Creek from Corps of Engineers (1972)

Balance Hydrologics, Inc also operates stations on the tributaries to San Francisquito Creek for Stanford University. Measurements began in 1997 on Corte Madera Creek at Westridge Road and in 1995 on Los Trancos Creek at Arastradero Road and they continue to the present (Owens, Chartrand, and Hecht 2002a; 2002b).

Crippen and Waananen (1969) reported flow and sediment measurements on three small tributaries in the Bay Foothills, from 1959 to 1965, for a study designed to examine the effect of suburban development on their existing hydrologic regime. Their study included the Los Trancos Creek Tributary described in Table 2-2.

CLIMATE

San Francisquito Creek has a Mediterranean climate, with warm, dry summers and mild, wet winters. Average annual precipitation varies from 15 inches at Palo Alto (Metzger 2002) to about 40 inches in the upper watershed (Rantz 1971). The Corps of Engineers (1972) estimated an average annual precipitation over the watershed of about 32 inches. Average annual flow at the Stanford University gage is 21.4 cfs, equivalent to 7.7 inches of runoff, or about 25% of average annual precipitation.

ANNUAL FLOWS

nhc *et al* (2002) extended the record of annual flows from 1899 through to the 2000 water years at the Stanford gage, filling missing years in the recorded flow record through correlation with nearby long-term gages. Examination of this record shows distinct periods of high and low annual flows, with the periods of high flows spaced roughly 15 to 20 years apart. Streamflow has been particularly high from 1995 to 2000; other periods of consistent high annual flows include 1899 to 1911 and 1937 to 1945.

FLOODS

The flood of record on San Francisquito Creek at the Stanford University gage occurred in 1998 with a peak of 7,200 cfs. Other notable floods – those exceeding 5,000 cfs based on reconstructed records – have occurred in 1894, 1895, 1911, 1955 and 1982 (Kittleson *et al* 1996; see also Corps of Engineers 1972). The Corps of Engineers (1972) also notes that between 1910 and 1972 San Francisquito Creek overflowed its banks eight times – in 1911, 1916, 1919, 1940, 1943, 1950, 1955 and 1958. It later overflowed its banks in 1982 and then again in 1998 (Cushing 1999). Levees and channel modifications now contain the flows that overtopped the banks earlier in the twentieth century. As described by the Corps of Engineers (1972) and Cushing (1999) overflow now mostly occurs along the lower part of the creek, downstream of Middlefield Road.

The tributaries to San Francisquito Creek in the upper watershed are mostly deeply incised. Flood insurance studies have been completed for Portola Valley and Woodside (US Department of Housing and Urban Development 1978; 1979). These studies show that peak flows are contained within the banks of most creeks, with the exception of Corte Madera and Sausal Creeks. Aggradation on the fan of Corte Madera Creek at the head of Searsville Lake now results in flooding along Family Farm Road and adjacent properties (**nhc** and JSA 2000).

LOW FLOWS

Low flows at the Stanford University gage typically occur in the late summer or early fall, before winter rains begin. Annual minimum 30-day low flows range from zero to about 1 cfs. 30-day low flows were typically zero during the early period of record but now typically range from 0.1 to 0.4 cfs. Downstream of this gage, the channel bed over the fan deposits is effluent and low flows infiltrate to groundwater, leaving much of the streambed dry for about six months of the year (Metzger 2002).

Most of the streamflow losses or infiltration to groundwater occurs between San Mateo Drive and Middlefield Road where San Francisquito Creek crosses the Pulgas fault. Further downstream, losses are minimal and groundwater returns may supplement stream flows. Storm drains also supplement natural flow at various sites along the reach and water chemistry measurements indicate that during moderate and low flows the water downstream of San Mateo Drive is a mix of natural flows from the upper watershed and urban runoff (Metzger 2002).

WATER MANAGEMENT STRUCTURES

The Corps of Engineers (1972) identified four major water management structures in the San Francisquito Creek watershed, as described in Table 2-3. There are also a large number of small reservoirs and water diversion structures in the watershed that are not included in this inventory.

Table 2-3: Large Water Management Structures on San Francisquito Creek and its Tributaries

Structure Name	Purpose	Capacity (acre-feet)	Year Built	Comment
Searsville Lake	Irrigation; fire protection	About 250 [1]	1890	Historically, flashboards installed in spring; removed in fall
Felt Lake	Irrigation	1,000	1930	Off-stream reservoir from Los Trancos Creek
Lagunita Lake	Recreation	360	1880s	Water diverted from San Francisquito Ck in spring; drained in summer
Bear Gulch Reservoir	Domestic	660	1896	

1. Remaining capacity as of **nhc** *et al* (2002).

The four reservoirs described above are thought to have only a minor effect on flood flows as their volumes are not very large compared to inflows, they are often full when large floods occur, and flood flows are diverted around Felt Lake to avoid siltation (Corps 1972).

In the past, flashboards were installed on Searsville Lake in the spring to store about 4.5 feet of water for irrigation; these flashboards were removed in the fall to lower winter water levels in Searsville Lake and upstream. Felt Lake is filled from December to April by diversion from Los Trancos Creek. The lake is drawn down between May and November for irrigation and fire protection.

During winter and spring, several acre-feet per day (roughly less than 10 cfs) are diverted from San Francisquito Creek, just upstream of the Stanford gage, to fill Lagunita Lake and maintain its water level. The lake is not filled every year and it is currently managed for tiger salamander breeding habitat. After commencement ceremonies, the lake is drained and water returned to San Francisquito Creek via the storm sewer system in mid-June (Metzger 2002). The California Water Company (CalWater) was not contacted regarding operation of Bear Gulch Reservoir.

The overall impact of the large reservoirs on flows in San Francisquito Creek is not well documented. However, it is likely that water utilization, evaporation, and diversion of flow to maintain summer reservoir levels has reduced spring, summer and fall flows to some extent in the San Francisquito Creek watershed. Considerable further analysis would be required to evaluate natural flows and the extent of their alteration.

2.5. Groundwater

The aquifer that underlies the San Francisquito alluvial fan is an arbitrarily defined sub-basin of the larger aquifer that extends into the Santa Clara Valley (Sokol 1964; Fio and Leighton 1994). The sub-basin beneath the fan includes both a shallow aquifer in the sandy deposits that lie beneath San Francisquito Creek and a deeper one with water bearing strata at depths greater than 200 feet below the local ground surface.

The shallow aquifer extends to depths of up to 100 feet and lies above a layer of clayey bay deposits. This aquiclude or confining bed ends near San Mateo Drive. Upstream of this point, the shallow aquifer is apparently connected to the deeper one (Sokol 1964; Metzger 2002). Water levels in the shallow aquifer are below the stream bottom, particularly upstream of San Mateo Drive where they are more than 20 feet below the creek bottom. Groundwater levels may be near the streambed just downstream of Middlefield Road and then again in the tidal reach, downstream of Highway 101 and through East Palo Alto.

As discussed earlier, stream flows from San Francisquito Creek infiltrate the streambed and recharge the aquifers. Metzger (2002) estimated annual losses of about 1,000 acre-feet, with most of the loss between San Mateo Drive and Middlefield Road. This is equivalent to about 9% of the long-term mean annual flow. Sokol (1964) estimated slightly smaller losses by comparing flows at the various gaging stations that operated on San Francisquito Creek in the 1930s (see Table 2-2). Seepage from Lake Lagunita, infiltration of runoff from the foothills, over-irrigation, urban watering, and leakage from water distribution and stormwater systems also contribute to aquifer recharge.

Metzger (2002), Metzger and Fio (1997), and Fio and Leighton (1994) indicate that groundwater pumping was an important water source for communities on the San Francisquito fan until the mid-1960s, when purchased water became the primary source.

Groundwater still remains a significant water source in some communities on the San Francisquito fan, such as Atherton.

Groundwater exploitation prior to the mid-1960s resulted in lowered groundwater elevations in Palo Alto, Menlo Park and Atherton (Metzger 2002), movement of saline water inland from San Francisco Bay (Iwamura 1980), and land subsidence in parts of Palo Alto and East Palo Alto (Poland and Ireland 1988). Groundwater levels are thought to have recovered since the mid-1960s. However, groundwater elevation data are limited near San Francisquito Creek and it is difficult to assess whether elevations are now similar to those at the end of the nineteenth century or whether they remain depressed. The limited information available (see maps in Fio and Leighton 1995) suggests that historic ground water elevations were below the local streambed on the upper part of the fan, resulting in similar losses of streamflow to groundwater to those observed now. Groundwater elevations may have been closer to the streambed along the lower part of San Francisquito Creek, resulting in more frequent surface flows in the past than occur there now. Note that streambed incision in the upper end of San Francisquito Creek and aggradation along the lower reaches over the past century may have also affected the extent of infiltration and groundwater influence along San Francisquito Creek.

Much less is known of groundwater levels in the upper watershed. Crippen and Waananen (1969) note that groundwater elevations are typically well below the surface in small tributaries to San Francisquito Creek in the Bay Foothills, although they may rise to streambed levels following intense winter storms. Little is known of the groundwater conditions in the upper watershed. Here, shallow soils over bedrock on the valley slopes limit the extent of groundwater storage and its influence on streamflow. However, groundwater may be an important component of streamflow along the valleys of the San Andreas Fault Zone where deep alluvial deposits store considerable volumes of water.

2.6. Hydromodification

DEFINITION

SCVURPPP defines "hydromodification" to refer to the changes in watershed hydrology, and the subsequent changes to streams that result from land use (GeoSyntec 2003). Urbanization, through creation of impervious areas, increasing drainage connectedness, and improvements to channels (levees, straightening, and reduced roughness) often affects interception, infiltration, overland flow and stream flow so that the volume, frequency and duration of peak flows are increased. It is changes in peak flows that result in adjustments to the stream channel.

LAND USE AND HYDROLOGY IN SAN FRANCISQUITO WATERSHED

Unfortunately, there are no detailed hydrologic modeling studies of San Francisquito Creek that compare existing peak flows or hydrographs to those that might have occurred prior to development. Consequently, the potential for modified hydrology must be assessed indirectly from measurements of impervious area prepared from land use data (see Section 3). EOA Inc (1998) estimated total impervious cover in the San Francisquito watershed from the 1995 Association of Bay Area Governments (ABAG) land use by applying estimates of impervious cover to 40 land use categories. They estimated total impervious cover as 22% of the watershed area. The Santa Clara Basin Watershed Management Initiative (SCBWMI 2000) subsequently estimated impervious cover of 20.8% as of 1995 and projected an impervious cover of 26.1% for the development expected as of 2020. These estimates refer only to the entire watershed; a breakdown by subwatersheds is not provided by either of these references. Recent spatial imagery obtained by the SCVWD includes a supervised classification of impervious area throughout the watershed as part of vegetation analysis by Space Imaging. Analysis of the impervious areas to be completed by the SCVWD and USGS will update the overall imperviousness and estimate imperviousness for the subwatersheds and sub-subwatersheds.

There are no studies of the relationship between impervious cover and channel stability that are specific to the San Francisco Peninsula or San Francisco Bay. However, studies from Washington (Booth and Jackson 1997) suggest that channel instability is observed for watersheds with greater than 10% impervious cover. (Booth and Jackson refer to effective impervious area, which is the impervious area that is directly connected to the stormwater system, excluding such features as roofs that drain to lawns and are not directly connected. The effective impervious area is less and may be much less than total impervious area.) Based on the above, it seems likely that urban development in Palo Alto, Menlo Park and East Palo Alto have increased the frequency of channel forming flows and also the duration of peak flows in San Francisquito Creek, thus increasing sediment transport and bank erosion. Levees to maintain flood flows in the channel and human modifications of stream banks likely also increase instability and erosion. Detailed hydrologic and geomorphic modeling would be needed to assess the magnitude and significance of urban development on erosion along San Francisquito Creek.

The lower watershed is substantially urbanized; however, the upper watershed is lightly developed, with low and moderate density residential areas in Portola Valley and Woodside, some agriculture along the SAFZ, and open space areas and parks on the steep slopes of the Santa Cruz Mountains. The San Francisquito Creek Coordinated Resource Management and Planning (SFCCRMP) Task Force (1998) provided estimates of impervious cover for the upper subwatersheds, based on 1983 land use (Table 2-4). While not explained in the text, it appears that the quoted values refer to total rather than effective impervious area. The impervious area estimates from CRMP may still be reasonably valid, as only limited development has occurred in the upper watershed in the past twenty years.

Based on the impervious cover quoted in Table 2-4, and recognizing that total impervious cover overestimates effective impervious cover, it seems likely that urban development and creation of impervious areas in Searsville Lake, Los Trancos and Bear subwatersheds only contribute in a minor way to altered flows and channel instability in the main streams in these subwatersheds.

However, flows may have been altered in some sub-subwatersheds. The watershed of Westridge Creek (part of SL-02) is mostly covered by residential development with lots of more than one acre. Typical total impervious areas for such developments are about 20% and some modification of peak flows might be expected as a result. Martin Creek (MC-01) and Bull Run Creek (SC-02) also exhibit more roads and houses than other sub-subwatersheds in the Santa Cruz Mountains and their peak flows may also have been affected by development.

Table 2-4: Total Impervious Cover and Road Densities for San Francisquito Subwatersheds

Subwatershed	*Area (mi^2)*	*Percent Impervious Cover* [1]	*Road Density* [2] *(mi/mi^2)*	
			Paved	*Unpaved*
Searsville Lake (Corte Madera, Alambique, Sausal, Dennis Martin and Westridge)	14.6	6%	4.8	2.9
Los Trancos	7.6	4%	4.7	1.9
Bear (Bear, Bear Gulch, and West Union)	11.6	7%	4.3	1.7
San Francisquito Creek from Searsville Dam to Junipero Serra Boulevard (SF-10 and SF-11)	3.4	12%	6.3	2.5
Total Watershed	47.1	21% [3]	–	–

1. From CRMP (1998); refers to 1983 land use. Assumed to be total impervious area.
2. Paved and unpaved road lengths from most recent revision of USGS maps (see **nhc** and JSA 2003a; Appendix E).
3. Average of EOA (1998) and SCVWMI (2003) percent impervious cover.

Crippen and Waananen (1969) examined the effect of conversion of rural lands on the hydrologic regime of three small tributaries in the San Francisquito Creek watershed, between the dam and Junipero Serra Boulevard. They identified large increases in storm and annual runoff, a more rapid response to precipitation, an increase in the occurrence of frequent floods, and a change from ephemeral to perennial flow as a result of golf course irrigation. Hydrograph changes apparently resulted in channel incision and other adjustments along these tributaries.

Roads and trails in the Santa Cruz Mountains, where there is little impervious area from development, may play a role in modifying hydrology. These are principally the unpaved roads listed in Table 2-4. Studies of forest road impacts on hydrologic processes have found that roads can increase peak flows by intercepting subsurface flow and dispersed overland flow from hillslopes and conveying it more rapidly via road surfaces and ditches to the stream channel network. In this way, roads serve to drain runoff from the landscape more quickly by increasing the effective length of channels in a watershed (i.e. increasing drainage density). The following attributes of road systems affect the degree to which they alter hillslope drainage:

- *Location on hillslope*: the greatest alteration results from mid-slope roads.
- *Orientation on hillslope*: the greatest alteration is by roads cutting across slopes.
- *Cut bank height:* the greatest alteration occurs when the cut bank intersects the complete subsurface flow zone.
- *Road surface and ditch roughness*: the greatest alteration occurs when roads and ditches are unvegetated.
- *Connectivity to stream channels*: the greatest alteration is from roads with long continuous grades and few cross-drains that lead to stream channel crossings.

The generation of overland flow on the compacted road surface itself can also be a factor. However, in most studies, this was considered secondary to the other effects because the area of the road surfaces is usually only a small percent of watershed area.

Inspection of maps and air photographs show that the main roads through the Santa Cruz Mountains are on the valley bottoms (in the SAFZ) or on the crest of the Santa Cruz Mountains (Skyline Boulevard); few roads are found on upper slopes and few of these are mid-slope roads that might intercept subsurface flows. Main roads that cross the Santa Cruz Mountains, such as Kings Mountain Road, Bear Gulch Road and Highway 84, and the trails in the Mid-Peninsula Regional Open Space typically climb ridges and do not typically cross slopes. Also, many of the trails do not have ditches connecting their surfaces to the stream network. It is our opinion that the existing roads and trails in the upper watershed may increase frequent flood peaks by a few to 10% or so in some sub-subwatersheds, depending on their degree of hydrologic connectivity, and have little or no effect on infrequent, large peaks. Such results are consistent with hydrologic modeling of forest roads in Washington with similar road densities (**nhc** 2003). Detailed modeling would be needed to assess the magnitude of changes in flood hydrology from roads and their contribution to channel instability and erosion.

Overall, the land use in the San Francisquito Creek watershed suggests significant modification to the frequency and duration of peak flows in San Francisquito Creek and little or no modification of hydrographs in the tributaries in the upper watershed. Low-density residential development and roads may modify peak flows in some sub-subwatersheds, particularly Westridge Creek and possibly Dennis Martin and Bull Run Creeks.

3. LAND USE AND WATERSHED RESOURCES

3.1. Background

This chapter provides a discussion of historic and existing land use and roads, including trends over time, and a review of historic and existing biological resources and habitats within the watershed. The analysis is based on existing reports, maps and other documents. Sources are described in the Existing Conditions Analysis Memorandum, which also provides further details on watershed resources.

One goal of the analysis is to provide information on human activities in the watershed that have either directly affected streams and sediment supply or have indirectly affected them by altering erosion, hydrology, vegetation communities, or topography. Urban development, particularly roads, clearing for development, construction of impervious areas, and modifications to drainage (including levees) is thought to have the greatest effect on hydrology and sediment supply, and thus on streams. However, agriculture, grazing, forest harvesting and other land uses may have been important historically and may still continue to affect erosion.

3.2. Political Jurisdictions in the Watershed

The San Francisquito Creek watershed includes several different political jurisdictions. The watershed lies in both San Mateo and Santa Clara Counties. Most of it lies in San Mateo County although about one-fifth of the area, southeast of San Francisquito and Los Trancos creeks, lies in Santa Clara County. Figure 6 shows the boundary between the two counties along San Francisquito and Los Trancos Creeks.

The County division is important because each county administers the National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharges to San Francisco Bay separately. Within Santa Clara County administration is by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and within San Mateo County by the San Mateo Countywide Stormwater Pollution Prevention Program (SM-STOPPP). Palo Alto, Santa Clara County, and the Santa Clara Valley Water District (SCVWD) are co-permittees with SCVURPPP; East Palo Alto, Menlo Park, Portola Valley, Woodside, and San Mateo County are co-permittees with SM-STOPPP. The two administrative groups have different NPDES permit requirements and different approaches to meeting their permits.

Figure 6 also shows the boundaries for local governments, including the cities of East Palo Alto, Palo Alto, and Menlo Park, and the towns of Woodside and Portola Valley. San Mateo and Santa Clara Counties are responsible for unincorporated areas and County Parks that lie outside of the boundaries of these cities and towns. Figure 6 also shows the area owned by Stanford University in the central part of the watershed and the regional greenbelt managed by the Midpeninsula Regional Open Space District (MROSD) in the upper watershed. Other significant landowners or managers include the Peninsula Open Space Trust, CalWater in upper Bear Gulch, and the Golden Gate Natural Recreation Area (Phleger Estate) in the upper West Union Watershed. Table 3-1 summarizes the areas within San Francisquito Creek and its main subwatersheds that are managed by each jurisdiction, as interpreted from the GIS shown on Figure 6.

Table 3-1: Total Area in San Francisquito Watershed and Area by Subwatershed for Different Jurisdictions

Jurisdiction	***Area by Subwatershed (acres)***				***Area in SF Watershed (acres)***
	Searsville	*Los Trancos*	*Bear*	*SF Creek*	
East Palo Alto	0	0	0	913	913
Palo Alto	0	1,778	0	1,673	3,451
Menlo Park	0	0	0	1,523	1,523
Portola Valley	2,967	1,023	0	175	4,165
Woodside	1,889	0	2,628	0	4,518
Santa Clara Unincorporated	0	134	0	0	134
San Mateo Unincorporated	1,457	443	1,869	39	3,808
Stanford	149	959	176	3,574	4,858
Jasper Ridge	418	0	0	352	769
CalWater	0	0	717	0	717
MROSD	2,153	310	771	0	3,234
Golden Gate NRA	0	0	1,224	0	1,224
Peninsula Open Space Trust	240	145	10	0	395
Other	0	79	11	329	419
Total					*30,126*

Stanford University is the largest landowner in the San Francisquito Watershed. Organizations that are responsible for substantial areas in the San Francisquito watershed include Palo Alto, Portola Valley, Woodside, San Mateo County (unincorporated lands and County Parks) and the MROSD.

3.3 Land Use

OVERVIEW

In the San Francisquito watershed, approximately 8,800 acres (29%) are protected by public agencies, property easements, or private land trusts, providing a natural feel within much of the watershed. The west side of the watershed is largely unpopulated, consisting primarily of forest and grasslands. The lower watershed is highly urbanized, and supports residential and commercial development. Large, contiguous areas of open space, including forest, rangeland and agricultural areas, are interspersed throughout the urban land uses, complementing the undeveloped, open nature of much of the watershed.

EXISTING LAND USE

Table 3-2 summarizes the existing land uses within the San Francisquito watershed, based on the Association of Bay Area Governments (ABAG) database for 1995. The dominant land uses are forest, rangeland, and residential development. As described above, the majority of forest and rangeland exist in the western portion of the watershed, while the residential development is dominant in the eastern portion of the watershed. As of 1995, development within the watershed consisted of 29.6 percent residential, 5.2 percent industrial/commercial, and 65.1 percent agriculture or open space.

Table 3-2: Area of Existing Land Uses for the San Francisquito Watershed [1]

Land Uses	Area (acres)
Residential, 4 or more DU/acre	2,027
Residential, 1 to 3 DU/acre	6,074
Residential, 1 DU/2 to 5 acres	25
Commercial	495
Public/Quasi-Public	707
Industry – Heavy	18
Transportation, Communication	217
Utilities	2
Agriculture	490
Forest	12,267
Rangeland	4,100
Urban Recreation	425
Vacant, Undeveloped	396
Wetlands	101
Fresh Water	72
Total	*27,416*

1. From ABAG Land Use Data (1995). Total area differs from Table 3-1.

TRENDS IN LAND USE

The Santa Clara Basin Watershed Management Initiative (2000) notes a broad trend of agricultural development on valley bottoms starting in the 1850s, followed by intensive agriculture, with urban growth and industrial development replacing agriculture following World War II. Most highways were built by the mid-1940s with freeway construction in the 1950s and 1960s. Brown (1966) and Stanger (1967) provide a history of early logging on the San Francisco Peninsula around San Francisquito Creek.

The area of commercial and residential development in the San Francisquito watershed has continued to increase recently, as part of the ever-growing San Francisco Bay Area. Review of historic and current aerial photos and maps indicate a steady growth in area of development, particularly in the eastern portion of the watershed where the topography is more gently sloping. In conjunction with the increasing areas of development, the roadways system has continued to expand, both in size and complexity throughout the watershed.

The Santa Clara Basin Watershed Management Initiative (SCBWMI 2000) has also projected future residential, industrial, and commercial development within the watershed through the year 2020 based on trends over time throughout the watershed, and in the surrounding areas. Although development will continue to increase over time throughout the watershed, only 8,149 acres are available for development, leaving a substantial portion of the watershed in a relatively natural condition. Development is expected to increase the total impervious area in the watershed from 20.8% in 1995 to 26.1% by 2020. Section 2.5 discusses hydrologic impacts of impervious area on streams in the watershed for the existing urban development.

ROADS

The Existing Conditions Analysis Memorandum documents the change in paved and unpaved roadways throughout the watershed from 1868 to 1999, based on historic air photos and USGS topographic maps. The memorandum shows the overall growth of the road network and shows that the total length of unpaved roads and trails in 1999 is only about 40 miles less than at the end of the nineteenth century, at around 90 miles. The memorandum also includes the number of intersections between roadways and streams within the watershed, showing a steady increase in the number of stream crossings over time in many of the subwatersheds.

UNPAVED ROAD AND TRAIL INSPECTIONS

Erosion from unpaved roads and trails in the Santa Cruz Mountains is anticipated to be a key component of the human-related sediment budget. However, there are no inventories for roads or descriptions of road erosion in the watershed. We inspected a selection of the unpaved roads and trails in the Santa Cruz Mountains in order to characterize their features and identify the type of erosion processes that were occurring.

Appendix B provides a map showing the sites that were visited, a summary of the observations at each site, and photographs of the unpaved roads and trails.

3.4. Biological Resources

BACKGROUND

The biological resources within the San Francisquito watershed have been separated into terrestrial and aquatic species and habitat types, as described below. The Existing Conditions Analysis Memorandum describes the studies and databases reviewed to prepare this assessment.

TERRESTRIAL HABITAT TYPES

Terrestrial habitat presence and species richness was defined using the California wildlife habitat relations (WHR) based on vegetation data from the California GAP analysis. The University of California at Santa Barbara (UCSB) completed the California Gap analysis in 1988. This system was selected for this study because mapping encompasses the entire watershed area. Local studies, the California Department of Fish and Game Natural Diversity Database, and field verification were used to determine more specific wildlife and habitat correlations for special-status species that are know to occur, or thought to occur, within the watershed. This information is described below under the special-status species section. Maps of the WHR habitat classifications by subwatersheds and acreages for each habitat type by subwatershed are provided in the Existing Conditions Analysis Memorandum.

A number of sensitive habitats are found within the urban environment as mapped by the WHR system. Within the urban areas of the watershed, riparian corridors line the streams of the watershed. Tree species that occur within the riparian corridor include valley oak, coast live oak, willows, and California buckeyes. Common riparian shrubs include coffeeberry, ocean spray, and creeping snowberry. These areas provide suitable habitat for a number of sensitive species, including California red-legged frog, California tiger salamander, western pond turtle, and, within the streams, steelhead. In addition, areas of coastal salt marsh habitat are included within the urban classification towards the mouth of the watershed where San Francisquito Creek meets the San Francisco Bay. The salt marsh habitat is dominated by cordgrass, pickleweed, and salt grass. This habitat type also supports a number of sensitive species, including the Point Reyes Bird's beak, Congdon's tarplant, salt-marsh harvest mouse, black rail and California clapper rail.

3.5 Aquatic Resources

The San Francisquito watershed supports a wide variety of aquatic resources, including a central California coast steelhead run. This section provides an overview of existing conditions, historic trends and an overview of current steelhead use of the watershed.

HISTORIC TRENDS

Recent fish sampling within the San Francisquito watershed include six native species and seven nonnative species. Native fish captured included the California roach, Sacramento sucker, hitch, speckled dace, threespine stickleback, and prickly sculpin. Three additional species of native fish were present historically, but are not thought to occur within the watershed now. These include the Sacramento perch, last collected in 1960, the squawfish, last collected in 1905, and the white prickly sculpin, of which the last capture date is unknown. The Existing Conditions Analysis Memorandum lists the native fish that were historically found in the watershed, and lists both native and invasive fish now found throughout the watershed.

EXISTING CONDITIONS

Within the San Francisquito watershed, nonnative fish populations outnumber native fish populations in many of the subwatersheds, particularly in the eastern section of the watershed. This occurs because the eastern section is more disturbed than the western subwatersheds where many of the tributaries flow from protected open spaces and natural areas. The aquatic habitat in the western portion of the watershed continues to flow through areas that are largely forested, and are bordered by high quality riparian corridors. Water temperatures remain cool, woody material remains abundant, and levels of dissolved oxygen in the water remain high. Riffles in this area provide spawning habitat for many fish, well-oxygenated water for juveniles, and habitat for aquatic insects that provide a healthy food source for a variety of fish.

STEELHEAD POPULATIONS

Portions of the San Francisquito watershed support a stable steelhead population and high quality habitat remains throughout the Los Trancos and Bear Creek subwatersheds. In addition, San Francisquito Creek, downstream of Searsville Dam through the Lagunita Diversion, provides quality steelhead habitat. Downstream of this area, the quality of steelhead habitat diminishes greatly. Searsville Dam is a terminal barrier on Corte Madera Creek, in the lower portion of the watershed.

STEELHEAD PASSAGE BARRIERS

A number of steelhead passage barriers exist throughout the San Francisquito watershed. These are both physical barriers (i.e. actual physical impediments to movement) and physiological barriers to movement (such as high temperatures and decreased flows). A number of these barriers have been identified through previous studies throughout the watershed. Within the Bear Creek, Bear Gulch and West Union Creek subwatersheds, stream passage barriers have been identified, ranked in severity, and recommendations for alleviating them have been provided (Smith and Harden 2001). The San Francisquito Watershed Council Coordinated Resource Management Plan has inventoried stream passage barriers throughout the watershed, identified recommended actions, and evaluated the severity for each. The Existing Conditions Analysis Memorandum identifies, lists and maps these barriers. Figure 7 shows the location of the identified barriers. Figure 8 identifies existing stream intersections with roadways and trails throughout the watershed that may present additional fish passage barriers, but that have not been field verified or evaluated.

A number of efforts have been made to increase fish passage throughout the watershed. In 1978, the non-functional fish ladder at the Lake Lagunita Diversion Dam was replaced with a Denil-style fishway to improve fish movement within the watershed. In addition, a fish ladder was installed in the Los Trancos Creek watershed at the Felt Lake Diversion Dam in 1995.

Currently, the FishNet 4C program is working to increase communication within local jurisdictions within the region of the San Francisquito watershed for counties that lie geographically within the Central California Coastal Evolutionary Significant Units (ESU) of coho salmon and steelhead trout. The program is county-based, joining San Mateo County with Santa Cruz, Monterey, Marin, Sonoma, and Mendocino counties to identify gaps in the region's fishery restoration efforts, develop restoration plans and sources of data that are compatible within the region, and increase and improve communication between local entities and state and federal regulatory agencies. Currently, the program is working on inventorying and evaluating fishery and restoration efforts in each county, reviewing and commenting on pending state and federal legislation related to fisheries issues, soliciting private and public funding to support fishery restoration efforts, participating in conferences and training programs, and meeting with and advising local government bodies issues related to fisheries resources within the region.

3.6. Special-Status Species

A number of special-status species are known to occur, or have potential to occur, throughout the San Francisquito watershed. The California Department of Fish and Game Natural Diversity Database has identified a number of known occurrences that are shown in Figure 9. This information has been supplemented through the evaluation of existing habitats throughout the watershed to determine the suitability of each to support special status species by Jones & Stokes biologists. A brief description of these species, and associated habitats, is provided below.

The mouth of the watershed meets the San Francisco bay in salt marsh habitat which provides suitable habitat for the salt marsh harvest mouse, California clapper rail, and black rail, which have all been observed within, or within the immediate vicinity of, the mouth of San Francisquito Creek. Moving west through the watershed as water becomes less tidally influenced and salinity levels decrease, riparian corridors are present along many of the streams throughout the watershed. These areas provide suitable habitat for the California red-legged frog, California tiger salamander, and western pond turtle, which have all been observed within the watershed.
Additionally, streams within the Bear Creek, San Francisquito and Los Trancos Creek watersheds provide suitable migration and spawning habitat for steelhead trout that have been observed in both of these areas. Throughout the watershed, a number of serpentine soil outcrops have been identified within the San Francisquito, Searsville Lake, Bear Creek, and West Union Creek sub-watersheds. This microhabitat supports a number of special status and common wildlife and plant species that have been observed at these areas, including the Bay checkerspot butterfly, serpentine bunchgrass, and Crystal Springs lessingia.

4. EROSION, TRANSPORT AND DEPOSITION

4.1. Background

This chapter describes erosion of hillslopes and streams in San Francisquito Watershed, transport of sediment through streams, and deposition of sediment in channels, lakes, reservoirs and San Francisco Bay, based on existing reports and studies. These existing reports and studies form the main background to the rapid sediment budgets described in Chapter 5. The Historic Conditions Analysis and the Watershed Sediment Analysis memoranda provide further details.

4.2. Overview of Erosion, Transport and Deposition

Over the long-term, landscape development in the San Francisquito Watershed, particularly in the Santa Cruz Mountains, results from channel incision into uplifted bedrock (Anderson 1994; Burgmann *et al* 1994). Incision in response to uplift rates maintains steep, often convex, valley sides, resulting in shallow landslides on the lower, steep sections of soil-mantled slopes and bedrock landslides on slopes near the overall threshold angle for failure (Burbank 2002). As documented in Brown and Jackson (1973) and in the Historic Conditions Analysis, landslides appear to be the dominant erosion process in the Santa Cruz Mountains. Abundant landslides occur every five to ten years, usually during severe storms or following infrequent large earthquakes. Channel incision and bank erosion during severe storms undermine the toes of slopes and remove colluvium and talus, playing an important role in initiating shallow landslides near the stream. Surface erosion is prominent on disturbed slopes and along roads and trails.

Landslides are less common in the Bay Hills and Foothills to the northeast of the San Andreas Fault Zone. Here, erosion is primarily from downslope movement of deep soils and bedrock by creep and deep-seated landslides (Brown and Jackson 1973). Sheet or surface erosion and gullying are also common, particularly where vegetation has been removed and soils disturbed. Following sections provide historic information on landslide, stream, and surface erosion in the watershed.

The frequency and areal extent of erosion processes is affected by both natural and human factors. Figure 10 provides a flow diagram that links the various elements that affect sediment production and transport. Human activities, particularly through land use and urban development, affect erosion and sediment transport in several ways. Vegetation removal and soil disturbance directly affect rates of shallow landsliding and surface erosion. Road construction, use and maintenance are particularly significant activities, as they may cause shallow or deep-seated landslides through failure of the road prism, contribute to downslope instability by re-distributing surface and groundwater flows, and result in surface erosion along the road surface, cutslopes or ditches.

Changes to stream hydrographs that result from creation of impervious area in urban developments are also potentially important human impacts on erosion and sediment transport. GeoSyntec (2002a) provides an overview and conceptual model of urban alteration of hydrographs (“hydromodification”) around San Francisco Bay for the Santa

Clara Valley Urban Runoff Pollution Prevention Program. Typically more frequent small to moderate peak flows increase sediment transport and stresses on banks, often leading to channel incision, bank erosion, and widening.

Land use such as clearing or vegetation conversion, fire, forest harvesting, road construction, soil compaction from grazing and loss of wetlands may also affect peak flows. Intensive forest harvesting, agriculture and grazing are thought to have been significant in the San Francisquito Creek watershed in the past and may still be locally important. While there are no specific studies in San Francisquito Creek watershed, urban development now appears to be the most important land use that potentially alters stream hydrographs in the San Francisquito Watershed (see Section 2).

In addition to stream erosion that results from altered hydrology, there may also be erosion that results from direct impacts on streams. These include removal of riparian trees, bank protection or instream structures, bridges and culverts, gravel removal or other activities in the stream environment zone. Long encroachments in the channel or floodplain by roads, levees or other features can also concentrate flows in the main channel, resulting in channel incision and bank erosion.

The steep tributaries in the Santa Cruz Mountains are deeply incised and often confined. Little of the sediment that enters streams from erosion on hillslopes is deposited along the stream or on floodplains. This occurs because of the relatively fine sediments contributed from the hillslopes, efficient transport, and limited depositional areas. Nolan and Marron (1988; also Nolan and Marron 1985) described a typical pattern in the Santa Cruz Mountains of scour in steep, upper reaches with minor aggradation in lower reaches that is removed by storms over the next few months.

Deposition in the upper watershed primarily occurs along stream courses in the San Andreas Fault Zone, on the fans constructed by Corte Madera, Sausal and Alambique Creeks at the head of Searsville Lake, and in Searsville Lake. Small volumes of sediment are also stored in steep tributaries behind logjams and in a few protected locations or sites. Sediments range in size from cobbles to sand, with most of the material being sand. Further downstream, sand is deposited along lower San Francisquito Creek (downstream of Pope-Chaucer Bridge) and on its delta in San Francisco Bay. The finest sediment fractions are carried past the delta, into San Francisco Bay.

4.3. Landslide Erosion or Slope Failure

DEFINITIONS

Slope failures are typically called landslides, defined by the Northern California Landslide Working Group (NCLWG) as "the downslope movement of rock, soil or artificial fills under the influence of gravity". The actual slope failure processes that are included as landslides have varied over time and from study to study. The three most common processes identified by the NCLWG are rockfall, deep-seated landslides, and debris flows (also referred to as "soil slip/debris flows"; see Ellen and Weiczorek 1988). The above list does not separate debris slides or "soil slips" from debris flows. However, it is valuable to treat these two processes separately. Debris slides are important sediment sources in San Francisquito Creek (see Frey 2001) but these failures are often small, obscured by vegetation, and are difficult to identify on air photos or during aerial reconnaissance. Rockfalls do not appear to be a significant slope failure process in San Francisquito Creek and are not discussed further.

As defined, the deep-seated landslides are primarily earthflows and rotational or translational failures in bedrock (NCLWG). Such slope failures usually move slowly and infrequently, often following prolonged rainfall or earthquakes, and leave head scarps and deposits that persist for many years and can be recognized on air photos. Removal or undercutting of toe material by rivers or by human activities (such as road construction or slope re-grading) may re-activate historic landslides or initiate new failures. Pike *et al* (2001) provided a recent summary of the factors that control the distribution of deep-seated landslides around San Francisco Bay. Nilsen *et al* (1976) provided an early evaluation of the factors controlling these failures. Slope, geological formation and the presence of historic landslides deposits are generally recognized as the most important contributing factors.

Debris slides initiate on steep slopes, often as a shallow slab of coarse soil and vegetation sliding over weathered bedrock or a low strength layer in the soil. The slides often initiate debris flows or turn into debris flows. Debris flows are saturated or supersaturated flows of water and soil. As defined, they include mudflows, debris avalanches as well as debris torrents (see Swanston and Swanson 1976). Mudflows are primarily composed of fine-grained soils, often move slowly, and may not be very erosive (Varnes 1978). Debris flows typically originate at a “soil slip” or “debris slide” and then flow downslope (Ellen *et al* 1988). The initiating failure usually occurs on slopes of more than 20^{o}; the flows then travel from a few tens of feet to thousands of feet, often down a steep drainage channel. The largest flows or torrents incorporate soil and organic debris from the bottom and sides of gullies and stream channels greatly increasing their volume. Flows may recur at the same site after recharge by soil movement from upslope.

Debris slides and flows occur episodically and are typically triggered by intense storms that follow seasonal precipitation adequate to saturate the soil profile. Ellen *et al* (1988) note that rainstorms capable of triggering debris flows occur about every five years around San Francisco Bay. Debris flows occurred during at least twelve winters between 1905 and 1978 and during eight winters between 1961 and 1981, indicating a more frequent occurrence in recent years. Cannon and Ellen (1983 & 1985), Wieczorek and Sarmiento (1983), and Wilson and Jayko (1997) describe the precipitation thresholds required to generate abundant debris flows around San Francisco Bay.

FREQUENCY OF OCCURRENCE

Debris slides, debris flows and deep-seated landslides are triggered by episodic events, such as severe storms or earthquakes. Consequently, while a few failures may occur throughout the San Francisco Bay region each year, abundant landslides only occur infrequently. Brown (1988) provides a summary of damaging rainstorms that affected the San Francisco Bay region from 1861 to 1982; Smith and Hart (1982) summarize those years when significant landsliding apparently occurred prior to 1982. Since the January 1982 storm, slope failures are thought to have occurred in February 1986 (Keefer *et al* 1987), during the 1997-98 El Nino rainstorms (Godt 1999), and possibly in 1995 (Kittleson *et al* 1996). The Historic Conditions Memorandum summarizes those years when landslides and debris flows are thought to have occurred around San Francisco Bay and, potentially, in San Francisquito Creek. Brown notes a broad trend of frequent damaging storms from 1879 to 1915, less frequent storms from 1916 to 1937, followed again by frequent storms from 1937 to 1982.

Earthquakes are also an important trigger of deep-seated landslides and debris flows throughout the San Francisco Bay region. Lawson (1908) and Albertson (1908) described the landslides that resulted from the 1906 earthquake; Youd and Hoose (1978) provided an overview of ground failures associated with earthquakes dating back to 1865, although mostly from the 1906 earthquake. They document thousands of "earth slumps" (possibly debris slides) in the Bay region as well as earthflows (possibly mudflows), and earth slides and avalanches (Youd and Hoose 1978; Albertson 1908). In San Francisquito Creek the earth slumps often were observed to originate at or along roads, particularly Bear Creek Road in Woodside and near Page Mill and Alpine Roads. Numerous other undocumented slope failures are likely to have occurred in steep tributaries in the Santa Cruz Mountains of San Francisquito Creek that were not visited.

Keefer (1998) inventoried the landslides that resulted from the Loma Prieta Earthquake of 1989 (see also Manson *et al* 1992). No landslides or earthquake features were observed in San Francisquito Creek as a result of the Loma Prieta Earthquake. The nearest failures are ten or so miles south of Los Trancos Creek in Santa Clara County.

(DEEP-SEATED) LANDSLIDE MAPS

While there is general knowledge of the years when landslides likely occurred late in the nineteenth and early in the twentieth century, none of the studies indicate the type of failures, their numbers, or the sediment delivered to streams. Brown (1988) notes that detailed study of landslides began in the late 1960s as development spread into the foothills and mountains around San Francisco Bay, resulting in damage or loss of life from landslides during intense storms. Studies prior to the late 1960's are rare.

Studies in San Mateo County began with an inventory of landslides identifiable on air photos, primarily addressing the deep-seated landslides described above (Brabb and Pampeyan 1972). Their map showed large landslide scarps and deposits that may be up to several thousand years old, small deposits, and also active landslides (area greater than 100 ft^2) identified from public sources. The largest landslides in San Francisquito Creek shown on their overview map lay on the eastern slopes of the Santa Cruz Mountains leading to upper Corte Madera and Sausal Creeks and also Los Trancos Creek; few large landslides are mapped in the Bear Creek watershed.

The San Francisco Bay Region Landslide Folio groups Santa Clara and San Mateo Counties into regions of most, many and few landslides (Wentworth *et al* 1997). In San Francisquito Creek watershed; the highest concentration of landslides occurs in Corte

Madera and Los Trancos Creek, lower concentrations occur in Bear and West Union Creeks, and few occur along San Francisquito Creek in the lower watershed (Figure 11).

The original maps of Brabb and Pampeyan have been revised and updated as part of detailed geologic mapping for Portola Valley (Rodine *et al* 1975; Cummings and Spangle & Associates 1975), Woodside (Dickinson *et al* 1992) and the unincorporated areas of San Mateo County. These maps show individual landslide scarps and deposits and classify them as deep or shallow (greater or less than 10 feet thick) and as active, dormant, or old. (The age classifications and mapping procedures differ from author to author). The maps do not show the rates of movement of landslides, their volumes, or the volumes contributed to streams over time.

Inspection of the Portola Valley and Woodside maps indicate the following:

- Active landslides were mapped along the lower slopes of most tributaries to Corte Madera and Sausal Creeks. These landslides were often the smallest shown on the maps, with areas of 20,000 to 40,000 ft^2, or 0.5 to 1 acres. The greatest numbers occur along Damiani Creek and Hamms and Neils Gulches; few occur along Creeks A and B and Rengstorff Gulch.
- Large shallow active landslide zones extend over 1,500 feet of the north sides (left valley walls) of Jones Creek and Bozzo Gulch, along their lower courses.
- Several large, active landslides are shown in the headwaters of Tributary L5 to Los Trancos Creek and along the course of Corte Madera Creek on the east side of Coal Mine Ridge.
- Very few landslides are shown along the lower slopes of creeks or gullies in the Westridge Creek subwatershed.
- Few active landslides are shown along Corte Madera Creek within the limits of the town of Portola Valley.
- The Woodside map showed about eleven large (50,000 to 100,000 ft^2) active landslides terminating in Martin Creek and its tributaries.
- The Woodside map also showed active landsliding along the lower valley walls over most of the course of Appletree and Tripp Gulches and the lower part of Squealer Gulch.
- Several small active landslides are shown along the cut slope of Highway 84 where it crosses the Alambique Watershed.

It appears that most of the active failures move slowly and sediment is often contributed to streams by debris slides or "slips" that occur along their toes or by rapid creep leading to active bank erosion. For instance, Frey (2001) noted a strong correspondence between her high sediment production reaches and the presence of historic landslides. However, the potential remains for a large, rapid-moving failure to contribute huge quantities of sediment to a stream. For instance, a very large failure may have blocked Los Trancos Creek in 1889-90 (see Historic Conditions Memorandum). Large deep-seated failures, such as the one along the closed section of Alpine Road, are also significant sediment contributors (Appendix C).

INVENTORIES OF DAMAGING LANDSLIDES

The Geological Survey has prepared inventories of damaging landslides around the San Francisco Bay region following severe storms, based on aerial reconnaissance, damage reports from the Counties that surround the Bay, and some limited field inspection. The landslides are shown on small-scale maps accompanying storm reports; typically the numbers of failures in San Francisquito Creek can be identified but the initiation points can only be roughly interpreted. The reports describing damaging landslides are:

- Taylor and Brabb (1972) –damaging landslides from the winter of 1968-69
- Taylor, Nilsen and Dean (1975) –damaging landslides from the winter of 1972-73
- Creasey (1988) –damaging landslides from the January 3-5th, 1982 storm. Smith and Hart (1982) describe those landslides that resulted in deaths or injury. Weiczorek *et al* (1988) provides details on large landslides that occurred throughout the San Francisco Bay region. No large landslides occurred in San Francisquito Creek.
- Jayko *et al* (1999) –damaging landslides that occurred during the 1997-98 El Nino storms. A worksheet describes each landslide, indicating the type of failure, nature of damage, and the volume of sediment involved.

The above studies typically only document those landslides that damage roads, residences or other human structures. They do not provide a complete inventory of the landslides that occurred and most do not indicate whether the failures were natural or human-caused, except for the inventory by Jayko *et al* (1999). Of the four failures that year, two initiated along La Honda Road (Highway 84) and one small one initiated in a residential landscaping project. Human activities likely contributed to these three failures. The Historic Conditions Memorandum summarizes the number of landslides by subwatershed and confirms the severity of the January 1982 storm in the San Francisquito Watershed.

INVENTORIES OF DEBRIS FLOWS AND DEBRIS SLIDES

While some debris flows are included in the damaging landslide inventories described above, the only comprehensive inventory of these features followed the January 1982 storm. Weiczorek *et al* (1988) prepared an inventory from aerial reconnaissance, air photos and limited field traverses and indicated the general factors resulting in their distribution (see discussion in following section). The location of failure initiation points and the approximate lengths of their tracks are provided; however, total volumes or volumes contributed to streams are not reported.

Figure 12 shows the debris flow initiation points in San Francisquito Creek; The Historic Conditions Memorandum summarizes the character of the debris flows; most were relatively small and originated on lower slopes near streams. The average concentrations of debris flows in the subwatersheds of San Francisquito Creek were ranked as "sparse (less than 5 per km^2)" and less than the typical concentration throughout San Mateo County (Table 4-2). No large debris torrents occurred in San Francisquito Creek in January 1982 (Weiczorek *et al* 1988; Smith and Hart 1982).

Inventories of debris flows have not been prepared for earlier or subsequent storms; however, Smith (1988) documented debris flows that occurred between 1941 and 1982 in a small area in northern San Mateo County near Pacfica, from air photos. Smith's analysis indicates that about as many debris flows may have occurred during the 1967 and 1969/70 storms as did in January 1982. Very few debris flows appear to have occurred during the 1937/38 and 1940 storms in his study area.

Frey (2001) documented debris slides and debris flows that had occurred along lower valley slopes near streams in the Searsville watershed, based on walking each of the channels. The failures were not divided by process but rather into "small" and "large" ones. Most of the failures identified by Frey apparently occurred during the 1997-98 El Nino storms in San Francisquito Creek. The Historic Conditions Memorandum summarizes the number and area of small slides she observed along the streams and the number of large failures that entered the stream from higher on the slope. All, or nearly all, of the material from these failures directly entered streams; volumes are not reported but can be estimated from the measured areas. These small failures, with an average area of about 300 yd^3, are not thought to be visible from the air or on historic air photos because of obscuring vegetative cover and may not be recorded in debris flow inventories, such as the one that followed the 1982 storm.

INVENTORY FROM THE 2000 AIR PHOTOS

The existing inventories, described above, do not provide a record of shallow slope failures in the San Francisquito watershed. To fill this gap, we inventoried the debris slides and flows visible on recent color air photographs (March 2000; nominal scale of 1:22,000). The inventory measured the following characteristics of debris slides (soil slips) and debris flows with areas exceeding 400 yd^2:

- Sub-subwatershed where the failure occurred
- Type of failure (debris slide or flow)
- Length and width (or height) of failure
- The age of the failure as categorized from re-vegetation of the scar
- The portion of the failure volume that entered a stream
- Land use near the initiation point, when it may have contributed to the failure
- Whether the failure was also enumerated by Frey (2001)

Table 4-1 summarizes the observed number and area of slides and flows for each sub-watershed. The average sizes of these failures are typically much greater than those measured by Frey (2001). In most cases the failures she identified could not be identified on the March 2000 air photos; those that could be identified were removed from the air photo inventory so that they were not counted twice.

The air photo inventory showed that most of the recent or fresh slides and flows occurred in Corte Madera and Los Trancos watershed; few were observed in the Sausal and Bear subwatersheds. The inventory also shows that more than half of all the failures identified on the air photos occurred in the Corte Madera subwatershed. Most of the remaining shallow slope failures occurred in the Searsville Lake and Los Trancos subwatersheds.

Table 4-1: Summary of Debris Slides and Flows Observed on Air Photos

Re-Vegetation	***Characteristic***	***Slope Failures by Subwatershed***					***Comment***
		Searsville Lake	***Corte Madera***	***Los Trancos***	***Bear***	***San Fran-cisquito***	
Fresh, no vegetation, assumed 1997-98 or later	Number Observed	3	26	12	1	0	
	Total area (m^2)	900	40,700	8,300	300	0	
	Average area (m^2)	300	1,600	700	300	N/A	
	Percent from Roads or other disturbance	100%	38%	35%	0%	N/A	In road fill, cut or drainage related
Shrub growth, assumed to be from less than 10 to 20 years old, but before 1997	Number Observed	8	26	13	7	0	
	Total area (m^2)	11,000	38,600	15,800	6,500	0	
	Average area (m^2)	1,400	1,500	1,200	900	N/A	
	Percent from Roads or other disturbance	5%	33%	32%	31%	N/A	In road fill, cut or drainage related
Trees on track, assumed to be 20 to 40 years old	Number Observed	7	19	2	7	0	
	Total area (m^2)	25,900	66,200	3,000	9,200	0	
	Average area (m^2)	3,700	3,500	1,500	1,300	N/A	
	Percent from Roads or other disturbance	42%	54%	33%	100%	N/A	In road fill, cut or drainage related
Track substantially revegetated but still apparent, assumed to be more than 30 to 40 years old	Number Observed	4	10	1	1	0	
	Total area (m^2)	11,900	52,100	15,800	3,300	0	
	Average area (m^2)	3,000	5,200	1,200	3,300	N/A	
	Percent from Roads or other disturbance	42%	38%	32%	31%	N/A	In road fill, cut or drainage related

1. Color Photos Roll number is WAC-C-00-CA, dated March 22, 2000; nominal scale of 1:22,000. Minimum size inventoried was about 300 m^2 (400 yd^2).
2. Ages estimated from re-growth of vegetation and are approximate. Inventory of older failures assumed incomplete because of vegetation re-growth obscuring the tracks of small failures.

The unvegetated or “fresh” failures – those assumed to have occurred since 1997-98 – account for about 22% of the total area of failures observed on the air photos. The ages of the partially revegetated slides and flows are not well known. However, if it is assumed that the partially revegetated failures are less than 40 years old, then the long-term annual area of shallow failure ranges from 0 in San Francisquito subwatershed, to 500 yd^2 in Bear Creek, to 4,300 yd^2 in Corte Madera Creek. The long-term averages are much less than observed following the intense 1997-98 storms, but they are reasonably consistent with abundant failures every five to ten years, as discussed earlier.

About one-third of the shallow slides and flows may have originated at roads or have been partly or wholly caused by local drainage modifications. The portion of failures that appear to be human-related is fairly constant for the different re-vegetation categories (failure ages) and subwatersheds.

FACTORS CONTROLLING SLOPE FAILURE

Brabb *et al* (1972) ranked the susceptibility of different geologic formations in San Mateo County to deep-seated landsliding based on the portion of their surface areas that had previously failed. The most susceptible areas were previous landslide deposits, as shown on the Wentworth *et al* (1997) map of San Mateo and Santa Clara Counties that was provided as Figure 11. The most susceptible formations were the Santa Margarita Sandstone, San Lorenzo Formation and Lambert Shale, and the Lobitos Mudstone member of the Purisima Formation. Other susceptible units were the Pomponio, Tahana, Tunitas and San Gregorio Sandstone members of the Purisima Formation and the Two Bar Shale member of the San Lorenzo Formation (see Figure 4).

Wieczorek *et al* (1988) provided an assessment of the factors that controlled the initiation of debris flows in San Mateo County based on observations following the January 1982 storms. Debris flows originated as soil slips or slides and then flowed downslope or into steep drainage channels. Typically, the greatest concentrations occur in areas of the most intense rainfall; initial failures occur on slopes greater than 20^o; often in swales or concavities; and the number of failures increased with slope. Greater numbers are also apparent on grasslands when compared to forest. Bedrock geology is particularly important and Wieczorek *et al* (1988) indicated high debris flow incidence or frequency in the Purisima Formation, particularly the Pomponio mudstone and San Gregorio sandstone members, and the San Lorenzo formation. Medium incidence was observed in the Lambert Shale and San Lorenzo Formation, the Lompico Sandstone, the remaining members of the Purisima Formation, and sandstone and limestone of the San Franciscan assemblage. The rock units susceptible to debris flows are very similar to those susceptible to deep-seated landslides, although the ranking changes somewhat.

Mark (1992) provided an initial map of debris flow probability for San Mateo County. Ellen *et al* (1997) later provided a digital map of debris flow source areas, based on slope and slope curvature calculated from USGS quadrangle maps but not incorporating geology. Figure 12 shows the calculated debris flow source areas and the 1982 debris flow initiation sites for San Francisquito Creek.

Both Kittleson *et al* (1996) and Frey (2001) evaluated the susceptibility of different geologic formations in the Searsville Lake portion of the San Francisquito Watershed to erosion. Based on their field observations, Kittleson *et al* (1996) identified the Purisima and Santa Clara formations as most significant, with the Lambert Shale and San Lorenzo Formation of next importance. Frey (2001) ranked the different formations by the percentage of high-sediment producing reaches that they contained. On this basis, the most erodible formation was the Vaqueros Sandstone, although it only included a short reach of stream. The next most erodible was the Purisima Formation, followed by the Whiskey Hill and Monterey Sandstones.

The Historic Conditions Memorandum summarizes some of the characteristics of the different subwatersheds that affect erosion, based on the above studies. It includes average slopes, ranking of stream erosion from Frey (2001) for the Searsville Lake subwatersheds, numbers of landslides, debris flows and the portion of the watershed with erodible geology and erodible slopes.

GRAIN SIZE DISTRIBUTIONS OF LANDSLIDES

Ellen *et al* (1988) provided an engineering analysis of 50 soil samples from sites around San Francisco Bay where debris flows occurred. Gravel contents are low in most samples and clay contents are usually more than 8% and less than 25% for fast moving failures. The content of clay in the samples appeared to vary with the underlying geologic unit. No specific studies of the grain sizes contributed by deep-seated landslides or by other processes were found. However, the grain sizes contributed by these processes can be roughly assessed from the characteristics of the soils and the geological formations where they originate (Kittleson *et al* 1996; Frey 2001). Many of the erosive formations are poorly indurated sedimentary rocks that break down rapidly into sand and finer sediment as their main erosion products. The deposits on the fan of Corte Madera Creek at Searsville Lake indicate that much of sediment supplied by erosion, as modified by transport through this subwatershed, is sand and gravel.

Wentworth *et al* (1985) characterized the physical properties of land surface materials in San Mateo County, including expansivity of material, cut-slope stability, permeability, excavatability, character of material as fill, texture of surficial mantle, physical properties of bedrock, and geologic unit. These data are useful in describing relative erosivity and grain size distribution of surface material delivered to streams in the subwatersheds in San Mateo County.

4.4. Stream and Gully Erosion

DEFINITIONS

Stream erosion includes both the erosion of stream banks and erosion or incision of the streambed. Bank erosion may result from detachment and removal of soil particles by flowing water or from toe erosion, oversteepening, and subsequent failure or collapse of high banks. By this definition, small debris slides on lower valley walls might be considered part of bank erosion and the small landslides identified by Frey (2001) may be best included as part of stream erosion. Bank erosion usually occurs during high flows, although saturation of banks may result in their failure during low and moderate flows. Bank erosion is usually greatest on bends or where high flows are directed at a bank. Instream works, bank alterations, removal of riparian vegetation, and land use on top of the bank may all increase erosion rates.

Incision or scour refers to the removal of streambed sediments and lowering of the overall streambed elevation. Scour usually refers to local lowering of the streambed associated with structures such as bridges; incision or degradation refers to long-term lowering of the streambed over long distances. Incision often results from changes to peak flows, the supply of coarse sediment to a reach, or such factors as stream roughness (Galay 1983). Incision or degradation is often indicated by "knickpoints" or steps in the profile that mark the present upstream limit of bed lowering.

FREQUENCY OF OCCURRENCE

Bank erosion occurs throughout the San Francisquito Watershed, primarily during the extreme floods discussed in Chapter 2. On San Francisquito Creek significant bank damage occurred in February 1940, December 1955, April 1958, January 1982 and again during the 1997-98 El Nino storms (Corps 1972; San Francisquito Creek Coordinated Resource Management and Planning 1998; Cushing 1999). Erosion also occurred during earlier floods but was likely not documented because of the lack of damage to structures or property. Cotton, Shires & Associates (2001) document bank erosion along Corte Madera Creek through Portola Valley that occurred during the 1982 and 1997-98 storms.

INVENTORIES OF BANK EROSION

Frey (2001) compiled a comprehensive inventory of bank erosion on streams in the Searsville subwatershed following the 1997-98 El Nino storms. She measured the percentage of banks with severe or moderate erosion along the main streams and tributaries reaches and incorporated this information into her classification of sediment production. She did not estimate the volumes eroded from the stream banks.

As noted above, Cotton, Shires & Associates (2001) mapped 45 bank erosion sites along Corte Madera Creek within Portola Valley. Erosion primarily occurred in fairly predictable areas, such as the outside of bends, where up to 5 to 10 feet of bank was lost, with maximum retreat of 20 to 25 feet since 1982. Cotton, Shires & Associates (1984) documents erosion during the 1982 storms. Total volumes of bank erosion are not estimated in either report. Historic bank erosion sites along Corte Madera Creek outside of the town boundaries could be reconstructed from drawings for erosion control projects that have been built over the past thirty or forty years (for instance, Wilsey Ham 2000). The volumes eroded from the stream banks are not provided for most of the projects but might be estimated from surveys or the general nature of the reconstruction.

Despite the damage from bank erosion damage along San Francisquito Creek, there is no comprehensive inventory of where erosion has occurred or the volumes of material lost from stream banks. Unfortunately, historic bank erosion cannot be easily calculated by comparing surveyed cross sections. Some cross sections show widening as a result of erosion but many other sections have narrowed since 1964, as a result of bank reconstruction and revetment placed on stream bank slopes after they eroded (**nhc** *et al* 2002).

INVENTORIES OF BED EROSION

Comparison of surveys on San Francisquito Creek from 1964 and 1998 shows two distinct zones of channel behavior (**nhc** *et al* 2002). From Sand Hill Road to Pope-Chaucer Bridge, the creek incised by about 2 feet; from Pope-Chaucer Bridge to Highway 101, the creek aggraded. Comparison of the 1964 surveys to the channel depth and width observed by Allardt and Grunsky in 1888 shows incision of about 5 to 10 feet over the earlier period. The San Francisquito subwatershed sediment budget (Section 6) provides details on volumes eroded from the streambed.

Reported incision on other streams is generally based on observations rather than surveys. Frey (2001) notes channel incision along some reaches in the Searsville subwatershed that apparently resulted from the 1997-98 El Nino storms. Many of the steep, upper reaches of tributaries to Searsville Lake were observed to have scoured to bedrock. Appendix A discusses observations of recent incision on the main tributaries to San Francisquito Creek.

Incised or degraded reaches are often indicated by knickpoints along channels. The main knickpoints observed during field inspections in the watershed are:

- West Union Creek near the boundary of Huddart Park – eleven foot high barrier (see Smith and Harden 2001)
- Bear Creek downstream of Olive Drive (see Appendix C)
- Martin Creek near old La Honda Road (see Appendix C)
- Corte Madera Creek upstream of Alpine Road (see Appendix C)

The above list is almost certainly incomplete because it is not based on a thorough inspection of all stream reaches.

GRAIN SIZE OF BED MATERIAL

RHAA *et al* (2000) and **nhc** *et al* (2002) provide detailed measurements of bed material in San Francisquito Creek that show a decline in size from cobbles and boulders near Searsville Dam to sand near Highway 101. Bed material size changes abruptly to gravel near the San Mateo Pedestrian Bridge and then to sand downstream of Newell Road. The California Department of Fish and Game (CDFG 1981) provides visual observations of bed material and channel form along upper San Francisquito Creek from the early 1980s.

There is no similar comprehensive survey of bed material in the tributaries. Appendix C provides bed material observations on the major tributaries to San Francisquito Creek. **nhc** and JSA (1999) and **nhc** *et al* (2002) describe bed material on the fan of Corte Madera Creek at the head of Searsville Lake. Coyote Creek Riparian Station (1994; 1998) provides substrate pebble counts and profile surveys near their stations on San Francisquito, Los Trancos, West Union, Bear and Corte Madera Creeks (see also Buchan and Hayden 2000). CDFG (1974, 1976, 1985) provide visual observations of bed material on Bear, Corte Madera and Los Trancos Creeks as part of fisheries reconnaissance surveys. Frey (2001) provides some miscellaneous observations of bed material in some tributaries to the Searsville watershed. This information is of little use in constructing a picture of sediment transport or sedimentation in the tributaries.

4.5. Surface Erosion

DEFINITIONS

Surface or sheetwash erosion refers to the detachment and transport of individual soil particles by overland flow. In the San Francisquito Watershed, overland flow and surface erosion (sheetwash) are relatively rare on undisturbed, forested slopes and they are usually confined to those sites where vegetation is removed and soils are exposed or disturbed, soils are compacted, or bedrock is exposed. Such sites include landslide scars, construction sites, range and agricultural lands, fire-damaged areas, and roads and urban developments. Kittleson *et al* (1996) report that erosion of road ditches, failures of cut and fill slopes, and sheet wash on gravel-surface roads, are important contributors to sediment loads in the tributaries to San Francisquito Creek. Roads are often thought to be the most significant source of surface erosion.

Surface or sheetwash erosion is a chronic process that occurs at many sites and often throughout the year. Typically, the contribution to total erosion is based on measurements at representative sites. No such measurements are available in the San Francisquito Watershed.

INVENTORIES AND STUDIES

Erosion along roads is from sheetwash on natural or gravel road surfaces, on cut and fill slopes, and from ditch erosion. Sediment is eroded from paved roads, natural or gravel surfaced roads and trails; often, trails are old roads. The lengths of existing roads in the individual sub-subwatersheds, both paved and unpaved, are included in the Existing Conditions Memorandum. Trails in the Searsville Watershed are included in this inventory as unpaved roads.

There are no studies of erosion from roads in the San Francisquito Creek watershed. Pacific Watershed Associates (2003) examined erosion along paved and unpaved (assumed mostly natural surface) roads and trails in San Mateo County Parks in Pescadero Watershed in the Santa Cruz Mountains. Predicted future surface erosion from the unpaved roads to streams averaged about 40 yd^3/mi per year over the road network, with most of the erosion expected from the part of the network where long-term lowering of ditches, cut slopes, and road surfaces is assumed to average 0.2 feet/year. Pacific Watershed Associates also estimated surface erosion from trails in the County Parks in the Pescadero Watershed. For the total length of 34.4 miles of trail, erosion averaged about 1.7 yd^3/mile per year, assuming a 6-foot wide trail prism and averaging lowering of 0.2 feet/year at those sites that appeared to have chronic erosion. The blended average erosion rate for all the unpaved roads and trails is 23 yd^3/mile per year.

Lehre (1982) provides a detailed sediment budget of a small watershed near Point Reyes Station in Marin County. While not specific to San Francisquito Creek, his study, plus studies of sediment yield from forestry roads, provide useful information on the magnitude of erosion and sediment delivery from surface processes that have not been measured or estimated for San Francisquito Creek watershed.

GRAIN SIZES

There are no measurements of the grain size of material contributed by sheetwash erosion but it is likely to be mostly fine sediment – silt, clay and fine sand.

4.6. Sediment Transport

DEFINITIONS

The total sediment load can be divided based on the mode of transport, into suspended and bed load (Figure 13 below). Suspended load consists of the finer sediment maintained in suspension by turbulent currents. This load usually consists of clay and silt, with sand suspended during high flows, when turbulence is greatest.

Bed load consists of the coarser particles transported along the bed by rolling, sliding, or saltating. The boundary between the size of particles moved in suspension or as bed load is not precise and varies with the flow strength; the greater the flow, the coarser the sediment that can usually be suspended by turbulence.

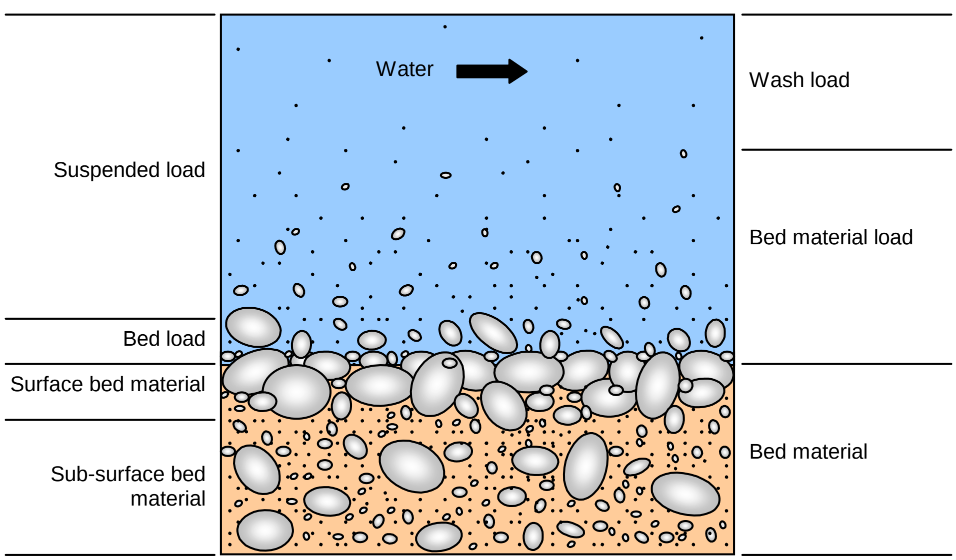

Figure 13. *Sediment transport and Bed Material Definitions*

The total sediment load can also be divided by its presence in the streambed, into bed material and wash load (Figure 13). Particles that are found in significant quantities in the bed and are exchanged with the bed material during transport are part of the bed material load. Wash load consists of fine sediments (usually silt and clay) that are continuously maintained in suspension by the flow turbulence and, thus, are not found in the bed in significant quantities. Under this division, total sediment load is bed material load plus wash load.

Bed material transport depends on hydraulic variables, which are closely related to water discharge, and consequently can often be calculated from knowledge of the bed material and the hydraulic characteristics of a particular site. The wash load is determined by its supply from upstream sources and it may be partly independent of water discharge. Typically, wash load is measured as part of a suspended-sediment gaging program.

SEDIMENT TRANSPORT MEASUREMENTS

Porterfield (1980) reports estimates of long-term suspended sediment transport in San Francisquito Creek based on applying a suspended-load rating curve developed from measurements at the USGS gage at the Stanford Golf Course between 1957 and 1962 to a flow duration curve at the gage. Porterfield also measured the portion of sand in the suspended load, developed a separate rating for sand load, and noted that most sand appeared to be in suspension at the gage measurement site. Brown and Jackson (1973) report on a suspended-sediment sampling program at this gauge for the period from 1962-1969. Balance Hydrologics, Inc also collected a few measurements at this gauge during the 1998 water year to confirm the Brown and Jackson (1973) sediment-rating curve (**nhc** *et al* 2002).

Balance Hydrologics, Inc has operated flow and suspended and bedload sediment gaging stations in the San Francisquito watershed for Stanford University in recent years. Records began in 1997 on Corte Madera and in 1995 on Los Trancos Creek (Owens *et al* 2002a; 2002b). They also collected miscellaneous measurements of sediment discharge on Searsville Dam, Bear, Sausal, Dennis Martin, Westridge and Alambique Creeks during the 1998 water year (**nhc** *et al* 2002). Balance has provided annual reports on their gauging programs in Corte Madera and Los Trancos to Stanford University.

A HEC-6 model of San Francisquito Creek predicted suspended and bedload sediment transport along San Francisquito Creek from 1964 to 1998 (**nhc** *et al* 2002). The model was calibrated to observed changes in the bed elevations and operated to predict future bed levels under different assumptions about filling of Searsville Reservoir.

SEDIMENT TRANSPORT FROM DEPOSITION

Certainly, the longest record of sediment yield is from deposition in Searsville Lake by Corte Madera, Sausal, and Alambique Creeks. Repeated reservoir surveys provide average sediment deposition from 1892 to 1913; 1913 to 1929; 1929 to 1946; 1946 to 1995; and from 1995 to 2000 (**nhc** *et al* 2002). Deposition in the reservoir underestimates total sediment transport because the finest grain sizes are carried over Searsville Dam to San Francisquito Creek and because coarse sediments that have accumulated on the fans of Corte Madera, Sausal and Martin Creeks upstream of the reservoir has not been surveyed, except between 1995 and 2000 (**nhc** *et al* 2002). The sediment budget chapter provides further details on total deposition and adjustments.

4.7. Sediment Deposition

DEFINITIONS

Sediment deposition, also called "sedimentation", refers to the deposit or storage of suspended and bed load on the streambed or floodplain or in lakes, reservoirs or San Francisco Bay. Deposition typically occurs when sediment transport capacity for a particular grain size is less than the volume of material supplied. Storage may be temporary, as occurs along the streambed between floods, or may be long-term, as occurs in lakes or reservoirs.

INVENTORIES IN THE UPPER WATERSHED

Frey (2001) measured the portion of the stream reach where deposition or sediment storage had occurred in the Searsville watershed based on field observations following the 1997-98 El Nino storms. Deposition primarily occurs in the lower-gradient reaches of these streams where they flow along the San Andreas Fault Zone and at the head of Searsville Lake, although some sediment was stored in steep tributary reaches behind logjams and debris slide deposits. Frey did not measure the volumes of sediment stored along the stream channels.

Smith and Harden (2001) provide a description of the channels in the Bear Creek watershed as part of their evaluation of barriers to adult steelhead passage. They note storage of coarse sediment behind dams, weirs, and logjams and deposition of (seasonal) fine sediment in pools along low-gradient reaches within an overall clean substrate. Of particular interest, they identify an 11-foot high knickpoint on upper West Union Creek, just past the Huddart Park boundary. They also describe the extent of bank protection and bank stability in the reaches they visited.

Kittleson et al (1996), **nhc** and JSA (1999) and **nhc** *et al* (2002) describe historic channel changes and aggradation along lower Corte Madera Creek resulting from deposition upstream of the head of Searsville Lake. **nhc** *et al* (2002) estimated the volume of recent sediment (1995-2000) deposited on the fan formed there and also summarized the historic deposition in Searsville Lake, based on earlier surveys. These are discussed further in Chapter 5.

DEPOSITION ALONG SAN FRANCISQUITO CREEK

nhc *et al* (2002) described changes in the streambed of San Francisquito Creek by comparing 1964 and 1998 surveys. Two distinct zones of channel behavior were observed. From Pope-Chaucer Bridge to Sand Hill Road the bed incised; downstream of Pope-Chaucer the channel aggraded. Aggradation amounted to about 16,000 yd^3. Field inspections (see Appendix A) also show deposition in the bedrock-controlled channel upstream of Sand Hill Road, including a substantial gravel fan downstream of Bear Creek. Volumes stored in this part of San Francisquito Creek have not been measured.

Bed material has been historically removed from San Francisquito Creek to maintain the capacity of the Highway 101 Bridge. Table 4-2 summarizes the quantities that have been removed since 1984, as provided by the Santa Clara Valley Water District (SCVWD).

Excavation volumes prior to 1984 are not reported and it is not known if material was not excavated or if removals were simply not recorded. Average annual excavation at the Highway 101 from 1984 to 1997 is 900 yd^3 per year.

Table 4-2: Summary of Reported Excavation at Highway 101

Year	***Comment***	***Reported Volume (yd^3)***
1984	Upstream and downstream of 101	3,290
1993	Downstream of bridge	1,260
1998	Emergency work	3,080
1997	Downstream of bridge	4,630
2000	Downstream of bridge	4,882
Total		*17,142*

Deposition has also occurred from Highway 101 to the mouth of San Francisquito Creek, a distance of about 7,500 feet. The San Francisquito Creek CRMP (1998) reports that this reach was excavated to an invert elevation of between –3 and –4 feet and widened, with levees raised to increase capacity in 1958. The excavated channel has since filled to a typical invert elevation of –1 foot, with bars or berms of silty clay along the channel margins. The excavated section varies along the channel but we have roughly estimated a total deposition of 35,000 yd^3. The grain size of the deposited sediment has not been measured but it may be roughly three-quarters sand and one-quarter fine sediment carried in from San Francisco Bay.

Deposition on San Francisquito Delta

Phillips (2000) reported measurements of the deposition on the delta at the mouth of San Francisquito Creek in San Francisco Bay based on detailed coring. His results show five distinct fining-upward layers that are spread extensively over the delta, which he associated with the five largest floods since 1930, when the mouth of the creek was moved north. The individual layers are not dated and cannot be readily assigned to specific storms; however, the uppermost layer is certainly a result of the 1997-98 storms.

The volumes deposited during each event can be roughly estimated from the mapped area and the cores. It appears that the layer deposited on the delta during the 1997-98 El Nino storms averaged about 6 inches thick; based on the observed distribution of the flood deposits about 30,000 to 40,000 yd^3 appears to have been deposited. The volumes deposited during earlier floods are more difficult to interpret than from the 1997-98 storm. Significant deposition appears to have occurred during the 1982 storm. Total deposition since the late 1950s appear to be about one foot, or 80,000 yd^3. We assumed that this sediment is about three-quarters sand, providing an annual deposition rate of 2,300 yd^3. Some of the fine sediment may be carried to the delta by tidal currents rather than deposited from San Francisquito Creek.

5. SUBWATERSHED SEDIMENT BUDGETS

5.1. Development of Sediment Budgets

The objective is to develop a rapid sediment budget, one which quantitatively describes the volumes of sediment mobilized on hillslopes, the volumes contributed from hillslopes to streams, the transport and storage of this sediment through the stream network, and the yield or volume leaving the watershed. Complete budgets can be very detailed; however, the sediment budgets constructed for this project are intended to address specific questions regarding long-term changes in sediment transport (water quality) and stream characteristics, which simplify the analysis. It is intended to address the following questions (see Reid and Dunne 1996):

- *Sediment Sources:* What are the major or most important types of natural and man-made sources of erosion and where do they occur? What are the approximate amounts of sediment from each source type over time and what portions of the totals have been contributed to streams?
- *Sediment Sizes:* What are the approximate grain size distributions of sediment from each source, particularly of the portions contributed to streams?
- *Sediment Deposition or Storage:* What are the volumes and grain sizes of sediment in storage along the streams? What are the volumes of sediment that are excavated or removed from streams? Where are sediments deposited?
- *Sediment Transport or Yield:* What are the rates of sediment transport through streams and out of the sub-watersheds?

Identifying the contribution of human activities to erosion, transport and deposition is a key objective of the budget.

The sediment budget is based on existing studies of erosion, transport and deposition in San Francisquito Creek Watershed, as summarized in the Historic Conditions Analysis and in Chapter 4, supplemented by air photo measurements and field observations.

In order to best accommodate the different periods of time and the different information on erosion, transport and deposition of sediment we developed separate sediment budgets for the following areas (Figure 2):

- Searsville Lake Watershed, including the Corte Madera, Alambique, Martin, Sausal and Westridge subwatersheds
- Los Trancos Creek
- Bear Creek, including the Bear Creek, Bear Gulch and West Union Creek subwatersheds
- San Francisquito Creek subwatershed, from Searsville Dam to San Francisco Bay including inflows from Bear and Los Trancos

The budgets for the first three groups are included in this chapter: the budget for San Francisquito Creek is included in Chapter 6. Each of these groupings of subwatersheds has either short-term or long-term sediment transport or deposition measurements that allow closure of the sediment budget by constraining erosion volumes or that permit estimation of important erosion components by balancing erosion, deposition and transport. However, the approach to the budget for each group of subwatersheds differs because of the different information on erosion and sediment transport and the nature of the significant erosion processes.

The sediment budgets separate coarse – sand, gravel, cobbles and boulders – and fine – silt and clay – sediments. Coarse sediments are of most concern for stream processes and long-term aquatic habitat. Fine sediments typically impact water quality. One goal is to extend the sediment budgets over as long a time period as possible. Generally, detailed measurements of erosion, transport and deposition are only available for the past few years. Consequently, the budgets are often very detailed for recent years and then become less detailed and more approximate as they are extended back in time through various assumptions.

5.2. Searsville Lake

The Searsville Lake Watershed, in the Santa Cruz Mountains southwest of Palo Alto, flows to Searsville Lake and has an area of about 14.6 mi^2. This watershed includes the Corte Madera, Sausal, Martin, Alambique and Westridge subwatersheds.

Deposition in Searsville Lake provides a partial record of 108 years of sediment transport from the Searsville Watershed. Detailed measurements of sediment transport for the period from 1995 to 2000, which includes the very large flood in 1998, are used to constrain estimates of erosion over that same period. This detailed budget identifies the relative importance of different sources, human modifications to erosion, and those areas that contribute the most sediment during a period of unusually high sediment discharge.

The long-term deposition record in Searsville Lake is then used to constrain estimates of contributions from different sources for both dry and average or typical conditions, based on adjustment of the detailed budget.

SEDIMENT TRANSPORT TO SEARSVILLE LAKE

Deposition in Searsville Lake provides a long record of sediment transport or yield from Corte Madera, Sausal, Westridge and Alambique Creeks. Repeated reservoir surveys measured average sediment deposition from 1892 to 1913; 1913 to 1929; 1929 to 1946; 1946 to 1995; and from 1995 to 2000 (**nhc** *et al* 2002). Deposited volumes are summarized in Table 5-1 following.

Deposition in the reservoir underestimates total sediment transport from the Searsville Watershed. This occurs for two reasons. First, the finest grain sizes are carried over Searsville Dam to San Francisquito Creek so they are not included in the total, and second, coarse sediment that has accumulated on the fans of Corte Madera, Sausal and Alambique Creeks upstream of the reservoir has not been surveyed, except between 1995 and 2000 (**nhc** *et al* 2002). The sediment that passes over the dam amounts to about 10% of the incoming load; the yields quoted in Table 5-1 have been increased to account for this loss (**nhc** *et al* 2002). However, it is not simple to adjust for historic deposition on fans at the head of the lake because the portion of the total load deposited there is thought to have increased over time. As such, adjustments are only available for the most recent period. Table 5-1 suggests that deposition on the fan may add half as much again to the sediment yields quoted for the reservoir, mostly consisting of sand, gravel and cobbles.

Table 5-1. Long-Term Sediment Deposition in and around Searsville Lake

Period	*Annual Deposition (acre-feet/yr)*	*Annual Sediment Yield (yd^3)* [1]		
		Total [2]	*Corte Madera* [2]	*Remainder* [2]
Searsville Lake Deposition				
1892-1913	17.4	31,000	25,000	6,000
1913-1929	3.6	6,500	5,200	1,200
1929-1946	7.2	13,000	10,000	2,500
1946-1995	7.1	13,000	10,000	2,400
1995-2000	23.5	42,000	34,000	8,000
1892-2000	9.4	17,000	14,000	3,000
Searsville Lake and Fan Deposition				
1995-2000	39	70,000	57,000	13,000

1. Sediment yields adjusted to account for 10% loss over dam crest.
2. Assumes that Corte Madera contributes 81% of the sediment to Searsville Lake (**nhc** et al 2002).

Owens, Chartrand and Hecht (2002a) summarize the results of their flow and sediment gaging on Corte Madera Creek at Westridge Road, upstream of Searsville Lake, for the water years from 1997 to 2001. Their measurements show that most of the sediment deposited in Searsville Lake and on the fan was moved during the 1998 water year. The total measured load consists of about 25% bed load and 75% suspended load. The bed load is assumed to consist entirely of sand and coarser sediment. No particle size distributions are available for the suspended load, so we have assumed that it is one-third sand and two-thirds silt and clay. On this basis, the total load is divided into about 50% coarse load (sand, gravel and cobbles) and about 50% fine load (silt and clay). The fine sands included in the coarse load are not found in the bed material in large quantities and so are not properly part of the bed material load.

SEDIMENT SOURCES

Sediment sources in the Searsville Lake watershed that contribute to streams can be divided into two broad categories; discrete, episodic sources, such as landslides and gully erosion, and diffuse, chronic sources, such as bank erosion, sheetwash or surface erosion, and other hillslope erosion processes. As discussed earlier, landslides are thought to be the dominant erosion process and the greatest effort has been applied to documenting this source, with less effort applied to those sources that are thought to be less important overall. The nature of each source, how we identified them in the watershed, and the estimated rates of erosion for the 1995 to 2000 period are described in the Watershed

Sediment Analysis Memorandum and summarized in Appendix C. Table 5-2 summarizes erosion volumes contributed to streams from 1995 to 2000, indicates the range of uncertainty in these estimates and the estimated grain sizes of the erosion products.

Table 5-2: Total Erosion and Erosion by Grain Size Contributed to Streams in Searsville Lake Watershed from 1995 to 2000

Sediment Source	*Total Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Coarse Sediment (yd^3) [1]*	*Fine Sediment (yd^3) [1]*
Small streamside	179,000	±25%	Depth uncertain	134,000	45,000
Large streamside	18,000	±75%	Rough estimate	13,000	5,000
Hillslope landslides	80,000	±50%	Depth uncertain	60,000	20,000
Bank Erosion	20,000	±50%	Unit volume uncertain	15,000	5,000
Channel Incision	8,000	±50%	Depth uncertain	8,000	0
Road Erosion	3,000	±75%	Likely overestimated	1,000	2,000
Scar/Scarp Erosion	3,000	±75%	Rough estimate	1,000	2,000
Sheet Erosion	700	±75%	Rough estimate	0	700
Gully Erosion	4,000	±75%	Length and volume uncertain	2,000	2,000
Totals	***317,000***	***196,000 to 441,000***		***234,000***	***82,000***

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

HUMAN CONTRIBUTIONS TO EROSION

Human contributions to erosion as a result of both direct and indirect (hydromodification) alterations of natural processes are summarized in Table 5-3. Direct contributions include:

- Landslides on slopes that appear to originate at roads, developments or areas disturbed by human activity
- Surface erosion of landslide scars that result from human activity
- Surface erosion from roads, and
- Surface erosion from grasslands or disturbed soils
- Gullies erosion attributed to human disturbance

Indirect contributions include bank erosion, channel incision, and landslides along streams that may result from increased peak flows from development or bank erosion or landslides along streams that may result from encroachment onto floodplains or streams or human modification of stream banks.

Table 5-3: Human-Related Total Erosion and Erosion by Grain Size Contributed Streams in Searsville Lake Watershed from 1995 to 2000

Sediment Source	*Total Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Coarse Sediment (yd^3) [1]*	*Fine Sediment (yd^3) [1]*
Direct Contributions					
Hillslope landslides	31,000	±50%	Depth uncertain	23,000	8,000
Road Erosion	3,000	±75%	Likely overestimated	1,000	2,000
Scar/Scarp Erosion	300	±75%	Rough estimate	100	200
Sheet Erosion	700	±75%	Rough estimate	0	700
Gully Erosion	1,600	±75%	Human impact very uncertain	800	800
Indirect Contributions (Hydromodification)					
Bank Erosion and Channel Incision	3,400	±50%	Human impact uncertain	2,400	800
Small streamside	10,700	±25%	Human impact uncertain	8,000	2,700
Totals	***50,700***	***27,000 to 76,000***		***35,300***	***15,200***

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

We have assigned an anthropogenic component to bank and stream landslide erosion as follows (Table 5-3; see also Appendix C):

- Westridge Creek (SL-02). We have assumed that half of all bank erosion and stream landslides are human-caused as a result of hydrologic modification from low-density residential development.
- Martin Creek (MC-01). We have assumed that one-quarter of all bank erosion and stream landslides are human-caused as a result of hydrologic modification from low-density residential development.
- Bull Run Creek (SC-02). We have assumed that one-quarter of all bank erosion and stream landslides are human-caused as a result of hydrologic modification from low-density residential development.
- Sausal Creek (SC-01 & SC-03). We have assumed that half of all bank erosion and stream landslides are human-caused as a result of hydrologic modification in upstream areas and modifications to stream banks from low-density residential development.
- Corte Madera Creek (CM-01 & CM-02). We have assumed that one-quarter of all bank erosion and stream landslides are human-caused as a result of floodplain encroachment and modifications to stream banks from low-density residential development through Portola Valley.

- Corte Madera Creek (CM-05, CM-07 & CM-10). We have assumed that one-quarter of all bank erosion, incision, and stream landslides are human-caused as a result of floodplain encroachment from Alpine Road, bridge crossings, modifications to stream banks, and minor increases in peak flows from roads and low-density residential development.

The above human-related contributions are crude estimates and further, detailed hydraulic and geomorphic analysis would be required to confirm these quantities.

CORTE MADERA CREEK

Appendix A summarizes stream observations in Corte Madera Creek and other tributaries to Searsville Lake. Significant features of Corte Madera Creek for the sediment budget analysis are summarized below.

In Sub-subwatershed CM-12, Corte Madera Creek is constricted into a narrow channel at the toe of the Alpine Road Slide. Here, landslide movements, combined with bank erosion and channel incision of about 5 feet, are an important source of sediment. Downstream, the channel appears to exhibit two or three knickpoints; one appears to be just upstream of Alpine Road where a local landowner has dumped concrete blocks to slow channel erosion. Corte Madera Creek shows evidence of long-term incision between the Alpine Road slide and Alpine Road but only minor recent incision.

Recent channel adjustments are apparent along Corte Madera Creek just downstream of Alpine Road. In this step-pool channel section, channel incision of about 5 feet appears to have occurred over the past several decades, as indicated by the step observed downstream of the Alpine Road culvert. Steep, high banks, abandoned overflow channels, and exposures of tree roots also indicate recent incision and widening of about one or two feet through this section. The boulder steps are steep here, formed of conglomerate boulders that are about 500 mm in diameter. The steps rest on soft bedrock and appear to fail by toe scour during large floods. The pools between the steps are filled with sand and gravel up to 50 mm diameter to a depth of 0.5 to 1 foot. The boulder steps appear to be stable during most floods but the sediment stored in the pools appears to move frequently. Rapid incision likely occurs when the boulder steps fail, resulting in general lowering of the channel bed. Such general bed movement may only occur infrequently.

This recently incised section seems to only extend a 1,000 feet or so downstream. The next site with significant local incision is at the road bridge leading to Skyline Ridge, downstream of Damiani Creek, where coarse sediment transport may have been interrupted by the debris fan at its mouth (see following paragraphs).

Some aggrading sections are also noted along the channel, often near tributary fans. A debris flow fan at the mouth of Damiani Creek has filled a wide section of the Corte Madera Creek floodplain with 6 to 8 feet of coarse sediment, formed behind a logjam at the face of the deposit. Coarse sediments have also accumulated upstream of this fan; Corte Madera Creek is now incising a channel through these sediments.

Floodplains are narrow and fragmentary along Corte Madera Creek through CM-07 and CM-05 and the fill for Alpine Road encroaches on part of the floodplain, narrowing it further, and into the channel at some sites. Various protective works have been constructed along Alpine Road to prevent erosion of the road prism by the stream. These appear to contribute to channel incision and bank attack at some other sites.

Downstream of the bridge to Skyline Ridge there is little evidence of recent incision; however terraces along the stream channel indicate long-term incision. Typically, the channel bed consists of cobble riffles with pools that are filled or partly filled by deposits of sand and fine gravel. Riffle substrates are also often filled with sand and gravel. These finer sediments are frequently mobile, moving over the stable, coarser bed material. Bed aggradation appears to be the dominant process by Willowbrook Drive, and here the creek is developing a sinuous pattern around bars and other sediment deposits. Bank erosion is an important process through Portola Valley and sub-subwatersheds CM-02 and CM-01, primarily occurring at the apices of bends (Cotton Shires & Associates 2001). Protective works extend along about 28% of the creek banks; with much of these works constructed since 1984 and many constructed after the 1998 flood. Many of the bank protection structures, particularly gabion baskets, are distressed and fail during large storms. Failure of gabion mats placed beneath bridges has resulted in incision and headcut migration up Corte Madera Creek.

SEDIMENT BUDGET 1995 TO 2000

The measured deposition in Searsville Lake and on the Corte Madera fan from 1995 to 2000, adjusted for losses over the Searsville Dam (Table 5-1), provides an opportunity to roughly confirm the erosion estimated from sediment sources (Table 5-2). Table 5-4 adjusts the two volume estimates to weights based on densities appropriate for the different stream deposits and an assumed average density for the eroded colluvial and fluvial sediments.

Table 5-4: Reconciliation of Searsville Lake Sediment Budget, 1995 to 2000

	Total Volume (yd^3)	*Estimated Density ($tons/yd^3$)*	*Total Weight (tons)*
Erosion adjusted for Instream Deposition	305,000	1.4	427,000
Deposition in Reservoir and on Fan	349,000	1.25 on fan; 1.0 in reservoir	384,000

Table 5-4 suggests that erosion may have been overestimated, likely as a result of incorrect estimates of the average depth of landslides or other small errors in erosion rates adopted for the dominant processes. Given that the two values correspond reasonably closely, and the broad uncertainty surrounding the erosion estimates, the procedures for estimating erosion from the different sources were not adjusted.

The total erosion is divided into roughly three-quarters sand and coarser sediment and one-quarter silt and clay (Table 5-2). This breakdown is much coarser than that estimated from sediment gaging at Westridge Road (Section 5.2), suggesting that either the portion of fine sediment in the eroded material is underestimated or that eroded sediments break down rapidly during transport to small sizes.

Table 5-2 summarizes sources of sediment production in the Searsville Lake watershed for 1995 to 2000, a period of unusually high sediment yield, associated with a very large flood in 1998. Erosion was divided into three main types: landslides, streams and surface processes. Landslides, including small landslides adjacent to stream channels, account for about 87% of the total erosion, the overwhelming majority for the 1995 to 2000 period. Stream and surface processes erosion account for about 9% and 4%, respectively, of total erosion. As discussed earlier, the small landslides partly result from stream incision, toe undercutting, and fluvial removal of talus and consequently their contribution may partly be a result of stream channel adjustments during the large flood.

Human-caused erosion in the Searsville Lake watershed from 1995 to 2000 accounted for an estimated 16% of the total erosion and represents the erosion from direct impacts, such as man-related landslides and road erosion as well as from indirect impacts from modifications to stream hydrology or encroachments on streams and floodplains (Appendix C). Landslides and stream erosion are also the most significant sources of human-caused erosion. The sediments from human-caused erosion are slightly finer than the total erosion because of the larger role of surface erosion in environments that are human modified. Note that the estimates of human contributions from surface erosion and from indirect impacts are only rough approximations. It would require detailed investigations to accurately estimate the component that is natural and that which is human-caused.

Corte Madera Creek is overwhelmingly the largest sediment producer in the Searsville Lake watershed, accounting for 78% of total erosion (see Watershed Sediment Analysis Memorandum). Sediment yield from Alambique, Sausal, and Martin Creeks account for 8.4%, 7.0%, and 6.0% of total yield, respectively. Westridge Creek and other small creeks on the east side of Searsville Lake (SL-1 and SL-2) account for only 0.7% of the total sediment yield.

A small number of the sub-subwatersheds account for much of the natural sediment production. Sub-subwatersheds CM-12 and CM-7 are by far the most important sediment source areas, producing about 50% of the total sediment yield in the Searsville Lake watershed (Appendix C; Figure 14). Both these sub-subwatersheds contain large number of small and large landslides and the numbers of landslides in the various sub-subwatersheds largely determine their rank. The 10 sub-subwatersheds with the highest erosion per unit area account for 86% of total sediment production whereas the bottom 10 sub-subwatersheds account for only 4.6% of total production.

Eight of the sub-subwatersheds with the greatest erosion per unit area are located in the Corte Madera Creek subwatershed, an observation in agreement with others (see Figure 14; also Kittleson *et al* 1996; Frey 2001; **nhc** *et al* 2002). Frey (2001) reported that about 40% of the streams in the Corte Madera subwatershed exhibit high sediment production whereas in Alambique, Martin, and Sausal Creeks only 19%, 11%, and 12% of the streams fall into the high sediment production category.

Natural and human-related erosion per unit area are illustrated in Figures 14 and 15. Both figures show some clear trends in sediment production. First, the greatest natural sediment producing sub-subwatersheds are located in the southern part of Corte Madera Creek, which is characterized by steep slopes, frequent landslides, erosive (Santa Clara Formation) geology, and high rates of instream erosion. These watersheds also show some of the greater human-related erosion per unit area. Watersheds with low natural erosion ranks are located in areas of low slopes – such as Portola Valley – and exhibit little or no landslide activity, and little or no instream erosion. Figure 16 shows human-related erosion as a percentage of total erosion, indicating where significant contributions from human activities occur.

LONGER-TERM SEDIMENT BUDGETS

Rates of sediment deposition in Searsville Lake have varied widely over the 108-year period measurements, with the periods from 1892 to 1913 and 1995 to 2000 being unusually high, apparently as a result of extreme floods (Section 2.4; Table 5-1). Deposition in the reservoir from 1995 to 2000 averages about three and one-half times the long-term average rate and may actually be even greater, given the considerable deposition on the fans of Corte Madera and other creeks from 1995 to 2000.

Both the total and relative contributions from the components of the sediment budget are expected to be different over the long-term average and when sediment production is low. Table 5-5 summarizes our understanding of the relative importance of the main erosion processes during periods of very high erosion and transport (1995 to 2000), low erosion and transport (1913 to 1929) and on average (1892 to 2000), as constrained by the measured deposition in Searsville Lake. Italicized values show our estimated ranges of annual erosion for the different processes.

Surface erosion processes tend to be chronic – occurring in most years and during most storms – and their overall annual rate may not change greatly from one period to another, remaining similar to the rates applied to 1995 to 2000. Consequently, we have assumed that long-term average rates would be similar to those estimated for 1995 to 2000; during dry periods, the contribution would be less but not much less. Bank erosion and channel incision are also chronic and they are thought to continue during all periods, although at significantly reduced rates during dry periods when few floods occur.

Landslides are by far the dominant erosion process from 1995 to 2000 but the rates observed during this period are not sustained over the long-term and must be dramatically less just to balance the observed deposition in Searsville Lake. Abundant landsliding from slopes is known to have occurred frequently over the past 150 years, about once every five years on average (Historic Conditions Memorandum). The air photo inventory in Section 4 suggests that the average area disturbed by landslides over the past thirty to forty years is roughly half of that observed from 1995 to 2000 and we have assumed that long-term erosion from landslides originating on slopes is from one-quarter to three-quarters of the rate observed from 1995 to 2000. During dry periods, when large storms rarely occur, this contribution declines much further. Although rare, a major earthquake caused widespread landsliding in the Searsville Lake watershed in 1906 and such processes are contributors to long-term landslide erosion.

Table 5-5. Simplified Searsville Lake Sediment Budget Over Three Different Time Periods

Sediment Source	***Annual Erosion (yd^3) from*** [1]		
	1995 to 2000	*1892 to 2000*	*1914 to 1929*
Surface Processes	2,500	*1,500 to 2,500*	*1,000 to 1,500*
Stream Erosion	5,600	*1,000 to 3,000*	*0 to 1,000*
Landslide Processes			
- Streambank landslides	36,000	*4,000 to 8,000*	*0 to 1,000*
- Landslides from slopes	20,000	*5,000 to 15,000*	*2,500 to 5,000*
Instream Deposition	(2,300)	*+500 to –500*	*+500 to –500*
Average Annual Transport to Searsville Lake [1]	62,000	17,000 [2]	6,500 [2]

1. From Table 4-1 or 4-2. Italicized numbers are rough estimates.
2. Deposition in reservoir only; underestimates annual transport.

Very large adjustments are thought to occur in the contribution from streamside landslides from one time period to the next. While they are the dominant source from 1995 to 2000, such rates of erosion cannot be sustained because slope processes do not provide sediment to the stream margins at high enough rates. These landslides seem to be driven by channel incision, widening, and other adjustments that occur as a result of bed mobilization during extreme floods, as indicated by the correlation of high sediment yield periods with extreme floods (Section 2.4). As a corollary, large numbers of streambank landslides are very unlikely to occur during periods when peak flows are low and they may be much less important to the long-term average sediment budget because of their infrequent occurrence. We have assumed that large numbers of the streamside landslides occur only every fifty years or so, yielding long term rates that are about one-tenth to one-fifth of that observed from 1995 to 2000. These landslides are assumed to occur very infrequently during dry periods when erosion and sediment transport are both low.

During the different time periods, different processes become important, which have consequences for management. Over the long-term, landslides originating on slopes away from streams seem to be the dominant erosion process; surface erosion is also more important than it might appear based on the 1995 to 2000 budget. During periods of relatively low sediment production, such as occurred from 1914 to 1929, surface erosion may even be the dominant erosion process.

As discussed earlier, human modifications of Searsville watershed are responsible for about 16% of the total erosion from 1995 to 2000. Over the past 100 years, human impacts are mostly from surface erosion from roads and other developments and landslides initiating at roads – hydromodification is assumed to be even less significant than over the past twenty years. The greater length of unpaved roads in the past may actually have increased yields from surface erosion, particularly along Alpine Road where cut bank and fill slope erosion appear to have been important sediment processes. Assuming that human modifications are responsible for about one-third to one-half of the surface erosion and about one-third of the erosion from large landslides (see Section 4.3), they might contribute between 12% and 37% of the long-term average erosion.

5.3. Los Trancos Subwatershed

Los Trancos Watershed lies south of Searsville Lake Watershed and joins San Francisquito Creek near Junipero Serra Boulevard, from the southwest (Figure 2). Los Trancos Watershed includes seven subwatersheds and has an area of about 7.6 mi^2.

Los Trancos has detailed sediment transport measurements from 1995 to 2001 and longer-term measurements based on applying sediment rating curves to simulated or estimated flows (see **nhc** *et al* 2002). However, the substantial database regarding erosion that is available for the Searsville Lake Watershed is not available for Los Trancos Creek. Consequently, the overall budget here is much less detailed. The budget is not closed nor verified with the sediment transport estimates as in the previous section, rather sediment transport is used to balance erosion and estimate missing quantities.

However, the purpose of the budget analysis is the same as for Searsville Lake: to identify those areas that are most important to sediment production, estimate the relative importance of different sediment sources to total yield, and estimate the contribution of human activities to erosion, particularly from 1995 to 2000.

SEDIMENT TRANSPORT

Owens, Chartrand and Hecht (2002b) summarize the results of their flow and sediment gaging on Los Trancos Creek, for the water years from 1995 to 2001. Annual suspended loads were not measured in 1995 or 1996, but bed loads were. Based on the observed loads in other years, it is likely that suspended transport was about 1,000 tons in 1996.

For WY 1996 to 2000, their gaging program shows a suspended load of 10,000 tons (8,700 yd^3; assuming 1.15 tons/yd^3) and a bed load of 10,400 tons (8,300 yd^3; assuming 1.25 tons/yd^3) for a total of 17,000 yd^3, or an annual average load of 3,400 yd^3. The bed load is assumed to consist entirely of sand and coarser sediment. No particle size distributions are available for the suspended load, so we have assumed that it is one-third sand and two-thirds silt and clay. On this basis, the total load is divided into just less than two-thirds coarse material (sand, gravel and cobbles) and about one-third fine sediment (silt and clay). The estimated coarse load includes quantities of fine sand that are not found in the streambed and are not properly part of the bed material load.

Long-term sediment yields (1964 to 2002) were calculated by applying the suspended sediment rating curve to simulated flows and from bed material transport calculated from the calibrated HEC-6 model (**nhc** et al 2002). The long-term loads are about 44% of those for WY 1996 to 2000, or about 1,500 yd^3. Coarse sediment is assumed to be half or more of the long-term total. As is discussed later, the above estimate of the long-term load appears to underestimate the average contribution to San Francisquito Creek.

SEDIMENT SOURCES

Sediment sources in the Los Trancos watershed can be divided into two broad categories; episodic, discrete sources, such as landslides and gully erosion, and diffuse, chronic sources, such as bank erosion, sheetwash or surface erosion, and other hillslope erosion processes. The nature of each source, how we identified them in the watershed, and the estimated rates of erosion for the 1995 to 2000 period followed the procedures adopted for Searsville Lake Watershed, with the exceptions described in Appendix C. Table 5-6 summarizes erosion volumes contributed to streams between 1995 and 2000 and indicate the range of uncertainty in these estimates and the likely grain sizes of the erosion products.

Table 5-6: Total Erosion and Erosion by Grain Size Contributed to Streams in Los Trancos Watershed from 1995 to 2000

Sediment Source	*Total Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Coarse Sediment (yd^3) [1]*	*Fine Sediment (yd^3) [1]*
Small streamside	0		Set to zero	0	0
Large streamside	0		Set to zero	0	0
Hillslope landslides	12,400	±25%	Depth uncertain	9,000	3,400
Bank Erosion	2,100	±50%	Unit volume and extent uncertain	1,400	700
Channel Incision	0	±50%	Set to zero	0	0
Road Erosion	1,300	±75%	Likely overestimated	400	900
Scar/Scarp Erosion	100	±75%	Rough estimate	0	100
Sheet Erosion	300	±75%	Rough estimate	0	300
Gully Erosion	2,000	±75%	Length and volume uncertain	1,000	1,000
Totals	***18,200***	***12,000 to 24,000***		***11,800***	***6,400***

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

HUMAN CONTRIBUTIONS TO EROSION

Human contributions to erosion resulting from direct and indirect (hydromodification) alterations of natural processes are summarized in Table 5-7. Direct contributions include:

- Landslides on slopes that appear to originate at roads, developments or areas disturbed by human activity
- Surface erosion of landslide scars that result from human activity

- Surface erosion from roads, and
- Surface erosion from grasslands or disturbed soils
- Gullies erosion attributed to human disturbance. We have assumed that about one-third of the total volume results from human disturbance.

Indirect contributions include bank erosion, channel incision, and streamside landslides that may result from increased peak flows from development. Bank erosion or streamside landslides that may result from encroachment onto floodplains or streams or human modification of stream banks are also included. It is our view that development has little or no effect on peak flows and, consequently, little or no effect on bank erosion. However, banks have been modified to some extent by development, as follows (Table 5-7; see also Appendix C):

- Los Trancos Creek (LT-03, LT-04, LT-06). We have assumed that one-quarter of all bank erosion is human-related, as a result of modifications to stream banks from low-density residential development and roads.

The above human-related contribution is a crude estimates and further, detailed hydraulic and geomorphic analysis would be required to confirm these quantities.

Table 5-7: Human-Related Total Erosion and Erosion by Grain Size Contributed to Streams in Los Trancos Watershed from 1995 to 2000

Sediment Source	*Total Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Coarse Sediment (yd^3) [1]*	*Fine Sediment (yd^3) [1]*
Direct Contributions					
Hillslope landslides	4,200	±25%	Depth uncertain	3,000	1,200
Road Erosion	1,300	±75%	Likely overestimated	400	900
Scar/Scarp Erosion	100	±75%	Rough estimate	0	100
Sheet Erosion	300	±75%	Rough estimate	0	300
Gully Erosion	600	±75%	Human impact very uncertain	300	300
Indirect Contributions (Hydromodification)					
Bank Erosion and Channel Incision	200	±50%	Human impact very uncertain	150	50
Small streamside	0		Set to zero	0	0
Totals	***6,700***	***3,800 to 9,900***		***3,900***	***2,800***

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

LOS TRANCOS CREEK

Los Trancos Creek is steep and incised into bedrock in the first 500 feet upstream of San Francisquito Creek. This reach is thought to be degrading or incising in response to adjustments in San Francisquito Creek. Incision does not yet seem to have progressed past the small weir at the head of this section.

Further upstream, through LT-03, LT-04 and the lower part of LT-06, Los Trancos Creek flows in a moderately broad valley and is seldom in contact with its valley walls. No small landslides into the creek were observed during a casual inspection from Los Trancos Road. The channel appeared to have stored coarse sediment and sand on bars and along the streambed following the 1998 storm and to move these sediments frequently (Appendix A). Gullies, and gully failures, along the steep left (west) valley wall north of Los Trancos Woods appear to an important historic sediment source; however, we observed no evidence of recent failures in these gullies.

SEDIMENT BUDGET FROM 1995 TO 2000

As noted earlier, the difference between estimated erosion and transport volumes from 1995 to 2000 was used to estimate the contribution from small landslides, so the transport estimates do not actually reconcile the budget. Table 5-8 adjusts the erosion and transport estimates to weights based on estimated densities.

Table 5-8: Reconciliation of the Los Trancos Sediment Budget, 1995 to 2000

	Total Volume (yd^3)	*Estimated Density ($tons/yd^3$)*	*Total Weight (tons)*
Erosion adjusted for Instream Deposition	16,400	1.40	23,000
Estimated Transport at Westridge gage	17,000	1.25 or 1.15	20,400

Table 5-8 suggests that estimated erosion is reasonably consistent with measured transport, assuming that small streamside landslides do not contribute to the overall erosion. Given that the two values correspond reasonably closely, and the broad uncertainty surrounding the erosion estimates, the procedures for estimating erosion from the different sources were not adjusted.

The total erosion is divided into roughly two-thirds sand and coarser sediment and one-third silt and clay (Table 5-6). This breakdown is considerably coarser than that that estimated for the sediment transport reported at the Arastradero Road gage (Section 5.3) and suggests that the distribution of the erosion products is too coarse.

Table 5-6 summarizes the sources of erosion in the Los Trancos watershed for 1995 to 2000, a period of unusually high sediment yield that includes the very large flood in 1998. Landslides on slopes account for 68% of the total erosion; stream and surface processes erosion account for about 12% and 20%, respectively, of total erosion.

Human-caused erosion in the Los Trancos watershed from 1995 to 2000 accounted for an estimated 37% of the total, mostly from direct impacts, such as human-related landslides and road and gully erosion (Appendix C). Landslides are also the most significant sources of human-caused erosion. The sediments from human-caused erosion are slightly finer than the total erosion because of the larger role of surface erosion in environments that are human modified. Note that the estimates of human contributions from surface erosion and from indirect impacts are only rough approximations. It would require detailed investigations to accurately estimate the component that is natural and that which is human-caused. Figure 16 shows human-related erosion as a percentage of total erosion, indicating those areas where human modifications are dominant.

About half of the total erosion occurs in sub-subwatershed LT-06 and the three sub-subwatersheds that extend to upper Los Trancos (LT-05, LT-06 and LT-07) include nearly all the erosion. Most of the human-related erosion also occurs in LT-06, although the sub-subwatersheds are ranked differently for human-related erosion, with LT-04 a significant contributor (see Watershed Sediment Analysis Memorandum).

Natural and human-related erosion per unit area are illustrated in Figures 14 and 15. Both figures show some clear trends in sediment production. First, the greatest natural sediment producing sub-subwatersheds are in upper Los Trancos Creek, which is characterized by steep slopes and erosive geologies, and is adjacent to upper Corte Madera Creek. Note that unit erosion rates are substantially lower than in the nearby sub-subwatersheds of upper Corte Madera Creek.

LONGER-TERM SEDIMENT BUDGETS

Erosion and sediment transport in Los Trancos are thought to vary greatly from year to year, with rates from 1995 to 2000 being much higher than the long-term averages. Table 5-9 summarizes our understanding of the importance of the different erosion processes from 1995 to 2000 compared to the average over 1964 to 2002.

Table 5-9: Simplified Los Trancos Sediment Budget Over Two Different Time Periods

Sediment Source	***Annual Erosion (yd^3) Over [1]***	
	1995-2000	*1964-2002*
Surface Processes	300	*100 to 200*
Gully Erosion	400	*100 to 200*
Stream Erosion	400	*100 to 200*
Landslide Processes		
- Streambank landslides	0	*0 to 200*
- Landslides from slopes	2,500	*700 to 1,200*
Instream Deposition	(400)	*0*
Average Annual Transport to San Francisquito Creek [1]	3,300	1,500

1. From Tables 5-6 and 5-7. Italicized numbers are rough estimates.

As discussed for the Searsville Lake budget, surface erosion processes tend to be chronic – occurring in most years and during most storms – and their average contribution may not change greatly from one period to another. Consequently, we have assumed that long-term average rates would be similar to those estimated for 1995 to 2000. Gully and bank erosion are also chronic, although they proceed at much lower rates over the long-term.

Landslides are by far the dominant erosion process from 1995 to 2000. Abundant landsliding from slopes is known to have occurred frequently over the past 150 years, about once every five years on average (Historic Conditions Memorandum). The air photo inventory reported in Section 4 suggests that average area disturbed by landslides over the past thirty to forty years is roughly half of that from 1995 to 2000 and we have assumed that long-term erosion from landslides originating on slopes to streams is from one-quarter to one-half of the rate observed from 1995 to 2000.

Landsliding on slopes seems to be the dominant process over 1995 to 2000 and also over the long-term. In Los Trancos watershed, human impacts on slope stability are probably the most significant factor in increasing erosion and the most important consideration for sediment management. Surface erosion processes are relatively unimportant, both over the short-term and long-term.

5.4. Bear Subwatershed

Bear Creek lies north of Searsville Lake Watershed and joins San Francisquito Creek just below Searsville Dam (Figure 2). The Bear Watershed includes the Bear Creek, Bear Gulch and West Union Creek subwatersheds and has a total area of about 11.6 mi^2.

Bear Creek has only a few miscellaneous sediment transport measurements. Sediment transport from 1995 to 2000 and over the longer-term has been estimated by applying sediment rating curves to simulated flows and by adjusting measured loads from the Los Trancos gage (**nhc** *et al* 2002). The substantial database regarding erosion that is available for the Searsville Lake Watershed is not available for Bear Creek and the overall budget here is much less detailed. The budget is neither closed nor verified with the sediment transport estimates, rather sediment transport is used to balance erosion and estimate missing quantities.

However, the purpose of the budget analysis is the same as for Searsville Lake: to identify those areas that are most important to sediment production, and estimate the relative importance of different sediment sources to total yield, and estimate the contribution of human activities to erosion, particularly from 1995 to 2000.

SEDIMENT TRANSPORT

Only occasional suspended and bed load measurements have been collected on Bear Creek. Based on applying sediment rating curves to simulated flows, bed load transport in Bear Creek is just over one-third of that in Los Trancos and suspended sediment transport is about 3.5 times greater than from Los Trancos Creek (see **nhc** et al 2002). On this basis, bed load transport from 1995 to 2000 is estimated to be 3,300 yd^3; suspended load transport is estimated to be 30,000 yd^3. Average annual load is then 6,700 yd^3.

Assuming that the bedload is sand and gravel and that the suspended load is one-third sand and two-thirds silt and clay, the total load from 1995 to 2000 is divided into about

40% coarse sediment and 60% fine sediment. The average load and grain size breakdown are not very accurate, but are thought to be adequate for evaluating estimated erosion.

Long-term sediment transport (1964 to 2002), calculated by applying the suspended sediment rating curve to simulated flows and from bed material transport calculated from the calibrated HEC-6 model (**nhc** et al 2002), is about 46% of that from 1995 to 2000, or about 3,100 yd^3. Coarse sediment is assumed to be only a small portion of the long-term annual load. Combined long-term annual transport from Bear and Los Trancos amount to a little more than half of the long-term annual load estimated for the gage on San Francisquito Creek, suggesting the long-term estimates for these two tributaries are too low (see Chapter 6).

SEDIMENT SOURCES

Sediment sources in the Bear Creek watershed that contribute to streams can be divided into discrete, episodic sources, such as landslides and gully erosion, and diffuse, chronic sources, such as bank erosion, sheetwash or surface erosion, and other hillslope erosion processes. Appendix C provides details. Table 5-10 summarizes erosion volumes contributed to streams between 1995 and 2000, indicating the uncertainty in these estimates and the likely grain sizes of the erosion products.

Table 5-10: Total Erosion and Erosion by Grain Size Contributed to Streams in Bear Watershed from 1995 to 2000

Sediment Source	*Total Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Coarse Sediment (yd^3) [1]*	*Fine Sediment (yd^3) [1]*
Small streamside	9,900	±50%	Estimated volume	6,600	3,300
Large streamside	0	±75%	Not estimated	0	0
Hillslope landslides	600	±25%	Depth uncertain	400	200
Bank Erosion	12,700	±50%	Unit volume uncertain	9,000	3,700
Channel Incision	2,000	±50%	Depth uncertain	1,600	400
Road Erosion	1,800	±75%	Likely overestimated	400	1,400
Scar/Scarp Erosion	200	±75%	Rough estimate	0	200
Sheet Erosion	500	±75%	Rough estimate	0	500
Gully Erosion	2,900	±75%	Length and volume uncertain	1,000	1,900
Totals	***30,600***	***13,000 to 47,000***		***19,000***	***11,600***

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

HUMAN CONTRIBUTIONS TO EROSION

Human contributions to erosion as a result of both direct and indirect (hydromodification) alterations of natural processes are summarized in Table 5-11. Direct contributions include:

- Landslides on slopes that appear to originate at roads, developments or areas disturbed by human activity
- Surface erosion of landslide scars that result from human activity
- Surface erosion from roads, and
- Surface erosion from grasslands or disturbed soils
- Gullies erosion attributed to human disturbance (We have assumed that one-third of the total erosion volume is human-related, as in previous sections.)

Table 5-11: Human-Related Total Erosion and Erosion by Grain Size Contributed to Streams in Bear Watershed from 1995 to 2000

Sediment Source	*Total Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Coarse Sediment (yd^3) [1]*	*Fine Sediment (yd^3) [1]*
Direct Contributions					
Hillslope landslides	0			0	0
Road Erosion	1,800	±75%	Likely overestimated	400	1,400
Scar/Scarp Erosion	0			0	0
Sheet Erosion	500	±75%	Rough estimate	0	500
Gully Erosion	600	±75%	Human impact very uncertain	300	300
Indirect Contributions (Hydromodification)					
Bank Erosion and Channel Incision	2,300	±50%	Human impact uncertain	1,700	600
Small streamside	0		Human impact uncertain	0	0
Totals	***5,200***	***1,900 to 8,500***		***2,400***	***2,800***

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

Indirect contributions include bank erosion, channel incision, and landslides along streams that may result from increased peak flows from development or bank erosion or landslides along streams that may result from encroachment onto floodplains or streams or human modification of stream banks. We have assumed that development has not modified hydrographs in Bear Creek or its tributaries but that development in the floodplain and modification of stream banks has contributed to bank erosion in the following sub-subwatersheds (see Appendix C):

- Bear Creek (BC-01 and BC-02). We have assumed that one-quarter of all bank erosion results from modifications to stream banks from low-density residential development, bridges and roads.
- Bear Gulch (BG-01 and BG-02). We have assumed that one-quarter of all bank erosion in BG-01 results from modifications to stream banks from low-density

residential development, bridges and roads. Incision in these two sub-subwatersheds is assumed to result entirely from human modifications.

- West Union Creek (WUC-01, WUC-03 and WUC-05). We have assumed that one-quarter of all bank erosion results from modifications to stream banks from low-density residential development, bridges and roads.

The above human-related contributions are crude estimates and further, detailed hydraulic and geomorphic analysis would be required to confirm these quantities.

BEAR, BEAR GULCH AND WEST UNION CREEKS

Smith and Harden (2001) describe the reaches of Bear Creek and West Union Creek that lie along the San Andreas Fault Zone. They found that Bear and West Union Creeks were entrenched, had relatively stable banks, with bedrock exposed in the bed of Bear Creek for several miles upstream of the mouth. Bank protection, consisting of riprap, gabions or concrete cribbing, has been placed along sections of the stream, primarily on lower West Union Creek, presumably where erosion has occurred in the past.

Smith and Harden identify a number of concrete diversion dams and other structures along Bear and West Union Creeks as part of their assessment of fish passage. Most of these structures show some evidence of incision downstream and filling upstream of the structures. Incision appears to be typically a few feet at the structures and such an extent of incision may extend along most of Bear and West Union Creeks. The period over which this incision occurred is not known but it is estimated to be several decades; little of the incision appears recent, based on examining site photographs. Significant incision is also observed on Bear Gulch at Highway 84. Removal of coarse sediment that accumulates at the water supply diversion dam reduces coarse sediment delivery to downstream reaches and contributes to the incision.

One of the more interesting observations by Smith and Harden is the presence of an 11-foot high falls in West Union Creek, upstream of Huddart Park. They identify this as a knickpoint that developed from displacement along the San Andreas Fault Zone during the 1906 San Francisco Earthquake. It is unclear how far this knickpoint has migrated over the past 100 years, but such deep incision may have been a significant sediment source in the past and again in the future, as it migrates upstream.

SEDIMENT BUDGET FROM 1995 TO 2000

As noted earlier, the difference between estimated erosion and transport volumes from 1995 to 2000 has been used to estimate the contribution from small landslides, so the transport estimates do not actually reconcile the budget. Table 5-12 adjusts the erosion and transport estimates to weights based on suitable densities.

Table 5-12 suggests that estimated erosion is reasonably consistent with measured transport, assuming that contribution from small streamside landslides is accurately estimated by the difference between erosion and transport. Given the broad uncertainty surrounding the erosion and transport estimates, the procedures for estimating erosion from the different sources were not adjusted.

Table 5-12: Reconciliation of Bear Sediment Budget, 1995 to 2000

	Total Volume (yd³)	*Estimated Density (tons/yd³)*	*Total Weight (tons)*
Erosion adjusted for Instream Deposition	30,000	1.40	42,000
Estimated Transport at Westridge gage	33,000	1.15 and 1.25	39,000

The total erosion is divided into a bit less than two-thirds sand and coarser sediment and a little more than one-third silt and clay (Table 5-10). This is very inconsistent with the breakdown estimated from adjusting sediment transport measures and suggests that either the sediment transport data is not accurate (Section 5.4) or that the portion of fine sediment in the erosion products has been greatly underestimated. Human-related sediment is finer than the overall erosion product.

Table 5-10 summarizes sources of erosion in the Bear watershed for 1995 to 2000, a period of unusually high sediment yield that includes the very large flood in 1998. Streamside landslides and landslides from slopes account for 34% of the total erosion (based on the adjustments discussed in Appendix C); streams accounted for 48% and surface erosion for about 18% of total erosion. If the adjustment that added erosion from streamside landslides to the total budget were ignored, stream bank erosion would be by far the dominant source.

Human-caused erosion in the Bear watershed from 1995 to 2000 accounted for an estimated 17% of the total erosion, mostly from indirect impacts on stream erosion through modification of banks, incision related to trapping of coarse sediment at the diversion dam on Bear Gulch and surface erosion from roads (Appendix C). Note that the estimates of human contributions from direct and indirect impacts are only rough approximations. It would require detailed investigations to accurately estimate the component that is natural and that which is human-caused.

Erosion is spread relatively evenly over the sixteen sub-subwatersheds, with the greatest erosion volumes from Bear Gulch (BG-02 and BG-03), which provides about 20% of the total (Appendix C). Natural erosion contributions are greatest from the steep tributaries that extend into the Santa Cruz Mountains (Figure 14). The sub-subwatersheds that lie along the main streams and in the valley of the SAFZ through Woodside typically have low natural erosion contributions per unit area. However, they have the greatest human-related erosion contributions (Figure 15) and these contributions are the greatest percentage of total erosion there (Figure 16). The greatest human -related erosion is from Bear Gulch, based on the assumed incision rates that occur there because of coarse sediment diversion. Natural and human-related erosion per unit area are illustrated in Figures 14 and 15. Note that unit erosion rates in the tributaries in the Santa Cruz Mountains in Bear Watershed are strongly affected by the assumptions made about streamside landsliding there and may not reflect the actual distribution of erosion volumes.

LONGER-TERM SEDIMENT BUDGETS

Rates of erosion and transport in Bear Creek from 1995 to 2000 are thought to be greater than long-term averages. Table 5-13 summarizes our understanding of the importance of the main erosion processes during 1995 to 2000 compared to the average estimated for 1964 to 2002.

Table 5-13. Simplified Bear Watershed Sediment Budget Over Two Different Time Periods

Sediment Source	***Annual Erosion (yd^3) Over*** [1]	
	1995-2000	*1964-2002*
Surface Processes	500	*200 to 400*
Gully Erosion	600	*200 to 400*
Stream Erosion	3,000	*1,000 to 2,000*
Landslide Processes		
- Streambank landslides	2,000	*0 to500*
- Landslides from slopes	100	*500 to 1,500*
Instream Deposition	(200)	*0*
Average Annual Transport to San Francisquito Creek [1]	6,000	3,100

1. Partly from Table 5-10. Italicized numbers are rough estimates.

As discussed for the Searsville Lake budget, surface erosion processes tend to be chronic – occurring in most years and during most storms – and their overall annual rate may not change greatly from one period to another. Consequently, we have assumed that long-term average rates would be only a little less than those estimated for 1995 to 2000. Gully and bank erosion are also chronic, although they proceed at much lower rates over the long-term, with stream bank erosion at about half of the rate estimated for 1995 to 2000.

Stream erosion is the dominant erosion process from 1995 to 2000 and, with landslides from slopes, may be the most significant process over the long term. Bear Watershed had unusually few landslides from slopes from 1995 to 2000. However, the air photo inventory reported in Section 4.3 suggests that average area disturbed by landslides over the past thirty to forty years is about the same as in Los Trancos and we have assumed that long-term erosion from landslides originating on slopes in Bear Watershed is similar to the long term rate in Los Trancos. The contribution of small landslides to the long-term budget is not certain and further stream inventory would be needed to address this issue.

Given that stream erosion is one of the dominant process over 1995 to 2000 and over the long-term, human impacts on stream banks, sediment transport, and watershed hydrographs are probably the most significant factors for sediment management. Gully erosion is also important and management of stormwater from roads and developments is an important component of sediment management. Other surface erosion processes are relatively unimportant, both over the short-term and long-term.

6. SAN FRANCISQUITO CREEK SEDIMENT BUDGET

6.1. Background

San Francisquito Creek is the most downstream subwatershed and it receives water and sediment from the Los Trancos, Bear and Searsville Lake subwatersheds. This subwatershed has 12 sub-subwatersheds – including the most urbanized part of San Francisquito Watershed – and a total area of about 13.4 mi^2 (Figure 2).

Suspended sediment transport was measured at the USGS station at Stanford in the late 1950s and 1960s (see Porterfield 1980; Brown and Jackson 1973) and a few miscellaneous measurements were collected in the 2000 and 2001 (**nhc** *et al* 2002; Owens, Chartrand and Hecht 2002b). **nhc** et al (2002) provide detailed bed load transport modeling along San Francisquito Creek. However, there are no measurements of erosion in the subwatershed for recent years, although erosion estimates can be constructed for longer time periods. As for Los Trancos and Bear watersheds, the budget is not closed nor verified with the sediment transport estimates, but rather sediment transport is balanced with erosion and differences are used to estimate missing quantities.

The budget analysis is restricted to 1964 to 1998 and focuses on identifying the relative importance of different sources to total erosion, and the contribution of human activities to erosion.

6.2. Sediment Transport

Porterfield (1980) reports estimates of long-term sediment transport in San Francisquito Creek based on applying a suspended-load rating curve developed from measurements at the USGS gage at the Stanford Golf Course between 1957 and 1962 to a flow duration curve at the gage (Table 6-1). Porterfield also measured the portion of sand in the suspended load, developed a separate rating for sand load, and noted that most sand appeared to be in suspension at the measurement site.

Brown and Jackson (1973) reported suspended sediment loads measured at the gage at Stanford University from 1962 to 1969 (Table 6-1). Balance Hydrologics, Inc (2001) subsequently measured a few suspended sediment loads in 2000 and 2001, confirmed no gross changes in their sediment rating curve, and recommended an equation relating sediment discharge and stream flow. Application of their equation to the daily flows recorded from 1964 to 1998, predicts an annual suspended sediment transport of 12,000 tons (9,600 yd^3, assuming 1.25 tons/yd^3), nearly the same as the long-term load estimated by Porterfield. Grain size distributions of the suspended load are not reported, but it is reasonable to assume that sand forms a significant component of the suspended load in the steep reach at the gage site.

Annual suspended sediment discharges for 1962 to 1969 are reported by Brown and Jackson (1973) and included in the Historic Conditions Memorandum (see Table 6-1). They show that annual suspended load varied from 1,100 to 50,600 tons, with the greatest transport during years with large peak flows.

nhc et al (2002) estimated wash load (silt and clay) transport for current conditions as part of their HEC-6 sediment transport model. The wash load, which includes overflow from Searsville Dam and contributions from Los Trancos and Bear Creek as well as other sources, appear to average about 4,000 tons per year. This suggests that about two-thirds of the average suspended load is sand; about one-third is silt and clay. This is about twice as great as that measured by Porterfield (1980).

Table 6-1: Suspended Sediment Transport Measurements in San Francisquito Creek

Source	*Period*	*Annual Suspended Load (yd^3)* [1]		
		Total	Sand	Silt and Clay
Porterfield (1980)	1909-1966	9,000	3,000	6,000
	1957-1959	13,000	4,000	9,000
	1957-1966	6,700	-	-
Brown and Jackson (1973)	1962-1969	12,000	-	-
	1964-1998	9,600	-	-

1. Assumes 1.25 tons/yd^3 for conversion of weights to volumes

Bed load transport has not been measured on San Francisquito Creek. Balance Hydrologics, Inc suggests that it may be from 10 to 20% of suspended load at the Stanford University gage, or about 1,000 to 2,000 yd^3. A better estimate can be obtained from the HEC-6 model output provided by **nhc** et al (2002). Their analysis shows an average sand component of 600 yd^3 and a gravel component of about 1,000 yd^3 per year near Los Trancos Creek. Bedload transport remains about this value until near El Camino, then declines rapidly by Highway 101. The sand component is thought to be included in the measured suspended load so only the gravel load is added for total load.

The above analyses suggests that long-term average sediment transport at the Stanford University gage is about 10,000 yd^3; divided roughly into 6,000 yd^3 of silt and clay wash load (60%) and 4,000 yd^3 of sand and gravel (40%).

6.3. Sediment Sources

OVERVIEW

Under current conditions, sediment is contributed to San Francisquito Creek from the following sources:

- Suspended sediment (silt and clay) carried over the Searsville Dam that originates in Corte Madera, Alambique and Sausal Creeks. This has been estimated to be 10% of the volume deposited in Searsville Lake.
- Los Trancos and Bear Creeks contribute fine and coarse sediment to the upper section of San Francisquito Creek. Previous chapters provide details on the sources of the sediment carried by these creeks.
- Erosion of stream banks along San Francisquito Creek.
- Incision of San Francisquito Creek into its streambed.

- Erosion from small tributaries, gullies and the land surface in the San Francisquito subwatershed.

The sources of information on erosion and deposition in the subwatershed are summarized in the Historic Conditions and Watershed Sediment Analysis Memoranda. Essentially, there is a reasonable understanding of coarse (sand and gravel) sediment erosion and deposition along the main creek from 1964 to 1998. However, bank erosion volumes along San Francisquito Creek have not been measured, nor have erosion contributions from the surrounding urban areas.

nhc et al (2002) were not able to estimate bank erosion volumes by comparing repeated surveys, as many of the cross sections had been modified by construction of bank protection works. However, bank erosion along San Francisquito Creek is an important component of erosion and we estimated its contribution by balancing sediment inflows and deposition, assuming that the difference results from bank erosion. The following paragraphs describe the methods used to estimate erosion and deposition. Table 6-2 summarizes erosion and deposition volumes for 1964 to 1998.

SEARSVILLE LAKE, LOS TRANCOS AND BEAR CREEKS INFLOWS

Long-term sediment inflows from Searsville Lake are assumed to be 10% of the long-term reservoir deposition (Table 5-1) or about 1,700 yd^3 per year. All this sediment is assumed to be silt and clay.

Los Trancos and Bear Creeks are then assumed to contribute a net of 3,800 yd^3 per year of sand and gravel and 3,500 yd^3 per year of silt and clay, based on reducing the estimated sediment transport at the gage on San Francisquito Creek by the inflow from Searsville Lake and the inflows from sub-subwatersheds SF-10, SF-11 and SF-12. This contribution is <u>larger</u> than the long-term loads estimated for Los Trancos and Bear subwatersheds (Sections 5.3 and 5.4). Note that part of the load from Bear Creek is deposited along upper San Francisquito Creek (Appendix A).

INCISION OF SAN FRANCISQUITO CREEK

nhc et al (2002), from comparison of the streambeds on the 1964 and 1998 surveys shows relatively slow incision from 1964 to 1998 upstream of Pope-Chaucer Bridge, amounting to 0.4 feet when spread over the bed, or a rate of about 0.012 feet/year. The calculated net incision was 4,800 yd^3, or an annual erosion of 140 yd^3.

EROSION FROM SUB-SUBWATERSHEDS

Little is known of erosion sources or transport in the San Francisquito Creek sub-subwatersheds, particularly the urbanized ones in East Palo Alto, Palo Alto and Menlo Park. Instead of estimating erosion by adding sediment sources, we have relied on sediment transport measurements. Crippen and Waananen (1969) provide miscellaneous measurements of suspended sediment transport on Sharon Creek, Los Trancos tributary, and San Francisquito Creek tributary. These small tributaries all lie near the junction of San Francisquito and Los Trancos Creeks in the Bay Foothills. Sediment concentrations measured during storms ranged from a few hundred to more than 15,000 mg/L with associated sediment transport rates of less than 1 to about 400 tons per day. Storm hydrographs were very peaky and actual suspended transport during storms was often less than 10 tons (8 yd^3), reasonably consistent with storm-based erosion quoted by Knott *et al* (1973) for open space and urban areas in Colma Creek. Assuming that transported volumes range from about 1 to 50 tons for storms of varying size, average annual transport likely ranged from 100 to 300 yd^3/mi^2, depending on stream and watershed characteristics and the extent of construction.

Table 6-2: Annual Erosion and Annual Erosion by Grain Size to San Francisquito Creek from 1964 to 1998

Sediment Source	*Annual Erosion (yd^3)*	*Likely Range (%)*	*Comment*	*Annual Coarse Sediment (yd^3)* [1]	*Annual Fine Sediment (yd^3)* [1]
Erosion or Sediment Inflows					
Sediment from Searsville	1,700	±25%	Based on a few measurements	0	1,700
Los Trancos and Bear Creeks	7,300	±25%	From SF Creek gage	3,800	3,500
Incision	140	±25%	From surveys	140	0
Sub-subwatersheds SF-10 to SF-12	1,000	±75%	Very uncertain	200	800
Sub-subwatersheds SF-01 to SF-09	500	±75%	Very uncertain	200	300
Bank Erosion	*0 to 3,000*	±50%	Estimated from balance	*0 to 1,500*	*0 to 1,500*
Total Erosion	*10,600 to 13,600*			*4,300 to 5,800*	*6,300 to 7,800*
Deposition					
To Highway 101	470	±25%	From surveys	470	0
Highway 101 to mouth	1,000	±50%	Section uncertain	750	250
Excavation	900	±25%	Past excavation volume unknown	900	0
Delta	3,100	±25%	Depth of deposit uncertain	2,300	800
To San Francisco Bay	*5,200 to 6,600*	±50%	From fine sediment balance	0	*5,200 to 6,600*
Total Deposition	*10,600 to 13,600*		Based on error estimates	*43000 to 5,800*	*6,300 to 7,800*

1. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).

Grain size analyses show that the suspended load was almost entirely silt and clay at moderate flows, increasing to about 40% sand at very high flows. On this basis, sand likely makes up 10 to 20% of the total load. Bed incision and bed load transport does occur, as indicated by knickpoints along some of the streams.

Based on the transport analysis, we have assumed that annual contributions in sub-subwatersheds SF-10, SF-11 and SF-12, which are agricultural and rural residential, are about 300 yd^3/mi^2. Contributions from the urbanized areas downstream are assumed to be much less, about 50 yd^3/mi^2. These yields are very much less than observed by Knott *et al* (1973) in Colma Creek but seem to be consistent with the measured sediment yields in San Francisquito Creek.

The above transport rates, with bank erosion contributions as discussed below are the basis of the erosion rates per unit area shown on Figures 14 and 15 for the San Francisquito Creek sub-subwatersheds.

BANK EROSION

The potential annual contribution of coarse sediment from bank erosion, calculated from the difference between the range of deposited sediment and the range of eroded coarse sediment or contributions, is from 0 to 1,500 yd^3. The fine sediment component of bank erosion was estimated from the general nature of the bank materials along San Francisquito Creek. Banks are typically composed of sandy clay to clayey sand overlying sandy, silty gravels. We have assumed that the banks are about half coarse and half fine sediment, so the range of fine sediment eroded from banks is equal to that of coarse sediment. As discussed later, we have assumed that annual bank erosion is actually near the upper end of the quoted ranges.

DEPOSITION ALONG SAN FRANCISQUITO CREEK

Some of the bedload (gravel and sand) delivered by Bear Creek is deposited along San Francisquito Creek, with gravel deposited through Jasper Ridge downstream of the mouth of Bear Creek and sand deposited through sub-subwatershed SF-11. Only the net transport to the San Francisquito Creek gage is included in Table 6-2. Rates or volumes of deposition in SF-11 have not been measured (see Appendix A).

nhc *et al* (2002) calculated net deposition from Pope-Chaucer Bridge downstream to Highway 101 of 16,000 yd^3 by comparing 1964 and 1998 cross sections. This is roughly equivalent to 1.7 feet of deposition when spread over the streambed, or to about 0.06 yd^3/foot of channel per year. Average annual deposition is 470 yd^3.

As described in Chapter 4, deposition has also occurred from Highway 101 to the mouth of San Francisquito Creek following excavation for increased flood capacity (San Francisquito Creek CRMP 1998). We have roughly estimated deposition of 35,000 yd^3 since 1958, roughly three-quarters sand and one-quarter fine sediment carried in from San Francisco Bay. Average annual deposition of sand from 1968 to 1994 is roughly estimated to be 750 yd^3.

EXCAVATION FROM SAN FRANCISQUITO CREEK

Table 4-4 summarizes excavation volumes near Highway 101. Average annual excavation from 1984 to 1997 is 900 yd^3 per year and we have assumed that this rate is appropriate for the 1964 to 1998 period. Such an assumption may overestimate actual removals.

DEPOSITION ON SAN FRANCISQUITO DELTA

Phillips (2000) reported measurements of the deposition on the delta at the mouth of San Francisquito Creek in San Francisco Bay based on detailed coring (Section 4.6). Total deposition since the late 1950s appear to be about one foot, or 80,000 yd^3. We assumed that this sediment is about three-quarters sand, providing an annual deposition rate of 2,300 yd^3. Some of the fine sediment may be carried to the delta by tidal currents rather than deposited from San Francisquito Creek.

6.4. Human Contributions to Erosion

The San Francisquito subwatershed is the most developed or urbanized watershed. We separate natural and human contributions to erosion, as follows:

- Estimated contributions from the land surface in the sub-subwatersheds are all assumed to be human-related (see Section 6.3 "Erosion from sub-subwatersheds")
- Incision of San Francisquito Creek is assumed to be all a result of human modification of hydrographs and from trapping of coarse sediment in Searsville Lake. This sediment contribution is divided equally between the SF-04, SF-05, SF-08 and SF-09 sub-subwatersheds
- Bank erosion along San Francisquito Creek is assumed to be half natural and half resulting from human modification. We assumed that the annual rate is at the top end of the range quoted in Table 6-2 and distributed this equally between sub-subwatersheds SF-02, SF-03, SF-04, SF-05, SF-08 and SF-09. This is, at best, a rough approximation. Bank erosion is thought to be negligible along San Francisquito Creek through SF-11, based on previous reports and field inspections (see Appendix A).

The above human-related contributions are crude estimates and further, detailed hydraulic and geomorphic analyses would be required to confirm these quantities.

6.5. San Francisquito Creek

San Francisquito Creek starts at the foot of Searsville Dam and flows to San Francisco Bay. The creek is incised into Quaternary and Holocene alluvial fan sediments along most of its course. We have divided the creek into four reaches, based primarily on slope and bed material. Table 6-4 summarizes the basic characteristics of each reach.

- Reach 1 (Searsville Dam to Sandhill Road): bedrock-dominated reach
- Reach 2 (Sandhill Road to upstream of El Camino Real): boulder reach
- Reach 3 (Upstream of El Camino Real to University Avenue): gravel bed
- Reach 4 (Downstream of Newell Road): sand bed leading to estuary

Table 6-4: San Francisquito Creek Reach Characteristics

Reach	*Description*	*Slope* [1]	*Surface Material (mm)* [2]		*Subsurface Sediment* [3]
			D_{50}	D_{84}	
1	Bedrock reach	Not surveyed	30 to 120	100 to 200	Mostly fine gravel; 30% sand (lower end of reach)
2	Boulder reach	0.007	60	200	Assumed similar to Reach 1
3	Gravel bed reach	0.003	10 to 20	30 to 60	Mostly fine gravel; 30% sand
4	Sand bed reach	0.001	Sand	About 10	Mostly fine gravel; 20% sand

1. Slopes averaged from Figure 3-19 of RHAA et al (2000).
2. Bed material sizes from Figures 7-12 to 7-14 of **nhc** et al (2002)
3. Subsurface materials from Appendix B of **nhc** et al (2002). Sample weights are inadequate to fully characterize the subsurface bed material.

In Reach 1, San Francisquito Creek is incised into the local bedrock, which is exposed in the bed and in the lower section of the bank (Appendix C). Pleistocene fan deposits overlie the bedrock throughout much of the reach (see Helley et al 1979). **nhc** et al (2002) note that the contact with the fan deposits is typically about 5 feet above the stream bed in the upper reach, often higher near Los Trancos Creek, and that bedrock is no longer visible in the bank by Junipero Serra Boulevard (Pampeyan 1993). Bed material consists of gravel and cobbles near Bear Creek and cobbles and boulders downstream of this tributary; apparently, some gravel bars have also formed in the channel downstream of the mouth of Los Trancos Creek.

Reach 2 is a short boulder bed section of San Francisquito Creek that extends downstream past the bedrock-controlled section, onto the alluvial fan, to near the San Mateo Drive Pedestrian Bridge and the Pulgas Fault. The coarse bed material appears to be a stable pavement formed by winnowing of finer sediment from the bed surface; the underlying subsurface material appears considerably finer. The bed surface is now immobile or mostly immobile under the current flow regime. Closure of the Searsville Dam and reduction of coarse sediment supply, while maintaining peak flows, is likely a contributing factor to formation of the pavement.

Reach 3 is incising into coarse, partly indurated, gravels exposed below the sandy material that forms the upper banks and fan surface. Bed material is gravel, with sand in the interstices; subsurface materials are fine gravel and sand. The bed material in Reach 3 is reasonably mobile during annual peak flows and there is no evidence of formation of a stable pavement here. Bed incision is expected to continue at the upstream end of this reach, lowering the overall slope closer to a stable slope for the given bed material.

Reach 4 is a deposition reach that extends from University Avenue downstream to the estuary and delta of San Francisquito Creek. Bed materials in this reach consist of fine gravels and sand; subsurface materials have a similar grain size distribution.

6.6. Sediment Budget 1964 to 1998

Table 6-2 shows that erosion in San Francisquito Creek watershed averaged about 3,600 yd^3 per year, assuming that bank erosion along San Francisquito Creek occurred at the top end of the quoted range. If this is correct, bank erosion is the most important source, exceeding the estimated contribution from the urbanized landscape. However, there are broad uncertainties in the volume contributed by bank erosion because of uncertainties in the other sediment inflow and deposition volumes and in the volume eroded from urban areas and rural residential areas.

It is worth considering what the erosion volumes that are quoted in Table 6-2 imply for bank retreat along San Francisquito Creek. Such an analysis provides a rough check on the estimated volumes. Royston, Hanamoto, Alley, and Abbey *et al* (2000) examined the length of eroding bank along San Francisquito Creek in 1999. Table 6-5 summarizes the results for their four study reaches, showing that most of the unstable bank now lies from Pope-Chaucer Road upstream to Sand Hill Road, where San Francisquito Creek has been incising into its bed and increasing bank heights.

Table 6-5. Summary of Eroding Bank Length from RHAA (2000)

Reach	***Description***	***Reach Length (ft)***	***% Severe Erosion [1]***	***Length of Severe Erosion [2] (ft)***
A	Hwy 101 to Pope-Chaucer	9,800	1%	200
B	Pope-Chaucer to Pedestrian Bridge	6,600	14%	1,800
C	Pedestrian Bridge to Sand Hill Road	12,800	60%	15,400
D	Sand Hill Road to USGS gage	3,200	0%	0
Totals		32,400	27%	17,400

1. Average of "least stable" category for left and right banks
2. Total bank length, right and left banks

Assuming that the banks are typically about 24 feet high, and have an average slope of 1.5H:1V, the total area of unstable bank would be about 80,000 yd^2. Further assuming that a similar bank area has been unstable since 1964, bank retreat at the eroding sites would need to average about 1.3 yard (4 feet) normal to the slope (about 6 feet parallel to the streambed) since 1964 to account for the estimated erosion volume. Such a retreat is reasonably consistent with that observed between 1964 and 1998 at cross sections where stream banks are not protected from erosion, other than by vegetation, where bank retreat seems to average about 1.5 to 3 yards (see **nhc** et al 2002). This suggests that bank erosion may be slightly underestimated or that other sections of vegetated banks between these cross sections showed little or no erosion.

It is also of interest to examine the average channel widening associated with the bank erosion. For the channel from Highway 101 to the USGS gage, the average bank retreat from 1964 to 1998 to match the estimated erosion volume would be about 0.4 yards (1.1

feet) normal to the slope, or an average widening of about 1.5 feet at the base of the bank slope. Steepening of some banks and construction of protection on other banks may mask any effects of the apparent widening of the overall valley. There are no measurements of average channel or valley widths over time along San Francisquito Creek but RHAA et al (2000) note that bank stability was already an issue in the 1960s and channel widening is likely to have occurred along at least part of the creek.

6.7. Budget Without Searsville Dam

The sediment budget quoted in Table 6-2 is for existing conditions along San Francisquito Creek, with the Searsville Dam in place. The dam traps sediment from the Searsville Lake Watershed and has reduced the supply of coarse and fine sediment to San Francisquito Creek since 1892, when it was closed. Table 6-6 summarizes long-term average coarse and fine sediment loads in San Francisquito Creek, for both existing conditions and without the dam. Sediment loads without Searsville Dam assume that the average annual load from the Searsville Watershed for 1982 to 2000 (Table 5-1) would be carried to San Francisquito Creek and that it is half coarse and half fine sediment.

Table 6-6. Average Annual Transport at the San Francisquito Creek gage at Stanford with and without Searsville Dam [1]

Sediment Source	***Scenario 1 – Existing Conditions***	***Scenario 2 – No Searsville Dam***	***Scenario 1 – Existing Conditions***	***Scenario 2 – No Searsville Dam***
	Annual Coarse Transport (yd^3) [2]		*Annual Fine Transport (yd^3) [2]*	
Searsville Watershed [1]	0	8,500	1,700	8,500
Los Trancos and Bear Cks	3,800	3,800	3,500	3,500
Sub-subwatersheds SF-10 to 12	200	200	800	800
Bank Erosion along upper San Francisquito Ck	minor	Increased?	Minor	Increased?
Transport past SF gage	4,000	12,500	6,000	12,800

1. Average transport for San Francisquito Creek is from 1964 to 1998; for Searsville watershed from 1982 to 2000
2. Coarse sediment is sand, gravel and cobbles; fine sediment is silt and clay.

Table 6-6 shows that coarse sediment transport past the San Francisquito Creek gage has been reduced by about two-thirds and fine sediment transport by about one-half as a result of the Searsville Dam and reservoir. Note that the loads calculated with and without the dam do not represent “natural” loads as they include a human-related erosion component. The coarse sediment transported past the gage is deposited along San

Francisquito Creek and on its delta in San Francisco Bay. **nhc** *et al* (2002) describe the changes that might occur along the creek as a result of increased coarse sediment supply.

Reduction of the coarse load is thought to be responsible for some of the historic changes observed along San Francisquito Creek. Incision in upper reaches and deposition in lower reaches has likely occurred as part of an overall adjustment to lower bed load transport. This incision has increased bank heights, steepened some bank and increased rates of erosion. One other response to the reduced coarse sediment supply has been coarsening of the bed material and formation of a coarse bed surface pavement along the upper reaches of the creek.

On the other hand, trapping of fine sediment has likely resulted in minor improvements to water quality (lower average sediment concentration and turbidity) with few consequences for the stream channel. This fine sediment is mostly carried through San Francisquito Creek to San Francisco Bay.

7. MANAGEMENT POLICIES AND PRACTICES

7.1. Background

The Existing Management Practices Memorandum assessed policies and regulations that provided erosion control or channel protection in the San Francisquito watershed, identified deficiencies in these policies and regulations, and recommended improvements. This Chapter summarizes previous reviews of sediment and erosion policies and practices for San Mateo and Santa Clara Counties and the towns and cities in the San Francisquito Watershed and discusses some practices that were not included in these reviews, either because they have been developed or adopted since the reviews were completed or because that particular jurisdiction was not included in the reviews. The chapter also summarizes stream and riparian corridor management policies and programs, as discussed in the Existing Conditions Memorandum.

7.2. Reviews of Policies and Practices

FISHNET 4C REVIEW

Harris *et al* (2001) completed a detailed assessment of existing management practices in Central California Coast Counties for the Fishnet 4C Program. The basic goal of their study was to evaluate the effectiveness of policies and practices on minimizing damage to salmon and their habitat from county funded or regulated activities and to recommend improvements to policies and practices. It did not focus exclusively on erosion or stream management. San Mateo County is the only one of the Central California Coast counties that has jurisdiction in San Francisquito Creek.

In summary, Harris *et al* (2001) found that County plans usually included habitat conservation as a goal but that protective policies were often lacking. San Mateo County lacked a riparian buffer policy or floodplain setback requirement, both of which are considered key policies and regulations for stream protection. However, the County does have sensitive habitat regulations. Harris *et al* (2001) also found that grading controls and erosion control plans were in place for private projects in San Mateo County and that permits were required for construction of stream bank protection structures. However, they noted that implementation and effectiveness of erosion controls was uneven, particularly during the rainy season. One particular lack identified in the report was policies or standards for rural road and culvert maintenance.

Important sediment sources identified by the study were the recurrence of road failures and landslides at certain locations and erosion of stored landslide debris, road spoils, or other stored materials. Sheetwash erosion from unpaved roads and trails and ditch erosion on paved roads were also considered important sediment sources that were not treated or considered directly in policies.

The study also identified specific practices detrimental to salmonids and their habitat. Channel maintenance, particularly clearing of woody debris and vegetation was an important habitat concern. Stream crossings, including culvert replacements and repairs on streams with anadromous salmonid habitat, were significant concerns as were bank stabilization structures, particularly the cumulative impacts from continued local construction along unstable reaches where houses are close to the top of bank.

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD (CRWQCB)

The CRWQCB (2002) provides a summary of non-point source management measures that were either in place or under consideration in the cities of East Palo Alto, Menlo Park, Palo Alto, the towns of Woodside and Portola Valley, and San Mateo and Santa Clara Counties in August 2001 (Table 7-1). Their summary is based on inventories prepared by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and the San Mateo County Storm Water Prevention Program (SM-STOPPP) -.

Table 7-1: Sediment Management Policies and Regulations Implemented by Jurisdictions in San Francisquito Creek Watershed by 2001

Management Measure	***Jurisdiction***						
	EPA	*MP*	*PA*	*Wood*	*PV*	*SM*	*SC*
Creek Setback Ordinance	●		●	●			
Heritage Tree Ordinance		● [2]	●	●	●	●	●
Non-Stormwater Ordinance		● [2]	●	●		●	●
Grading Standards	●	●	●	●	●	●	●
Design Standards	●		●	●	●	●	●
Road Maintenance Standards	●		●		●	●	●
Impervious Surface Limits				●			
BMP Inspections		●	●				
Conservation Easements				●			●
Confined Animal Ordinance						●	

1. EPA is East Palo Alto, MP is Menlo Park, PA is Palo Alto, Wood is Woodside, PV is Portola Valley, SM is San Mateo County, SC is Santa Clara County.
2. Information provided by City of Menlo Park (Patrick Stone).

Table 7-1 shows that policies and regulations for controlling sediment from construction sites, such as grading standards, were broadly implemented throughout San Francisquito watershed by 2001, as were road maintenance standards and non-stormwater discharge ordinances through countywide NPDES permits. BMP inspections, creek setback ordinances and impervious surface limits were much less common.

The CRWQCB report also notes that sediment management measures are underway by the Joint Powers Authority on San Francisquito Creek. The JPA is implementing the Bank Stabilization and Revegetation Master Plan developed by the cities of Menlo Park, Palo Alto, East Palo Alto and San Mateo and Santa Clara Counties and also coordinates an annual inspection of the creek as part of assessing vegetation removal plans and examining erosion at storm drains.

SANTA CLARA MUNICIPAL DEVELOPMENT POLICIES COMPARISON

SCVURPPP (2003b) provided a comparison of development policies, implementing ordinances, regulations and guidelines for their co-permittees. The overall purpose of the project was to develop “model” municipal planning principles and then compare existing policies and practices to the model principles to identify areas for improvement. Regulatory bodies examined in the document that operate in San Francisquito Creek watershed are Santa Clara County, Santa Clara Valley Water District, Palo Alto, and Menlo Park. Recommendations were not prepared for Menlo Park because it is not a co-permittee. The report provides a very detailed summary for each jurisdiction.

The report notes that Palo Alto has a comprehensive set of policies and ordinances and that water quality issues are addressed through the Comprehensive Plan and guidance or standards documents. These documents address water quality and stormwater management by recommending suitable design techniques. SCVURPPP (2002) also provides a brief description of the sediment management practices of Palo Alto, which focus on construction site stormwater pollution prevention programs. SCVURPPP (2003b) notes that San Mateo is nearly entirely built out. San Mateo has adopted the Model Development Policies of SM-STOPPP that address water quality and maintaining stream buffers and native vegetation.

The report identified six general areas where policies or practices are deficient and where improvements would be beneficial. While derived for Santa Clara County, these recommendations are also thought to be helpful for San Mateo County:

- *Erosion and Sediment Control*: Training of municipal engineers and inspectors, design engineers and contractors in design, installation and maintenance of sediment controls.
- *Limiting Site Imperviousness and Incorporating Post-Construction BMPs*: Most municipalities lacked ordinances or regulations to limit or reduce site imperviousness and instead rely on municipal planners or engineers.
- *Requirements for Drainage Design*: Drainage design is addressed by policies and regulations but stormwater treatment and limitations on peak flow and volumes are not included.
- *Natural Resource Protection or Restoration*: Policies, implementation and enforcement of buffers or establishing allowable uses within buffers or for vegetation maintenance vary widely. Recommendations for specific practices are required for many jurisdictions.
- *Promoting Regional or Watershed based Planning and Zoning:* Most agencies lacked policies that allowed preparation of a joint watershed or subwatershed based plan.

7.3. Other Policies or Practices

SAN MATEO COUNTY

In 2001, The County of San Mateo summarized their San Francisquito Creek Watershed Erosion Control and Prevention Plan (County 2001c). Harris *et al* (2001) reviewed most of the practices summarized in the plan. The County of San Mateo Department of Public Works (2001a) has prepared general policies and procedures and provides recommended best management practices (BMP) for their maintenance activities. General guidelines and standards are provided for bank stabilization, slide debris, berms, and large woody debris management or removal, both for emergency and non-emergency maintenance and repair.

San Mateo County Parks and Recreation has begun to assess sediment production from their roads and trails. Their initial assessment focused on Pescadero Creek Watershed (Pacific Watershed Associates 2003). They recognize that roads and trails in Huddart and Wunderlich parks in San Francisquito Creek Watershed are potential sediment sources and are attempting to secure funding for assessment and implementation of erosion control measures (County 2001b).

SCVURPPP Rural Public Works

SCVURPPP (2003a) and Santa Clara County have also prepared a Performance Standard for their Rural Public Works Maintenance and Support Activities document. The document provides policy statements, implementation procedures, and model BMP for removal of large woody debris, stream bank stabilization, road construction, maintenance and repairs for erosion control, as well as road planning and design. SCVURPPP also provides performance standards for planning procedures for control of pollutants related to development or redevelopment projects. The County also manages a grading ordinance that provides best management practices for erosion prevention and sediment control (SCVURPPP 2002).

SCVURPPP Hydromodification Management Program

As part of the NPDES permit requirements, GeoSyntec Consultants have developed a Hydromodification Management Program (HMP) for the SCVURPPP. The HMP is intended to manage runoff from new development and significant redevelopment to protect streams, as required under the NPDES permit. To date, a literature review has been completed, an assessment method developed (GeoSyntec 2002a & 2002b) and the program has been applied to the Lower Silver-Thompson Creek subwatershed (GeoSyntec 2003).

Application of the HMP requires continuous hydrologic simulation and detailed analysis of stream hydraulics, based on cross section surveys and geomorphic analysis. GeoSyntec (2003) provides details on methods.

SCVWD (Santa Clara Valley Water District)

The sediment management practices of the Santa Clara Valley Water District (SCVWD) are described in their Stream Maintenance Program and consist of sediment removal, vegetation management and bank protection. The Existing Conditions Memorandum provides further details, as does the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP 2002). The Stream Maintenance Program and Best Management Practices are designed to effectively implement their routine maintenance (SCVWD 2001; 2002).

The District currently removes sediment from San Francisquito Creek upstream of Highway 101 to maintain the bridge opening. This sediment removal is not thought to have any consequences for local or downstream stream erosion.

SCVWD participates in the annual inspections of San Francisquito Creek downstream of Los Trancos Creek and are responsible for vegetation and sediment management. They also identify concerns for bank protection works in their right-of-way and maintain a list for priority maintenance. Through their Ordinance 83-2 they are responsible for the fifty-foot riparian buffer, in collaboration with Palo Alto and Santa Clara County, and for review of construction and drainage plans to ensure flood conveyance and bank protection.

STANFORD UNIVERSITY

Stanford University has "Special Conditions for Stormwater Pollution Prevention (Revision 4)" that apply to construction projects. The special conditions that are available on their water resources website or through Facilities Operation. Their document provides policies and best management practices that are then incorporated in Storm Water Pollution Prevention Plans (SWPPP) for grading and construction. The contractor, Stanford, or the governing City or County inspects installed BMP daily or weekly, depending on weather.

Stanford has also developed a "Recommended Best Management Practices for Management of Animal Waste, Compost and Sediment on Creeks" that is implemented by their agricultural tenants. Their tenants maintain the private roads on Stanford lands following practices outlined in the Handbook for Forest and Ranch Roads (Weaver and Hagans 1994).

PALO ALTO OPEN SPACES

Palo Alto's Open Space Group manages their Baylands and Arastradero Preserves and Foothills Park. Old roads in Arastradero Park have been closed and revegetated; existing utility roads have been re-surfaced with soil cement to reduce surface erosion. Foothills Park primarily has dirt paths constructed for recreation and openings constructed for firebreaks. An annual program identifies maintenance concerns and rehabilitates or closes trails and roads that appear to be eroding (Greg Betts; personal communication). We have not reviewed any documents that describe their policies or practices.

MIDPENINSULA REGIONAL OPEN SPACE DISTRICT

The policies of the MROSD are described in their Resource Management Five-Year Strategic Plan (MROSD 2003). Their overall polices are to protect natural ecosystems and restore disturbed or degraded sites. Their specific practices as applied to roads and trails in their jurisdiction are not known.

GEOLOGICAL HAZARDS (PORTOLA VALLEY, WOODSIDE, SAN MATEO COUNTY)

In the mid-1970s, geologic maps and interpreted movement potential or hazards maps were prepared for the three jurisdictions that manage development on the eastern slopes of the Santa Cruz Mountains. Portola Valley and Woodside have incorporated these maps in their development policies and municipal codes. These maps are used as screening for assessing geological hazards and for identifying sites where site-specific geotechnical or geological investigations are required prior to development.

PORTOLA VALLEY CREEKSIDE CORRIDOR

As part of Portola Valley's initiatives related to erosion control on Corte Madera Creek, Cotton, Shires & Associates (2001) updated their 1984 inventory of bank erosion and bank protection structures through the town. Spangle Associates (2001) also recommended specific regulations for creek protection – these are presently under consideration by the Town Council. As a follow-up to these two studies, Portola Valley and the JPA have contracted for a "Bank Stabilization and Revegetation Recommendations Report" to guide future bank protection works.

SAN FRANCISQUITO CREEK JOINT POWERS AUTHORITY (JPA)

In 2000, the Cities of Menlo Park, Palo Alto, East Palo Alto, the Santa Clara Valley Water District, and the County of San Mateo co-sponsored the San Francisquito Creek Master Plan to provide guidance for future bank stabilization and revegetation projects (RHAA 2000). Subsequently, the Joint Powers Authority (JPA) was charged with management of San Francisquito Creek and the development of demonstration projects, based on the Master Plan. As part of this obligation, they conduct annual creek walks to inspect vegetation growth in the channel and bank erosion.

A contract that developed concept designs for future bank stabilization and revegetation projects at selected sites on San Francisquito Creek between Junipero Serra Boulevard and US Highway 101 (**nhc** *et al* 2003). The report describes the selection of demonstration sites, the development of design concepts and the permitting process for implementing the projects.

7.4. Stream Corridor Policies and Practices

RIPARIAN CORRIDORS

The riparian corridors that border streams throughout the watershed provide habitat for a number of special-status and common wildlife and plant species. The Existing Conditions Memorandum examined riparian corridors in detail, overlaying the WMI riparian corridors, defined as in the City of San Jose's Riparian Restoration Action Plan, with the ABAG 1995 land use data. This analysis showed that about half of riparian corridors are protected and support natural land uses, including wetlands, forest, range, and freshwater habitats. The other half of the riparian habitat is located in residential, urban recreation, agricultural, and urban land uses. For this reason, a number of studies and policies have been developed local government agencies to guide future planning and development near these sensitive areas, which are described below.

A CRMP process has been under way since 1993 for the entire San Francisquito watershed. This process includes over 30 organizations that are dedicated to preserving the natural resources, and in particular riparian corridors, throughout the watershed. The

CRMP Draft Management Plan and Reconnaissance Investigation Report identified alternatives for addressing flood and erosion issues throughout the watershed. This process is continuing as local fisheries, wildlife resources, and land uses are identified and studied throughout the watershed.

STREAM MAINTENANCE AND MANAGEMENT

The management and maintenance of the streams and local drainage systems within the San Francisquito watershed is the responsibility of several local agencies including the SCVWD, the San Mateo County Flood Management District, and the cities of Palo Alto, Menlo Park, and East Palo Alto. In 1999 these entities formed the San Francisquito Creek Joint Powers Authority (JPA) to coordinate flood protection, creek maintenance, habitat protection, and restoration activities along the creek and within the watershed.

The SCVWD is a special purpose governmental agency responsible for providing water supply and flood protection for Santa Clara County in an environmentally responsible manner. The District manages streams, canals, reservoirs, dams, pipelines, groundwater percolation facilities, and water treatment plants throughout the county. The District's jurisdiction on a stream begins at the point where 320 acres (1/2 square mile) of watershed drain to the stream, and continues downstream to San Francisco Bay.

The District routinely conducts maintenance activities (e.g., sediment and vegetation removal, bank protection) on streams and canals within its jurisdiction to meet flood protection and water supply mandates, provide access and flood protection, and protect property. Recently, the District developed the Stream Maintenance Program (SMP), which was approved by regulatory and resource agencies, to provide specific programs to effectively implement individual routine stream maintenance projects. The SMP specifies procedures for maintenance design, field operations and Best Management Practices (BMP), and includes a regional mitigation program to mitigate cumulative wetland and riparian impacts (SCVWD 2001; 2002).

Routine stream maintenance activities addressed in the SMP include:

- *Sediment Removal:* The District typically removes sediment in areas where sediment deposition has: 1) reduced flood conveyance capacity; 2) impeded function of facilities and/or structures (e.g., flap gates, culverts); or 3) impede fish passage and/or access to fish passage structures.
- *Vegetation Management:* The District typically removes vegetation in and adjacent to streams and canals to: 1) maintain flood conveyance capacity; 2) maintain water conveyance for supply purposes; 3) reduce fuel loads on adjacent banks to meet local fire code requirements; and 4) control invasive nonnative vegetation. Specific vegetation management activities conducted the District are based on site-specific environmental conditions, but generally include mowing, discing, hand clearing, or herbicide application.
- *Bank Protection:* Bank protection activities are typically conducted by the District to repair eroding stream banks or to implement preventative erosion protection. The District implements bank protection in areas where erosion

> and bank failure could: 1) cause significant property damage; 2) pose a public safety concern; 3) negatively affect transportation; 4) negatively affect beneficial use of surface water; or 5) negatively affects riparian habitat. Bank protection measures implemented by the District are based on site-specific conditions and range from the installation of "hard" structures (e.g., rock, concrete, sack concrete, gabion baskets) to the use of "soft" structures (e.g., brush mattresses, root wads, crib walls).

Within the San Francisquito watershed, stream maintenance activities routinely conducted by the District are limited to the main stem of San Francisquito Creek and primarily include vegetation removal and herbicide application.

NON-NATIVE SPECIES CONTROL

Because nonnative species dominate much of the watershed, particularly in the lower portion of the watershed, a number of plans and policies have been developed by local entities to control further invasion by these species. Invasive, nonnative plant species have come to dominate many of the riparian corridors throughout the watershed. These include blue gum eucalyptus, acacia, giant reed, fennel, periwinkle, English ivy, French broom, black locust, Algerian ivy and Cape ivy. In order to control these species, the CRMP process have produced the *Streamside Planting Guide for San Mateo and Santa Clara County Streams* (STOPPP undated) to guide local landowners with planting selection, highlighting the benefits of incorporating native species into local landscapes. In addition, the District routinely removes non-native vegetation, in conjunction with the SMP.

8. SEDIMENT REDUCTION PLAN

8.1. Background

The basic objectives of the sediment reduction plan are to identify the sediment sources or groups of sources that are to be managed to reduce sediment loads, recommend measures to manage erosion of these sources and estimate the sediment load reduction that can be achieved by these measures. The measures focus on sediment control or reduction, rather than treatment, and include measures applied during siting, design, construction and post-development phases and those measures applied to existing developments.

The sediment reduction plan only addresses human-related sediment sources. Also, we have considered the Searsville Lake subwatershed separately from the rest of the San Francisquito watershed. Sediment eroded in the Searsville Watershed is now mostly deposited in Searsville Lake and is only a small part of the overall budget for San Francisquito Creek. However, as Searsville Lake fills over the next few decades, erosion in this subwatershed will become a major component of the sediment supply to San Francisquito Creek and the sediment reduction measures proposed for Searsville Lake will become more significant to aquatic habitat in San Francisquito Creek.

8.2. Sources of Human-Related Erosion

SAN FRANCISQUITO (EXCLUDING SEARSVILLE LAKE)

Table 8.1 summarizes human-related erosion in the San Francisquito watershed (excluding Searsville Lake) based on the sediment budgets reported in Chapters 5 and 6. The broad ranges around the contributions from individual groups of sources indicate the considerable uncertainty in the estimated contribution of human activities to erosion.

Table 8.1 indicates that the greatest potential reductions in human-related erosion can be achieved in the San Francisquito Creek subwatershed. This subwatershed includes a large total human-related contribution from erosion from urban and rural development and from bank erosion along San Francisquito Creek, half of which is assumed to be human-related (see Section 6.4 for details). Potential sediment load reductions in Los Trancos and Bear subwatersheds are about half of that which might be achieved in San Francisquito subwatershed. While the greatest benefits to sediment reduction may be obtained by treatments in the San Francisquito subwatershed, the greatest benefits to habitat are likely achieved by concentrating first on erosion in the upper watershed because such an approach benefits aquatic habitat over the greatest length of stream and may also benefit the most significant or valuable habitat.

Table 8-1: Human-related Annual Erosion in the San Francisquito Watershed (excluding Searsville Lake)

Sediment Source	*Assumed Grain Sizes* [3]	*Annual Erosion (yd^3) by Subwatershed*			*Annual Erosion (yd^3) by Grain Size*	
		Los Trancos [1]	*Bear* [1]	*SF Creek* [2]	*Coarse Sediment (yd^3)* [3]	*Fine Sediment (yd^3)* [3]
Landslide Erosion						
- Hillslope Landslides	About ¾ coarse	600 to 1,000	0 [4]	0	600	200
Stream Erosion						
- Streamside landslides	About ¾ coarse	0	0	0	0	0
- Bank Erosion	About ½ coarse	20 to 60	230 to 690	0 to 1,500	650	650
- Incision	Nearly all coarse	Included above	Included above	120 to 160	140	0
Surface Erosion						
- Road Erosion	About ¾ fine	125 to 375	180 to 540	750 to 2,250	600	1,900
- Gully Erosion	About ¾ fine	30 to 210	30 to 210			
- Other	About ¾ fine	20 to 140	25 to 175			
Total Human-Related		***1,300 ± 500***	***1,000 ±700***	***2,400 ±1,500***	***2,000 ±1,000***	***2,700 ±1,400***
Total Erosion [5]		***3,600***	***6,100***	***3,100***	***7,500***	***5,500***
%Human-Related [6]		***40%***	***20%***	***80%***	***25%***	***50%***

1. Annual erosion from 1995 to 2000; see Table 5-6 for Los Trancos and 5-11 for Bear Subwatershed.
2. Annual erosion for 1964 to 1998; see Table 6-2 and explanation in Section 6.4.
3. Coarse sediment is sand and larger (>0.063 mm); fine sediment is silt and clay (<0.063 mm).
4. Long-term rate is assumed to be greater than zero.
5. See Table 5-5 for Los Trancos, Table 5-9 for Bear, and Table 6-2 for San Francisquito Creek.
6. Total human-related erosion divided by total erosion, expressed as a percentage and rounded to nearest 10%.

Table 8.1 also indicates that there is a greater potential to reduce contributions of fine sediments (silt and clay) than coarse sediments (sand, gravel and cobbles). As noted earlier, reduced fine sediment erosion mostly benefits water quality because these grain sizes are wash load that moves through San Francisquito Creek to San Francisco Bay, with little deposition in the streambed. On the other hand, reduced coarse sediment erosion, particularly of sand, benefits aquatic habitat by reducing sedimentation in pools and by reducing potential impacts on substrate quality.

Table 8.1 indicates that the greatest reductions of coarse sediment erosion can be achieved by addressing human-related landsliding in the upper Los Trancos Watershed, reducing bank erosion along San Francisquito Creek, incision on Bear Gulch and, to a lesser extent, bank erosion on Bear, Bear Gulch and West Union Creeks.

Reducing land surface erosion in tributaries to upper San Francisquito Creek, road erosion in upper Los Trancos and Bear, and gully erosion in Los Trancos and Bear subwatersheds are thought to provide the greatest reductions in fine sediment erosion.

SEARSVILLE LAKE SUBWATERSHED

Table 5.3 summarizes human-related erosion for the Searsville Lake subwatershed from 1995 to 2000. Human-related erosion is dominated by landslides originating at roads or from drainage diversion and by stream erosion, including bank erosion, incision and small streamside landslides resulting from human modifications from stream banks or from floodplain encroachments. Surface erosion from roads and trails contributes less than 10% of the total for 1995 to 2000. Over the longer term, landsliding is expected to still be the dominant process; however, road erosion is likely to be a much larger contributor to the total (Table 5-5). As noted in Section 5.2, the human-related erosion is only an estimate; further detailed studies would be required to confirm the quoted values.

The greatest potential reductions in coarse sediment would result from addressing human-related hillslope landsliding in upper Corte Madera Creek, followed by reducing bank erosion and channel incision along Corte Madera Creek; the greatest reductions in fine sediment would be achieved by rehabilitation or deactivation of unpaved roads and trails throughout the upper watershed.

8.3. Human-Related Erosion by Jurisdiction

Figure 15 shows the contribution of human-related erosion to streams by sub-subwatershed, either for the period from 1995 to 2000 or from 1964 to 1998 (San Francisquito subwatershed). Average erosion rates for the jurisdictions responsible for a significant area in the San Francisquito Watershed were estimated by overlaying boundaries onto the sub-subwatershed erosion map, assuming that the erosion rate in portions of a sub-subwatershed is the same as for the entire sub-subwatershed. Table 8-2 summarizes the results of the GIS analysis.

The estimates of human-related erosion in Table 8-2 required a number of assumptions that are described in earlier chapters and in the Watershed Sediment Analysis Memorandum. While there are considerable uncertainties in the erosion rates quoted above, the table does indicate that San Mateo County and the MROSD have had the greatest recent human-related erosion. Table 8-2 also indicates that relatively little sediment arrives from the urban areas in the lower watershed and that only small benefits can be achieved by sediment reduction practices there. Long-term erosion rates from the different jurisdictions are not known and the relative contributions from the jurisdictions may differ when considered over several decades, particularly because of the very active erosion in Corte Madera Creek that occurred during the 1997-98 El Nino storms.

Table 8-2: Recent Human-related Sediment Contributions by Jurisdiction

Jurisdiction	*Erosion to Streams (yd^3/acre per year)*	*Comment*
East Palo Alto	0.1	
Palo Alto	0.2	Includes Foothills and Arastradero Parks
Woodside	0.3	
Stanford	0.3	Includes Jasper Ridge
Menlo Park	0.4	Mostly San Francisquito Creek bank erosion
Portola Valley	0.6	
San Mateo County (Unincorporated)	1.0	Includes Huddart and Wunderlich Parks
MROSD	1.1	

8.4. Human Impacts on Erosion Processes

An earlier section of this chapter identified the sediment sources or groups of sources that dominate human-related erosion in the four major subwatersheds. These are summarized in Table 8-3 following.

Table 8-3: Human-Related Erosion in the San Francisquito Creek Subwatersheds

Subwatershed	***Dominant Processes***	***Less Significant Processes***
Searsville Lake	Development-related landslides	Road erosion and stream bank modification also important
Los Trancos	Development-related landslides	Component of road erosion and gully erosion
Bear	Bank erosion in developed areas; incision on Bear Gulch	Gully erosion; component of road erosion and landslides
San Francisquito Creek	Bank erosion and incision along SF Creek from sediment trapping and bank modification	Erosion of developed lands in the upper subwatershed

The following sections describe human impacts on the main erosion processes, where these processes occur or are most significant in the San Francisquito Watershed, and which jurisdictions may require management measures to control the contributions from different human-related sources.

SLOPE FAILURES OR LANDSLIDES

As discussed earlier, landslides in San Francisquito Creek are typically of two types – deep-seated landslides in bedrock and shallow debris slides and flows in surficial materials. Urban development and road construction on potentially unstable slopes can accelerate deep-seated landslides; road construction, drainage diversion, or clearing of vegetation or development on steep slopes may initiate debris slides and flows. While records are not complete, historic landslides associated with development have occurred in Woodside, Portola Valley, Ladera, subdivisions in upper Corte Madera Creek (Los Trancos Woods and Vista Verde), and along Alpine Road and Highway 84, roads in Los Trancos Woods, and along roads and trails in the upper Corte Madera and Los Trancos subwatersheds (Historic Conditions Memorandum). Observed human-related landslides from 1995 to 2000 were mostly in upper Corte Madera and Los Trancos watersheds and appeared to be caused by drainage diversion from roads and trails, often from private roads. Design and as-built drawings held by the County of San Mateo and Portola Valley indicate the extent of the failures on public lands and their contributions of sediment to streams.

Figure 17 shows the distribution of debris flow source areas by jurisdiction based on overlaying the jurisdictional boundaries onto the USGS map of source areas in San Francisquito Creek included as Figure 12 (Historic Conditions Report; **nhc** and JSA 2003a). Figure 18 shows the distribution of areas that are mostly landslide deposits, by jurisdiction, following a similar approach. Figure 17 shows that the debris flow hazard areas are concentrated in San Mateo County, Midpeninsula Regional Open Space District, Portola Valley, and Palo Alto (Foothills Park), although any jurisdictions that extend into the Santa Cruz Mountains typically have some debris flow source areas in steep portions of tributary watersheds. Large areas of landslide deposits, which are often associated with streamside landslides and sediment supply to streams (see Frey 2001), are mostly in San Mateo County, Portola Valley, MROSD and Woodside (Figure 18).

The above suggests that the greatest potential for impacts of new development on landslides lie in unincorporated San Mateo County, Portola Valley and Woodside. While there are large source areas in MROSD and San Mateo County Parks, little or no development is expected in these areas, eliminating the risk of human-related failure. An indication of the potential for landslides from existing development can be developed from the network of paved roads and unpaved roads and trails that lie in the jurisdictions with significant risk of debris flows or landslides. Table 8-4 summarizes the lengths of paved road and unpaved road and trail that cross steep slopes (greater than 35^{o}) and, as such, are thought to have the greatest potential to initiate landslides either by slope loading or by drainage diversion. The analysis is based on querying the San Francisquito Watershed GIS layers that include slopes, road networks, and the jurisdiction boundaries (see definitions and description in **nhc** and JSA 2003a).

Table 8-4: Length of Paved Road and Unpaved Road and Trail Crossing Steep Slopes

Jurisdiction	*Road and Trail on Steep Slopes (miles)*	
	Unpaved Roads and Trails	*Paved Roads*
San Mateo (Unincorporated)	1.97	0.91
Huddart Park	0.88	0.36
Wunderlich Park	3.65	0
MROSD	2.07	2.19
Portola Valley	1.65	1.20
Palo Alto (Foothills Park)	0.65	0.11
Woodside	0.74	2.49
Totals	*11.61*	*7.26*

Table 8-4 only expresses part of the landslide risk from existing development because it does not include structures other than roads. However, it does suggest that the unpaved roads and trails with the greatest risk of landsliding are concentrated in San Mateo County and the MROSD. Paved roads with landslide risk are in Woodside and MROSD, including Skyline Boulevard. The risk of initiating landslides may be concentrated along a total of about 19 miles of paved and unpaved road and trail.

STREAM EROSION

Stream erosion can be accelerated through at least five different human-related activities, as follows:

- Altering hydrology through creation of impervious area or other development modifications
- Modifying stream banks, particularly removing vegetation
- Encroaching onto floodplains or stream channels and altering local velocities and shear stresses
- Removing vegetation and woody debris from streams
- Trapping or removing coarse sediment.

Stream erosion, particularly bank erosion and channel incision, occurs throughout the San Francisquito Watershed. Particularly significant human-related incision, bank erosion or streamside landsliding has occurred in the upper Searsville Lake watershed along Corte Madera, along San Francisquito Creek and, to a lesser extent, in the Bear Creek subwatershed.

Hydromodification (Peak Flows)

Increased peak flows from urban development or roads appear to play only a minor role in stream erosion in the Searsville Lake, Bear and Los Trancos subwatersheds. Impervious area created by development appears to be too low to affect major streams in the Santa Cruz Mountains; however, some smaller watersheds may be affected. Westridge Creek in Portola Valley likely has increased peak flows from low-density residential development and Bull Run in Portola Valley and Martin Creek in Woodside may also be affected.

Urban development has almost assuredly increased peak flows in San Francisquito Creek. Detailed modeling would be required to evaluate the magnitude and significance of the altered flows to bank erosion and stream adjustments. Small tributaries to the upper part of San Francisquito Creek also have more frequent peak flows following development in the 1960s, as documented by Crippen and Waananen (1969), with subsequent stream adjustments. It is not known if adjustments still continue in these small streams or whether accelerated sediment yields have returned to pre-disturbance levels.

Hydromodification (Bank and Floodplain Disturbance)
The Existing Conditions Analysis Memorandum indicates that about half of the area of riparian corridors in San Francisquito Creek is affected by residential or other development, primarily concentrated along streams in the lower part of the watershed. Bank erosion along San Francisquito Creek is thought to be partly or largely human-related, as a result of the peak flow modification discussed above, clearing of riparian vegetation or other bank modifications, construction of houses on top of the stream banks, and the sediment trapping discussed in the next section. San Francisquito Creek appears to be the greatest source of human-related bank erosion in the watershed. Even greater contributions may have occurred in past years, before the construction of the extensive bank protection works now seen along much of the creek.

Floodplain encroachments along Alpine Road and development in Portola Valley contribute to incision, bank erosion, and streamside landslides along Corte Madera Creek. Bridges and culverts also contribute to bank erosion and cause local channel incision by trapping bed material; knickpoints migrate upstream through Portola Valley when aprons below these structures fail. Poorly designed bank protection structures result in erosion of nearby banks and also contribute to sediment loads when they fail (see Cotton, Shires & Associates 2001). Corte Madera Creek through Portola Valley seems to be the most important source of human-related bank erosion in the upper watershed, although erosion along Alpine Road is also important. Human-related stream erosion also appears to be significant in Martin and Bull Run Creeks.

Human-related erosion also occurs in Bear Creek and Los Trancos subwatershed, as a result of clearing of riparian vegetation, modification of stream banks, and development along stream banks or in the floodplain. Overall bank erosion rates in Bear Creek and Los Trancos subwatersheds are much less than in Corte Madera Creek, particularly in Woodside and along the San Andreas Fault Zone, apparently because of lower stream gradients and less supply of coarse sediment. Consequently the human-related contributions are much less from Bear and Los Trancos than from Corte Madera.

Channel Incision
Incision also occurs throughout the San Francisquito Watershed. As discussed in the following section, incision may result from reduced sediment supply. In other reaches, incision may be part of a process of long-term channel adjustment to both natural and

human-related changes in the watershed. The extent of incision is generally indicated by "knickpoints" along stream channels, which often become fixed at stream crossings or other instream structures by protective works such as concrete aprons. Failure or removal of the protective works ultimately allows incision to proceed upstream.

Smith and Harden (2001) describe knickpoints at some structures in the Bear watershed, which often create difficult fish passage. Knickpoints or recent incision have also been observed on Corte Madera Creek, Bear Creek at Olive Drive, Martin Creek near old La Honda Road and on Bull Run Creek during field investigations (Appendix A). Without surveys, it is difficult to determine when incision began, what caused the incision, and what the typical annual sediment contribution from bed lowering has been. However, annual sediment contributions may not be large and the material is usually cobbles, gravel and sand. The main concerns may be bank erosion from undercutting, fish passage and habitat modification, and deposition at downstream structures, rather than erosion and sediment contributions from incision.

Impaired fish passage created by incision is difficult to treat. If knickpoints are fixed at bridge structures, removal of the aprons or other protective structures may result in damage or failure of the bridge and lead to upstream channel incision and bank erosion – where it may damage private property – and downstream deposition that blocks culverts or other structures.

Sediment Trapping or Removal

Trapping of the coarse sediment load of Corte Madera Creek and other tributaries in the reservoir behind Searsville Dam is an important component of the incision, bank erosion and channel adjustments observed along San Francisquito Creek over the past century. The overall volumes contributed by incision are not large, but lowering of the streambed and steepening of stream banks is thought to be important in accelerating bank erosion rates. Lowering of the streambed of San Francisquito Creek has also resulted in a cycle of incision in the lower reaches of its major tributaries that is particularly obvious along lower Los Trancos Creek.

Bear Gulch is apparently affected by trapping and removal of coarse sediment at the California Water Service (CalWater) diversion weir (Smith and Harden 2001). The extent of downstream incision and bank erosion on Bear Creek has not been documented as it has been on San Francisquito Creek by surveys or other measurements. However, very rough estimates of incision rates suggest that this may be one of the most important sources of human-related erosion along streams in the Bear subwatershed.

SURFACE AND GULLY EROSION

Surface erosion primarily occurs where vegetation is removed and mineral soils are exposed. Human development causes surface erosion at the following sites:

- Construction or development sites
- Agricultural fields

- Roads and trails, including cut and fill slopes, ditches, and gravel-surfaced or native surfaces
- Human-related landslide scars or bank erosion sites
- Human-caused fire damaged sites

Construction or Development
In urban centers such as East Palo Alto, Menlo Park, and Palo Alto, residential areas provided increased sediment delivery during their construction years ago, but they are now mostly built out with stormwater carried to San Francisquito Creek by storm drains. Little sediment is now contributed to San Francisquito Creek or small tributaries other than some fine sediment and sand washed from gardens and roads into storm drains.

In these urban areas, clearing and grading for re-development projects are the greatest potential sources of surface erosion and delivery of sediment to streams. These sources are not thought to be very significant contributors to the human-related sediment yield because of their small area and because of erosion control practices applied to grading and construction.

Prior to development, natural levees along the creek and the shape of the alluvial fan restricted the contribution of sediment eroded from the fan surface to San Francisquito Creek (Helley *et al* 1979). Consequently, although small, the sediment delivery from the urban areas may be greater than that before development.

In rural areas, clearing and grading for new development also potentially provide short-term pulses of sediment that disappear when construction is finished and revegetation complete. Again, erosion control practices are thought to often reduce the significance of construction as a sediment source.

Agricultural Fields
Agricultural fields were not treated as a separate source in the Watershed Sediment Analysis Memorandum. The total area of agricultural land use was estimated to be 490 acres in 1995 (Existing Conditions Memorandum), nearly all on Stanford Lands in upper San Francisquito and Los Trancos subwatersheds. The breakdown into different types of agriculture, the actual use of this agricultural land, and its potential sediment contribution to streams is not known, but agriculture is expected to contribute fine sediment to San Francisquito Creek.

Roads and Trails
In rural areas, roads and trails are often the major source of surface erosion. Native or gravel-surfaced roads are usually the most significant contributors of sediment; their yields depend on road slope, road and drainage design, road maintenance practices and traffic volumes. Old roads that are incorporated into trail networks in the Santa Cruz Mountains may also be important sediment sources. The overview of the road network provided in the Watershed Sediment Analysis Memorandum indicates that unpaved road and trail erosion was ubiquitous throughout the Santa Cruz Mountains but was particularly significant in upper Corte Madera Creek (San Mateo County and MROSD),

Alambique Creek (Woodside and San Mateo Parks), Bear Gulch and some of the upper tributaries to West Union Creek in Huddart Park. The Assessment of Existing Management Practices Memorandum provides details on the distribution of unpaved roads and trails by jurisdiction. The jurisdictions with the greatest length of unpaved road and trail are San Mateo County (23.4 miles), Stanford University including Jasper Ridge (19.5 miles), MROSD (12.4 miles), Portola Valley (11.4 miles) and Woodside (10.1 miles).

It is fairly certain that the estimated erosion rates applied to the roads and trails exaggerate their actual contribution to streams. Field inspection of some trails shows that most are distant from streams, narrow, and well maintained and appear to contribute little sediment to streams; their narrow prism means that they contribute much less sediment per unit length than maintenance or utility roads (Appendix B; see also Pacific Watershed Associates 2003). In some parks, maintenance roads are either gravel-surfaced or treated with soil cement (Arastradero Park, Palo Alto) to reduce erosion.

However, specific problem sites remain. These include ditches and cut banks that erode when there are insufficient cross drains, stream crossings with inadequate culverts that block or fail during floods resulting in erosion of the road or trail prism, and severe erosion of the road surface. Such features have been observed in Martin Creek near Old La Honda Road and in Huddart County Park. There are relatively few stream crossings in the Santa Cruz Mountains (see Figure 8) but failures may still occasionally contribute significant quantities of sediment (Pacific Watershed Associates 2003).

Landslides and Fire Scars

Erosion of human-related landslide scars and bank erosion sites provides a small but consistent volume of sediment to streams each year. Vegetative treatments immediately after failure might reduce the yield from these sources. Fire scars are a very important potential source of surface erosion but none were identified in the land use analysis and they are not included as a separate source in the Watershed Sediment Analysis Memorandum.

Gully Erosion

Human-related gully erosion primarily occurs in existing swales or zero order channels rather than from rilling and gully development on previously unaffected slopes. Diversion of local drainage or surface flows from roads, re-development of rural lots with larger homes, or creation of impermeable areas seem to be the main causes of erosion. The erosion caused by incision and bank erosion in gullies or zero-order channels may well continue to provide sediment to streams long after direct impacts from development (clearing and grading) are recovered.

The number or length of gullies disturbed by flow diversion from roads or other developments is not well known and has not been mapped or identified in detail. However, field inspections showed such features in Woodside, Portola Valley and Los Trancos Woods and they may occur on moderately steep developed lands throughout the watershed.

8.5. Management Measures

The Environmental Protection Agency defines management measures as "economically achievable measures that reflect the best available technology for reducing pollutants". The EPA has developed measures to address a range of human activities, including urban development, agriculture, forestry and marinas. The most relevant measures for sediment management in San Francisquito Creek are those that address urban and hydromodification non point source erosion.

The State Water Resources Control Board (SWRCB) and California Coastal Commission (CCC) (2000) developed an urban management measures strategy that addresses source control throughout the development process, under the following general headings (those not relevant to this project are not included):

- Runoff from developing areas (watershed protection, site development and new development)
- Runoff from construction sites (site erosion and sediment control)
- Runoff from existing development
- Transportation Development (planning, siting, construction, operation and maintenance and runoff systems for roads, highways and bridges)

Hydromodification is also significant for erosion in the San Francisquito watershed and the EPA describes management measures under the following headings:

- Channelization and channel modification (manage planning and operation and maintenance to reduce impacts; stream and riparian habitat restoration in modified channels)
- Dams (erosion and sediment control during construction and improvements to operating procedures to reduce water quality impacts)
- Streambank erosion (stabilization of eroding banks, focusing on bioengineering and vegetative practices)

The following sections describe management measures for the major human-related sediment sources. We have also identified information needs to implement the measures, where data gaps have been identified. The section also briefly describes the benefit and potential effectiveness of the measures in addressing erosion in the Searsville Lake and San Francisquito (excluding Searsville Lake) subwatersheds and which jurisdictions would implement the measures.

Table 8-5, on the following pages, summarizes the discussion, identifying information gaps and data needs and the potential measures for management of sediment for both new and existing developments.

SLOPE FAILURES OR LANDSLIDES

Overview

In a broad sense, the least stable geologic formations and the greatest risk of accelerated landsliding from development lie in the Santa Cruz Mountains west of the San Andreas Fault Zone, although historic and recent slope failures have also occurred in the Bay Foothills just east of the fault zone. Typically, land use planning for new developments either avoids these landslide hazards by identifying and mapping potentially unstable areas or mitigates them through detailed geologic and geotechnical studies completed for individual developments.

Table 8-5: Summary of Recommendations for Sediment Management Measures

Issue	***Information Gaps and Data Needs***	***Potential Management Measures for***	
		New Development	***Existing Development***
Landslide Erosion			
Initiation of Landslides and Debris flows	- Centralized database of slope failures in the watershed - Updated maps of potential landslide hazards areas	New development in landslide susceptible areas is managed through site-specific geotechnical studies; updated hazard maps for east slopes of Santa Cruz Mountains may be beneficial	- Studies to identify potential landslide hazards along public and private roads and trails - Repair or decommissioning of sensitive sites - Treatment of chronic sources, such as Alpine Road
Emergency Planning for Major Storms/Fires	- No coordinated emergency planning to minimize sediment impacts	Not applicable	Not applicable
Stream Erosion			
Hydromodification	- Hydrologic models to assess cumulative impacts and manage new development - Standards for control of urban stormwater runoff	- Watershed-based coordinated planning for new development - Adopt policies and regulations for management of impervious area in most jurisdictions - Hydromodification Mgmt Plans (SCVURPPP 2003)	- Retrofit stormwater management (detention or retention storage) where cumulative impacts occur?
Bank Erosion	- Centralized database of bank erosion and bank structures - Field inventory of bank erosion and structures in Bear and Los Trancos Watersheds	- Adopt streamside buffer regulations - Review cumulative impacts of development on stream banks as part of permitting	- Adopt Bank Stabilization and Revegetation Programs - Review impacts of encroachments on stream erosion; consider floodplain mitigation - Develop methods to repair or prevent erosion at existing crossings

Issue	***Information Gaps and Data Needs***	***Potential Management Measures for***	
		New Development	***Existing Development***
Channel Incision	- Centralized database of "knickpoints" and incised reaches in the watershed	- Review plans for stream crossing to ensure they accommodate potential channel incision and avoid barriers	- Develop methods to repair or prevent erosion and incision at existing crossings - Develop programs to add large woody debris or structure to streams to slow incision or re-build the bed
Sediment Trapping or Removal	- Recommend surveys of Bear Gulch to document channel incision	- SCVWD removes sediment at Highway 101. Removals have no implications for erosion.	- Work with agencies to restore coarse sediment to Bear Gulch - Continued planning for Searsville Dam filling
Surface Erosion			
Roads and Trails	- Studies to identify priority erosion sites at crossings, ditches and road surfaces. - Prescriptions for repair or rehabilitation consistent with access and recreation	- Develop consistent standards for trails and private roads for the watershed - Develop best management practices for erosion control	- Repair existing erosion concerns on trails and unpaved roads - Repair erosion concerns on paved road prisms crossing the Santa Cruz Mountains
Grading and Construction	- None identified	- Well addressed by existing policies and regulations - Training in sediment management practices for municipal staff and developers	- Not applicable
Gully Erosion	- Extent of problem is not well known. Inventory and inspection to identify sediment contributions and causes	- Adopt policies and regulations for on-site management of stormwater for new developments	- Develop policies for gully rehabilitation or retrofit of stormwater management where gully erosion is significant

Information Gaps and Data Needs

The USGS inspects landslides and slope failures following major storms in the Bay area, focusing on those that damage property. San Mateo and Santa Clara Counties record failures along roads and on public property and often prepare engineering plans to restore landslide damage. Other failures that do not directly damage property are usually not inventoried or described.

At present, there is no organization that maintains a record or database of recent landslides and debris slides and flows in the San Francisquito Watershed, estimates the volumes of sediment delivered to streams, or identifies their causes. Such a database would be helpful in developing a detailed understanding of the factors that control slope failures, the effect of development on these failures, and in allocating funds for remedial work or erosion protection works.

The role of large storms in initiation of landslides in the Santa Cruz Mountains is reasonably well understood from studies by the USGS. The role of fire in slope stability in the Santa Cruz Mountains is not well understood but, based on studies elsewhere, is likely to greatly accelerate landsliding and sediment supply to streams. We did not find a plan or an organization that is responsible for coordinated emergency planning to address landslide erosion. Such planning might include removal of debris from streams, revegetation or treatment of landslide scars, diversion of flow from deep-seated landslides, or treatment of fire scars to reduce future erosion and sediment contributions to streams.

Management of New Development

The towns of Woodside and Portola Valley and the County of San Mateo base their development approvals on maps of geologic hazards prepared in the mid-1970s, policies and ordinances based on these maps, and site-specific geologic and geotechnical studies. San Mateo County is responsible for development in the most active sediment producing areas in the San Francisquito watershed in upper Corte Madera Creek (see Figure 15). The MROSD, Palo Alto (Foothills Park), San Mateo County Parks and Recreation, Peninsula Open Space Trust, CalWater, and Golden Gate National Recreational Area also manage areas that include landslide or debris flow hazards. These jurisdictions are parks or open spaces and new developments are not expected.

It may be advantageous to update the existing geologic and geologic hazard maps to a common standard for all jurisdictions along the eastern edge of the Santa Cruz Mountains. Such an approach is not likely to greatly alter development approvals, which are generally based on site-specific studies, but may be helpful in regional planning or in emergency response to major storms or fires.

Management of Existing Development

Reports and inspection of recent air photos suggests that existing roads and trails are the main cause of development-related landslides. These landslides appear to result from failure of cut and fill slopes and, potentially, from diversion and concentration of flow onto marginally stable slopes. Recent human-related landslides have been concentrated in a small area in upper Corte Madera and Los Trancos watersheds along the active and inactive sections of Alpine Road, on private roads and driveways, and along trails. Highways 84 and 35 (Skyline Boulevard) may also contribute to failures and drainage diversion. Reduction of sediment contributions from these sources requires the following steps:

- Studies to map potential landslide hazards along public and private roads and trails and identification of significant factors contributing to instability
- Design of road prism, road drainage or other improvements to address potentially unstable sections of roads. De-activation or re-routing may be required for some road and trail sections.
- Treatment of chronic landsliding sources, such as the Alpine Road failure in upper Corte Madera Creek.

San Mateo County, Portola Valley, MROSD, and Palo Alto are the main jurisdictions that would be required to organize, participate in, or sponsor such studies.

Sediment Reduction and Implementation
Landsliding is the dominant human-related source of coarse sediment to streams in the Searsville Watershed from 1995 to 2000 and, likely, over the long term. Hillslope landslides are also thought to be dominant in Los Trancos subwatershed from 1995 to 2000 and over the long-term and also important in Bear subwatersheds. It is our view that the greatest potential benefit to streams and aquatic habitat would be achieved by addressing potential human-related landslide erosion related to existing roads and trails in the upper watersheds of Los Trancos and Corte Madera Creeks and, to a lesser extent, in Bear Creek. The jurisdictions that require such a program are San Mateo County, MROSD, Portola Valley, Palo Alto (Foothills Park) and Woodside (Table 8-4) and it would be best coordinated with an overall assessment of road-related erosion and sediment issues in the San Francisquito watershed.

STREAM EROSION

Overview
Stream incision, bank erosion, and streamside landsliding occur throughout the San Francisquito watershed. These processes can be accelerated by urban developments that alter hydrology, by modifications of stream banks, by encroachments onto floodplains or into stream channels, by removal of vegetation and woody debris from streams, or trapping or removal of coarse sediment. Particularly significant human-related incision, bank erosion and streamside landsliding appear to occur along Corte Madera Creek, San Francisquito, and Bear Creeks.

Information Gaps or Data Needs
The extent that stream hydrographs have been or will be modified by urban development in San Francisquito Creek is an important part of managing new and existing development but it is not well understood. A continuous hydrologic model for San Francisquito watershed that uses rainfall and other meteorological records to track soil moisture and compute continuous flow hydrographs would allow assessment of

cumulative impacts and help plan and manage new development. The hydrologic model would incorporate watershed characteristics such as vegetation, soils and land use, as part of the simulation. By adjusting land use or other characteristics, pre-urban, existing and future or built-out conditions can be simulated.

Continuous modeling is particularly helpful if watershed-based planning is adopted. Watershed-based planning would consist of collaborative development planning by different agencies within subwatersheds, allowing implementation of appropriate stormwater treatment or flow control. The continuous hydrologic model would eventually be incorporated in a Hydromodification Management Plan (HMP) when such an approach is adopted for San Francisquito Creek.

Bank erosion inventories have been prepared for much of the Searsville Watershed and bank structure inventories have been prepared for part of Corte Madera and much of San Francisquito Creek (see Frey 2000; RHAA 2000; Cotton, Shires and Associates 2001). Engineering plans also document recent erosion protection work along Alpine Road and upper Corte Madera Creek. Bear and Los Trancos have not been examined in detail.

It would be valuable if an organization maintained a central database of stream erosion in the San Francisquito Creek watershed, similar to that discussed for landslides. An inventory of erosion and bank structures in Bear and Los Trancos watersheds would be required, with the highest priority for the Town of Woodside. Inventories in upper tributaries of Bear and Los Trancos Creeks would also be valuable, as they would indicate where the most significant sources of sediment are found. A detailed record of knickpoints, indicating reaches that have been incising, would be helpful in projecting future damage to structures and banks.

Management of New Development

The primary management measures for stream protection from new development are control or management of impervious areas, establishment of buffer zones, and control and management of bank stabilization works. Altered hydrology from urban impervious areas is not thought to be an important contributor to bank instability or stream incision on Bear, Corte Madera or Los Trancos Creeks now, but peak flows in San Francisquito Creek, Westridge Creek, Bull Run and Martin Creeks, and small tributaries in the Bay Foothills appear to have been altered by development.

The town of Woodside seems to be the only jurisdiction with regulations to manage impervious area (CRWQCB 2002); however, it is not known how these regulations are implemented or whether they implemented on a watershed basis. One issue is that many watersheds lie in more than one jurisdiction, making it difficult to manage cumulative hydrologic impacts. Regulations to manage hydromodification seem to be particularly important for Portola Valley and Woodside and for the urban areas that lie along San Francisquito Creek. Again, these regulations would be most effective if a watershed-based planning process is considered.

Few of the jurisdictions in San Francisquito Creek have regulations for streamside buffers although they are being considered in the town of Portola Valley (Spangle Associates 2001) and San Mateo County (CRWQCB 2002) but have not been adopted yet. These regulations are most beneficial where riparian corridors are not already built out.

All the major jurisdictions have a stream permitting process to control construction of bank stabilization work. As noted by Harris *et al* (2001) these permitting regulations generally do not consider cumulative impacts of development and works built during or immediately after flood emergencies often circumvent them (see also Cotton, Shires & Associates 2001). Best management practices for stream bank stabilization that incorporate restoration of riparian vegetation and habitat features would be beneficial if adopted by the various jurisdictions, particularly where riparian zones are substantially developed.

Management of Existing Development
The Bank Stabilization and Revegetation planning process that has been adopted by the Joint Powers Authority for San Francisquito Creek provide a proactive approach that identifies appropriate practices and develops feasible plans for stabilizing eroding banks and upgrading existing protection to incorporate environmental features. Portola Valley is developing a similar process and such an approach is also recommended for Woodside (West Union and Bear Creeks and tributaries) and San Mateo County (Upper Corte Madera Creek).

Floodplain and stream encroachments by roads and stream crossings may contribute to bank erosion and channel incision. Channel erosion along Corte Madera Creek is an important contributor to sediment production in the Searsville Lake watershed and it appears to be aggravated by encroachment of Alpine Road on the stream and its floodplain. Recent upgrades to Alpine Road by Portola Valley document the bank protection structures placed there (see Wilsey Ham 2000). Older engineering plans document past repairs and indicate the general areas of bank erosion and landsliding. Restoration of floodplain would reduce erosion, where this is practical.

Roads and Bridges
Undersized culverts or bridges and other instream structures contribute to channel adjustments. Trapping of bed material upstream of these structures and scour and bed adjustments downstream contribute to overall sediment loads and impair fish passage. Often, knickpoints in the streams are fixed at crossing structures by concrete aprons or other instream works. Failure of bridge protection aprons may initiate stream incision that undermines bank protection structures, leading to their failure and contribution of sediment to downstream reaches (Cotton, Shires & Associates 2001). Private as well as public structures contribute to this problem (see Smith and Harden 2001; Cotton, Shires & Associates 2001).

No jurisdictions seem to have policies or practices for treatment of existing culverts and bridges to restore fish passage while managing or preventing channel incision. While these treatments are likely to be complex and difficult to design and construct, such a program might be valuable for nearly all jurisdictions in the San Francisquito Watershed.

Most jurisdictions have a process for permitting stream crossing structures; these applications are also referred to other agencies for review. However, it is not clear if adequate standards for culverts and bridges have been adopted that address the potential for channel incision or other channel adjustments at these structures. Founding abutments on piles and avoiding instream piers seem to be key design practices for the San Francisquito Watershed (see Cotton, Shires & Associates 2001). There is a legacy of older, inadequate structures in the San Francisquito Creek watershed that require assessment and upgrading. Counties, towns and cities regularly replace old bridges and culverts and we recommend a review of their design and approval practices to ensure that they provide adequate stream protection.

Large Woody Debris
Similarly, most jurisdictions now have a process for permitting or managing vegetation and large woody debris removal from streams. Santa Clara and San Mateo Counties and their co-permittees have recently adopted best management practices (BMP) for debris removal (SCVURPPP 2003b; County of San Mateo 2001a). Past practices may have left many streams lacking in large woody debris and instream vegetation, reducing their ability to resist channel incision. Adding large woody debris may be a suitable restoration process in many streams that may help reduce channel incision during large floods and benefit fish habitat. Such programs need to consider local flood levels as part of their design.

Dams and Stream Impacts
Trapping of coarse sediment also affects stream incision and bank erosion. The most significant issue is the trapping of bed material from Corte Madera Creek in Searsville Lake. Planning associated with the filling of Searsville Lake and decommissioning of the Searsville Dam is underway by Stanford University and others.

Sediment removals from Bear Gulch at the California Water Service (CalWater) Diversion Dam (see Smith and Harden 2001) are thought to contribute to downstream channel incision on West Union and Bear Creeks; however, it is not clear what the actual practices are at this site. Such removals do not appear to be under the control of Woodside or San Mateo County; however, it would be beneficial if this sediment was placed downstream of the weir rather than removed from the stream. At least, a monitoring program for Bear Gulch is recommended.

Sediment Reduction and Implementation
The most immediate sediment load reduction would be achieved by addressing the legacy of existing, eroding banks and poor stream crossing structures. Thee greatest reduction in the Searsville Watershed would be from bank and bed stabilization and revegetation along Corte Madera Creek, within Portola Valley, further upstream along Alpine Road in San Mateo County, and in Martin (Woodside) and Bull Run (Portola Valley) Creeks. Stormwater (hydromodification) control may be required as part of the implementation of

stream erosion control in Martin and Bull Run Creeks. Policies that provide streamside buffers or stream protection will provide long-term benefits but little short-term reduction of human-related sediment loads.

In the San Francisquito Watershed (excluding Searsville), stabilization and revegetation of stream banks along San Francisquito Creek would provide the greatest reduction of coarse sediment loads. Treatments along San Francisquito Creek are the responsibility of the JPA, are likely to be expensive, and mostly benefit the lower reaches of San Francisquito Creek, which are often thought to provide the least valuable aquatic habitat (see **nhc** *et al* 2003).

Bank stabilization and treatment of streambed incision (possibly including adding coarse sediment to Bear Gulch) in Bear subwatershed reduces coarse sediment load less than treatments along San Francisquito Creek but may provide a much greater benefit to downstream aquatic habitat. Other practices, particularly measures to treat new development, are expected to reduce sediment loads to a lesser extent in the short term.

SURFACE EROSION (ROADS AND TRAILS)

Overview

Roads, particularly rural roads, are widespread sediment sources in the Searsville Lake subwatershed and in Los Trancos and Bear subwatersheds that may contribute as much as bank erosion, but mostly fine sediment instead of coarse (see Table 8-1). Erosion is chronic and, in dry years, may be the most important human-related source.

Erosion occurs on cut and fill slopes, in ditches and from unpaved road surfaces, either gravel-surfaced or native. Road crossings, particularly culverts on trails and native roads, are also potential sediment sources, if they fail. Culvert blockage, overflow of the road surface, and failure of the road prism can contribute occasional, large quantities of sediment during large storms (Pacific Watershed Associates 2003).

Information Gaps and Data Needs

The road and trail network is well represented in the GIS of San Francisquito Creek; however, sediment contributions have been estimated from average values applied to the network. Typically, road erosion is concentrated at relatively few sites. Field inspections indicated erosion problems in Huddart County Park, on the closed section of Alpine Road, and along sections of trails in Foothills Park and through the MROSD.

A detailed assessment and erosion control program seems to be required for all the unpaved roads and trails in the San Francisquito Watershed, such as has been started in the GGNRA (Alvarez *et al* 2002). While such a program could be undertaken by the individual jurisdictions it might be best if coordinated by a central authority in order to best assign priorities for the expenditures of funds. Such a program would include:

- Inventory of stream crossing of roads and trails, identifying existing erosion problems and the adequacy of crossing structures

- Inventory of areas of ditch and road surface erosion that contribute sediment to streams
- Development of prescriptions and costs for rehabilitation of stream crossings and eroding roads consistent with access requirements and recreation use.
- BMP (prescriptions) for road and trail erosion management

Some paved roads in the Santa Cruz Mountains, such as Kings Mountain Road and Highway 84, experience ditch erosion, cut slope slides, and "slip-outs (fill failures)" during major storms. It would be valuable to extend the inventory to include paved roads and develop potential prescriptions for reducing erosion, in cooperation with other responsible agencies such as CalTrans.

Management of New Development
SCVURPPP (2003b) provides standards for design, construction and maintenance of rural public roads, both paved and unpaved. These standards have been adopted by all the political jurisdictions in San Francisquito Creek and appear to be adequate to minimize sediment from construction and maintenance. However, erosion from native or gravel road surfaces will continue during use, unless the road surfaces are sealed or paved. A policy that minimized or eliminated native or gravel-surfaced roads would provide the best overall protection to streams.

Private roads and driveways and trails – including trails that occupy old roads – are not covered by these standards. These include trails and old roads in San Mateo County Parks (Huddart and Wunderlich), Palo Alto (Foothills Park and Arastradero Preserve) and in the Midpeninsula Regional Open Space District (Los Trancos, Coal Creek, Windy Hill, Thornewood and Teague Hill) and Stanford University (Jasper Ridge Preserve). Based on limited discussions and field inspections, construction and maintenance practices differ considerably from one jurisdiction to another and it would be beneficial to adopt uniform trail standards or best management practices that could be applied across the watershed.

Management of Existing Development
The steps in managing sediment contributions from existing trails and roads are described under "Information Gaps and Data Needs".

Sediment Reduction and Implementation
The most immediate sediment reduction benefit would be achieved by assessment and rehabilitation of existing unpaved roads and trails. Section 8.4 and the Assessment of Existing Management Measures Memorandum summarize the length of road in different jurisdictions; San Mateo County and Stanford University have the greatest overall length of unpaved road and trails. Adoption of trail standards and paving or sealing of roads are thought to provide the greatest benefit once the backlog of eroding road segments is treated.

SURFACE EROSION (GRADING AND CONSTRUCTION)

Overview and Information Gaps

Grading for new construction typically exposes mineral soil that may be eroded during storms. The actual quantities delivered to streams from this process are thought to be very small, primarily because of the policies and best management practices already adopted by the jurisdictions in San Francisquito Creek. We see no need for studies to better evaluate actual sediment contributions from this process.

Management of New Development

All the jurisdictions in San Francisquito Creek have policies and regulations that manage grading for new construction. Palo Alto also provides guidelines for suitable design techniques for water quality and stormwater management that might be adopted elsewhere. The primary issue or concern noted in previous reviews has been uneven enforcement and maintenance of erosion controls. SCVURPPP (2003a) recommends training programs for municipal engineers and inspectors and design engineers and contractors in sediment management practices.

Sediment Reduction and Implementation

Relatively minor reductions in sediment loads, primarily of fine sediments, are anticipated from increased enforcement and training programs. The most significant jurisdictions for implementation are those experiencing the greatest number of development or re-development applications.

GULLY EROSION

Overview

Human-related gully erosion primarily occurs from incision or bank erosion in existing swales or zero order channels rather than from rilling and gully development on previously unaffected lands. Diversion of local drainage or surface flows from roads, development of rural lots with large homes, and creation of impermeable areas seem to be the main sources of increased flows that cause erosion. The erosion caused by incision and bank erosion in gullies or zero-order channels often provides sediment to streams long after direct surface erosion from development (clearing and grading) has recovered.

Information Gaps and Data Needs

The overall number and length of gullies in San Francisquito Creek has only been very roughly estimated and the gullies disturbed by flow diversion from roads or other developments have neither been measured nor mapped. However, field inspections identified eroding gullies in Woodside, Portola Valley and Los Trancos Woods and they may be fairly widespread in the watershed. Further inventory and inspection is recommended to identify the potential extent and sediment contribution of human-related gully erosion.

Management of New Development

In Palo Alto, the provisions of their Grading and Erosion and Sediment Control require management of the quality and quantity of stormwater flows from new development or re-development sites. Zoning regulations that manage the total impervious area that can be developed on a lot also help control stormwater flows. Other rural jurisdictions such as Portola Valley, Woodside, and unincorporated San Mateo County do not seem to have similar policies or practices and we recommend that they be adopted in these jurisdictions.

Management of Existing Development

No jurisdictions seem to have policies for rehabilitating or restoring eroding gullies or zero order stream channels, although some repairs may be undertaken as part of public works maintenance. Various best management practices are available to reduce erosion in the gullies, ranging from in-gully bed and bank stabilization to retrofitting stormwater management BMP.

Sediment Reduction and Implementation

The overall contribution from gully erosion to the human-related sediment budget is not well known; however, it may be significant if as widespread as estimated in Chapter 5. BMP may be required to treat erosion at some sites, but the best overall treatment is to manage stormwater drainage from new and existing rural developments in Portola Valley, Woodside and San Mateo County.

8.6. Management Practices

Appendix D summarizes management practices suitable for implementing or addressing the measures described in the previous section. The practices are those that are typically suitable but different practices or combination of practices may be applied depending on local conditions, such as slope, geological materials or climate.

8.7. Monitoring Program

Further sediment data collection and sediment source analysis is an important part of the Sediment Reduction Plan, both to address existing data gaps and to confirm the benefits that might result from adopting the measures discussed in the Sediment Reduction Plan.

The program for sediment data collection would consist of maintaining the existing sediment gages on Los Trancos and Corte Madera Creeks, re-activating the sediment gage on San Francisquito Creek, and expanding the network to include Bear Creek. The gage on San Francisquito Creek is thought to be particularly important to document the existing regime and the changes that are expected to occur as Searsville Lake fills with sediment.

There are some significant gaps in our understanding of erosion that are important to implementing any sediment reduction plan The quantities of erosion from some human-related sources are not well known, particularly the human-related contribution from bank erosion. For instance, bank erosion rates along San Francisquito Creek are not well known, but may be the largest erosion source along the lower creek. Bank erosion rates, particularly the human-related component are also not well known along Bear Creek. Monitoring programs, consisting of inventory, surveys and other observations, would assist in selecting options or practices to manage this source, evaluating priorities for remediation and evaluating benefits. Sediment contributions from urban areas are not well known and monitoring of storm outfalls is recommended, both to better define sediment loads and the implementation of various measures to manage them. Section 8.5, above, identifies other data gaps and information needs.

9. RESULTS AND CONCLUSIONS

EROSION AND SEDIMENT TRANSPORT

The San Francisquito Creek watershed has an area of about 47 mi^2, most of which lies in the Santa Cruz Mountains southwest of Palo Alto. The San Andreas Fault Zone (SAFZ) is the most prominent feature in the San Francisquito Creek watershed, bisecting the watershed along a northwest-southeast direction. The steep, upper watershed lies southwest of the SAFZ in the northern Santa Cruz Mountains, whereas more gradually sloping areas lie to the northeast.

The main tributaries of San Francisquito Creek are Bear, Los Trancos and Corte Madera Creeks. Corte Madera Creek, plus smaller tributaries such as Alambique, Sausal, Martin and Westridge Creeks flow into Searsville Lake, a reservoir behind Searsville Dam. The reservoir has trapped nearly all the sediment transported by these streams since 1892; it is expected to fill over the next few decades, increasing the sediment transport from the Searsville Lake watersheds to San Francisquito Creek.

Separate sediment budgets were prepared for Searsville Lake, Bear and Los Trancos subwatersheds and for the San Francisquito Creek watershed, incorporating inflows from Bear and Los Trancos Creeks. Detailed budgets were prepared for 1995 to 2000, and were also extended over as long a time period as possible. The budgets separated coarse – sand, gravel, cobbles and boulders – and fine – silt and clay – sediments contributions and focused on identifying the human-related component of erosion.

Unusually high erosion and sediment transport appeared to occur in the Searsville Lake, Los Trancos and Bear subwatersheds from 1995 to 2000, particularly in Corte Madera Creek. During this period, about half of the sediment transported in the Searsville Watershed was eroded from two sub-subwatersheds in upper Corte Madera Creek; nearly all of the sediment carried to Searsville Lake came from Corte Madera Creek. Landslides that originated along the stream channel were the greatest contributors to the total erosion; landslides originating on upper and mid-valley slopes were next most important. Both stream bank erosion and surface erosion were relatively insignificant to the total erosion during this period. Human-related erosion accounted for about 16% of the total, primarily from human-related landslides and surface erosion along roads.

The relative importance of different sources changes during the long-term. Landslides from mid- and upper slopes appear to be the important contributor. Human activities, such as road construction or drainage diversion, can be important in initiating these landslides. Chronic sources, such as surface erosion and bank erosion, become significant during dry years. The main human contributions to surface erosion are erosion along paved and unpaved roads and drainage modification of gullies. Human impacts on long-term erosion are not as well known as for 1995 to 2000 but may amount to 20 to 50%, depending on the impact of human activities or development on landsliding. They likely lie near the lower end of this range.

The sediment budgets for Los Trancos and Bear subwatersheds for 1995 to 2000 and for the long-term are less certain than that for Corte Madera Creek. However, both short-term and long-term erosion rates in these subwatersheds are very much lower than from Searsville Lake watershed. Long-term erosion from Los Trancos and Bear Creek watersheds is only about one-quarter of that from Searsville Lake watershed, despite their much larger areas. The greater erosion in Searsville Lake subwatershed seems to result from a combination of erosive geologies (particularly the Santa Cruz formation), steep stream slopes, and plentiful historic deep-seated landslides, which accelerate colluvial transport (creep) to stream margins.

Los Trancos Creek shows little channel incision or bank erosion along the main channel and landslides in the upper subwatershed dominate the sediment budget. Development impacts on landsliding and surface erosion from roads seem to be the main human-related sediment sources. In Bear subwatershed, bank erosion and streamside landslides are the dominant processes from 1995 to 2000. Over the long-term landslides from slopes become an important erosion process. Few such landslides were observed between 1995 and 2000, possibly as a result of areal variations in rainfall intensity, but the longer-term inventory shows reasonably frequent shallow landslides in the watershed.

SAN FRANCISQUITO WATERSHED AND SEARSVILLE DAM

Sediment eroded in the Searsville Lake Watershed, other than some of the silt and clay carried over the dam, has been mostly deposited in the Searsville Reservoir for the past century. Over this period, the sediment transported by San Francisquito Creek has only been eroded from the Los Trancos, Bear and San Francisquito subwatersheds.

In San Francisquito subwatershed, erosion from human impacts dominates natural sources. The main sediment sources are bank erosion and, to a lesser extent, incision along San Francisquito Creek that is partly caused by trapping of sediment behind Searsville Dam and increased peak flows from development. Land and stream erosion from agriculture and development in the upper part of the subwatershed may also be important. Unfortunately, neither rates of bank erosion along San Francisquito Creek or rates of erosion in small tributaries are accurately known.

Prior to construction of Searsville Dam, the long-term average coarse sediment transport through San Francisquito Creek was likely three times greater than it is now, based on constructing a sediment budget that includes contributions from Searsville Lake subwatershed; fine sediment transport was likely twice as great. It is our view that this reduction of coarse sediment transport has contributed to the historic changes observed along San Francisquito Creek. Slope adjustments in response to the lowered sediment transport are thought to be an important cause of the incision that has occurred along the upper part and the deposition along the lower part of San Francisquito Creek. Other impacts on channel morphology include coarsening of the streambed from winnowing and armoring during incision.

HUMAN IMPACTS ON EROSION

Urban development, including clearing of land, impervious areas, and roads is now thought to be the most important human activity affecting erosion in the San Francisquito Watershed. Other land uses, such as intensive forest harvesting, agriculture and grazing may have been very significant in the past and may still be locally important. Vegetation removal and soil disturbance directly affect rates of shallow landsliding and surface erosion. Roads and trails are particularly significant, as they may cause shallow or deep-seated landslides through failure of the road prism, cause downslope instability by re-distributing surface and groundwater flows, and their unpaved or gravel road surfaces, cutslopes and ditches erode.

Changes to stream hydrographs that result from creation of impervious area are also important to erosion and sediment transport. Typically more frequent small to moderate peak flows increase sediment transport and stresses on banks, often leading to channel incision, bank erosion, and widening. In addition to stream erosion that results from altered hydrology, there may also be erosion that results from direct impacts on streams. These include removal of riparian vegetation, bank protection or instream structures, bridges and culverts, gravel removal or other activities in the stream environment zone. Long encroachments in the channel or floodplain by roads, levees or other features can concentrate flows in the main channel, resulting in channel incision and bank erosion.

Estimated total impervious area in the San Francisquito watershed, derived from land use, suggests that the frequency and duration of peak flows in San Francisquito Creek have been significantly modified but that the hydrographs in the large tributaries in the upper watershed are relatively unaffected. Low-density residential development and roads may modify peak flows in some sub-subwatersheds, particularly Westridge Creek and possibly Dennis Martin and Bull Run Creeks. Development does not seem to have altered stream hydrographs in tributaries to Los Trancos or Bear subwatersheds.

In the watershed contributing to San Francisquito Watershed, the greatest human-related erosion is from San Francisquito subwatershed; erosion in Los Trancos and Bear subwatersheds are about half of that in San Francisquito. While the greatest benefits to sediment reduction may be obtained by treatments in the San Francisquito subwatershed, the greatest benefits to habitat are likely achieved by concentrating first on erosion in the upper watershed because such an approach benefits aquatic habitat over the greatest length of stream and may also benefit the most significant or valuable habitat.

The greatest reductions of coarse sediment transport can be achieved by managing human-related landsliding in the upper Los Trancos Watershed, bank erosion along San Francisquito Creek, channel incision on Bear Gulch and, to a lesser extent, bank erosion on Bear, Bear Gulch and West Union Creeks. The greatest reductions in fine sediment transport would be from managing land surface erosion in tributaries to upper San Francisquito Creek, road erosion in upper Los Trancos and Bear, and gully erosion in Los Trancos and Bear subwatersheds.

In Searsville Lake subwatershed, the greatest reductions in coarse sediment would result from managing human-related hillslope landsliding in upper Corte Madera Creek, followed by bank erosion and channel incision along Corte Madera Creek; the greatest reductions in fine sediment transport would be from rehabilitation or deactivation of unpaved roads and trails throughout the upper watershed.

EXISTING SEDIMENT MANAGEMENT POLICIES

San Francisquito Watershed lies partly in Santa Clara but mostly in San Mateo County. East Palo Alto, Palo Alto, Menlo Park, Woodside and Portola Valley also have jurisdiction over land development. Much of the upper watershed lies in the Midpeninsula Regional Open Space District, San Mateo County Parks, Palo Alto Open Spaces or other preserves, parks or recreation areas. Stanford University is the largest private landowner in the watershed.

The Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and San Mateo Countywide Stormwater Pollution Prevention Program (SM-STOPPP) administer the National Pollution Discharge Elimination System (NPDES) permits for the two counties. Both organizations are very involved in reviewing existing water quality management policies and regulations in the watershed and active in developing and promoting policies, regulations and best management practices.

Most of the existing policies and regulations and the recommendations for improvements focus on managing new private and public development, particularly on grading and erosion and sediment control for construction. Most jurisdictions have effective policies in place to address construction; the main issues now are training of municipal engineers, developers and contractors and enforcement. Fewer jurisdictions have policies that address watershed based planning, management of impervious area, or creek setback ordinances or buffers.

New development in San Francisquito Creek is limited by the lack of available land. While polices and regulations to manage new development are important to control sediment contributions to streams, over the next few decades existing development is expected to be the more significant contributor to erosion. Few jurisdictions have policies or regulations that address rehabilitation or restoration to reduce sediment impacts of existing development.

MANAGEMENT MEASURES

Our management measures focused on urban development and hydromodification, as these seemed to be the main human-related sources of non point source erosion. Management measures are proposed for the three main groups of sources – landslides, streams and surface processes, both for new and for existing development. Monitoring, both continued sediment data collection and further sediment source analysis, is important to confirm the benefits from the measures and to complete our understanding of erosion. The quantities of erosion from some human-related sources are not well known and improving our understanding may be important to implementing any sediment reduction plans.

One important issue that arose from the review was a need for an overall planning or coordinating agency for sediment management in the San Francisquito Watershed. Such an agency would coordinate the different jurisdictions and help develop common standards. The agency would develop watershed-wide databases of landslides, and stream, road, and gully erosion and organize field inspections to complete databases, as part of developing priorities for rehabilitation or restoration. It would also develop and coordinate emergency planning for sediment management following storms or fires, and coordinate watershed-based planning and assessment studies for development.

The areas with significant risks of deep-seated landslides and debris flows are San Mateo County, MROSD, Portola Valley, Woodside and Palo Alto (Foothills Park). San Mateo County, Portola Valley and Woodside base development approvals on hazard maps, policies and ordinances, and site-specific geologic and geotechnical studies. Updating of hazard maps throughout the Santa Cruz Mountains might be helpful to regional planning but would not likely alter development approvals.

Recent human-related landslides appear to be mostly shallow slides and flows that originate from drainage diversion at roads and trails or on cutslopes on roads and trails crossing steep terrain. Mapping of potential hazards, identification of factors contributing to instability, and design of improvements to address unstable sections or de-activation or re-routing of road, driveway or trail sections are the necessary steps to manage existing development. There are about 19 miles of roads and trails crossing steep terrain that might potentially cause slope failures. Treatment of chronic sources, such as the Alpine Road failure, would also significantly reduce sediment contributions to streams. San Mateo County, MPRSOD, Portola Valley, and Palo Alto would be the main jurisdictions contributing to such rehabilitation works.

The extent that stream hydrographs have been modified by urban development is an important part of managing new development but it is not well understood. Certainly, a continuous hydrologic model would be required to assess cumulative impacts from existing development and impacts from new development and implement watershed-based planning. The hydrologic model would be an important component of a Hydromodification Management Plan, when such an approach is adopted for the watershed. Management of new development would require policies and regulations regarding stormwater management. Streamside buffers or setbacks are also required to manage sediment impacts of urban development.

Bank erosion and channel incision are also affected by human modifications of stream banks, stream crossing structures and encroachments on floodplains and streams. Adoption of streamside buffer regulations would benefit bank erosion where riparian areas are not developed; however, many riparian areas are already developed and the buffers will provide limited benefit there. Instead, bank stabilization and revegetation programs that provide standards to reduce erosion and restore habitat features seem to be the most beneficial to reducing erosion. Such programs also will help reduce the number of poorly designed and constructed emergency bank protection works that result in erosion opposite or downstream or ultimately fail.

Bank stabilization and revegetation programs are underway on San Francisquito Creek and Corte Madera Creek through Portola Valley. These are two of the significant human-related bank erosion sites and addressing erosion would provide an immediate reduction of human-related erosion. However, construction of the bank stabilization works will be expensive. Such programs should be extended next to upper Corte Madera Creek, through San Mateo County, and Bear and West Union Creeks through Woodside.

Bridges, culverts and stream crossings are also important contributors to human-related stream erosion. Careful review of proposed crossing designs to ensure that they can accommodate channel incision or other adjustments is a priority, structures with abutments founded on piles and no instream piers seem to be required. We found no policies or programs to address existing barriers. The problem is complex as removal of aprons or other structures may result in failure of the structure and upstream incision, bank erosion and property damage, however it is a component of stream erosion.

Unpaved roads and trails are the major source of chronic surface erosion in the upper watershed and they also contribute to initiation of landslides in susceptible areas. Adequate standards are now available for the design, construction and maintenance of rural roads. However, erosion of the running surface will continue during use, unless the road is paved or sealed. A policy to minimize or eliminate native or gravel surfaced roads would provide the best overall protection to streams. Development of common standards for trail construction and erosion control best management practices is also recommended.

A coordinated study of existing roads and trails in the Santa Cruz Mountains is required to address existing development. Such a program would identify erosion areas, priorize and rehabilitate them within San Mateo County, MROSD, Portola Valley, Woodside and other preserves in the Santa Cruz Mountains.

Human-related gully erosion also contributes sediment to streams. While not well documented, this erosion appears to result from stormwater from roads and developments that is diverted into swales, gullies, or zero-order streams. Adoption of policies and regulations for on-site stormwater management is recommended for all rural jurisdictions, particularly San Mateo County, Woodside and Portola Valley. Gully rehabilitation or retrofit of stormwater management practices may be required for a few of the most significant erosion sites.

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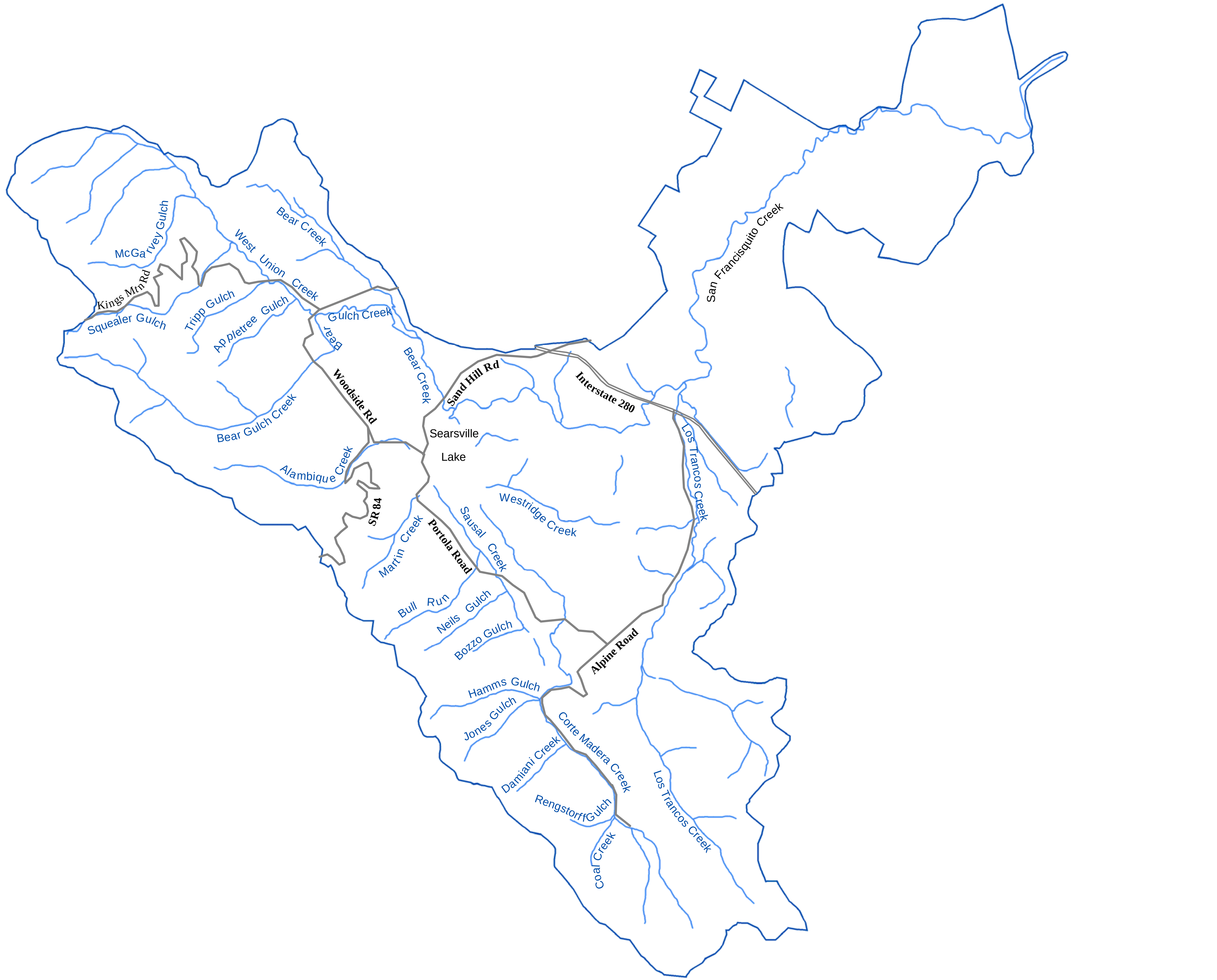
Figure 1 San Francisquito Creek Watershed Study Area



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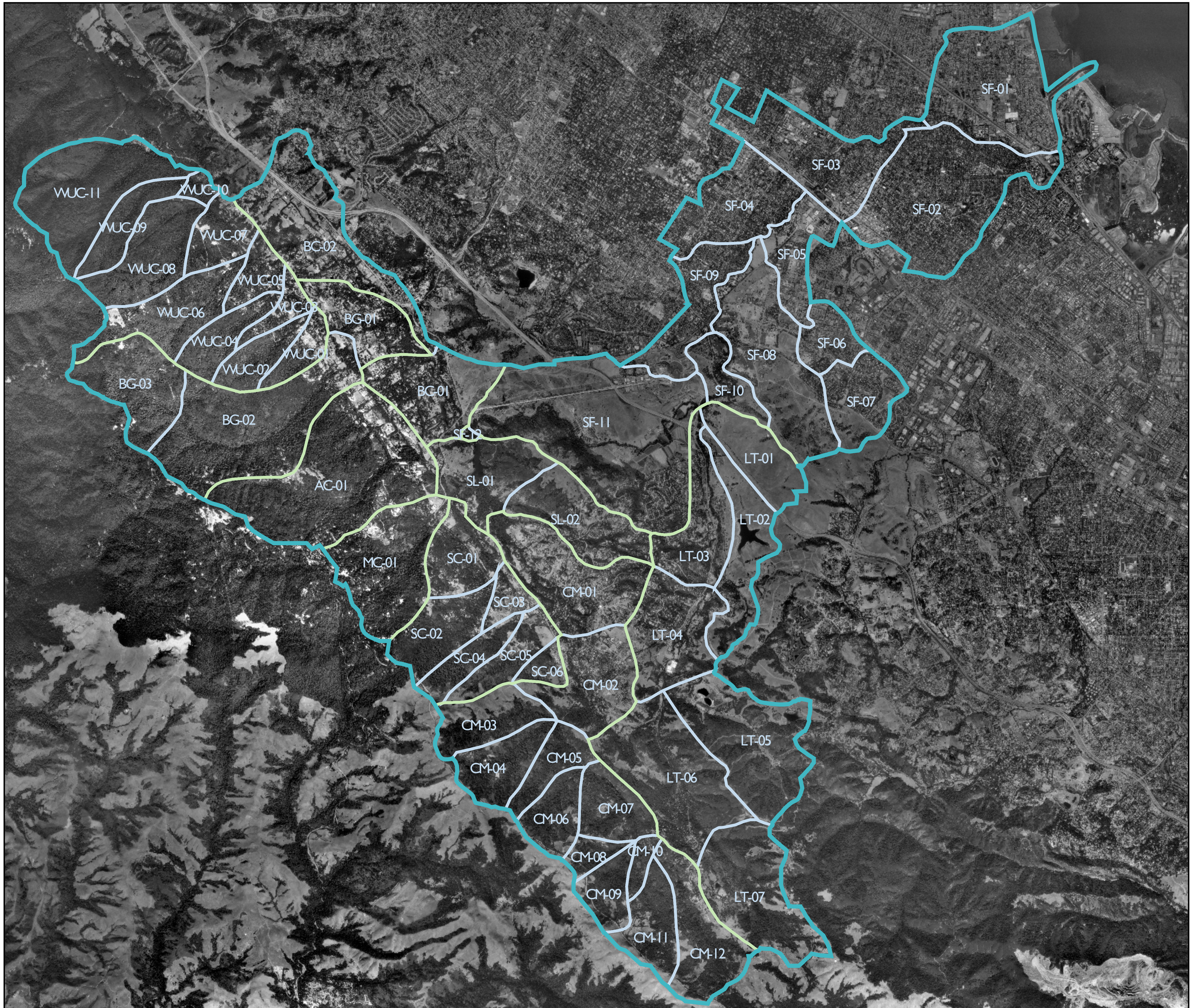

Legend

Sub-sub-watershed boundary

Sub-watershed boundary

Watershed boundary

Source: USGS 1993 Palo Alto, CA DOQ.

N

3000 0 3000 6000 9000 12000 Feet

Scale: 1 inch = 6000'

Figure 2
Watershed and Sub-Watershed Boundaries
San Francisquito Creek Basin

San Francisquito Creek Watershed Analysis and Sediment Reduction Plan

San Francisquito Creek Joint Powers Authority

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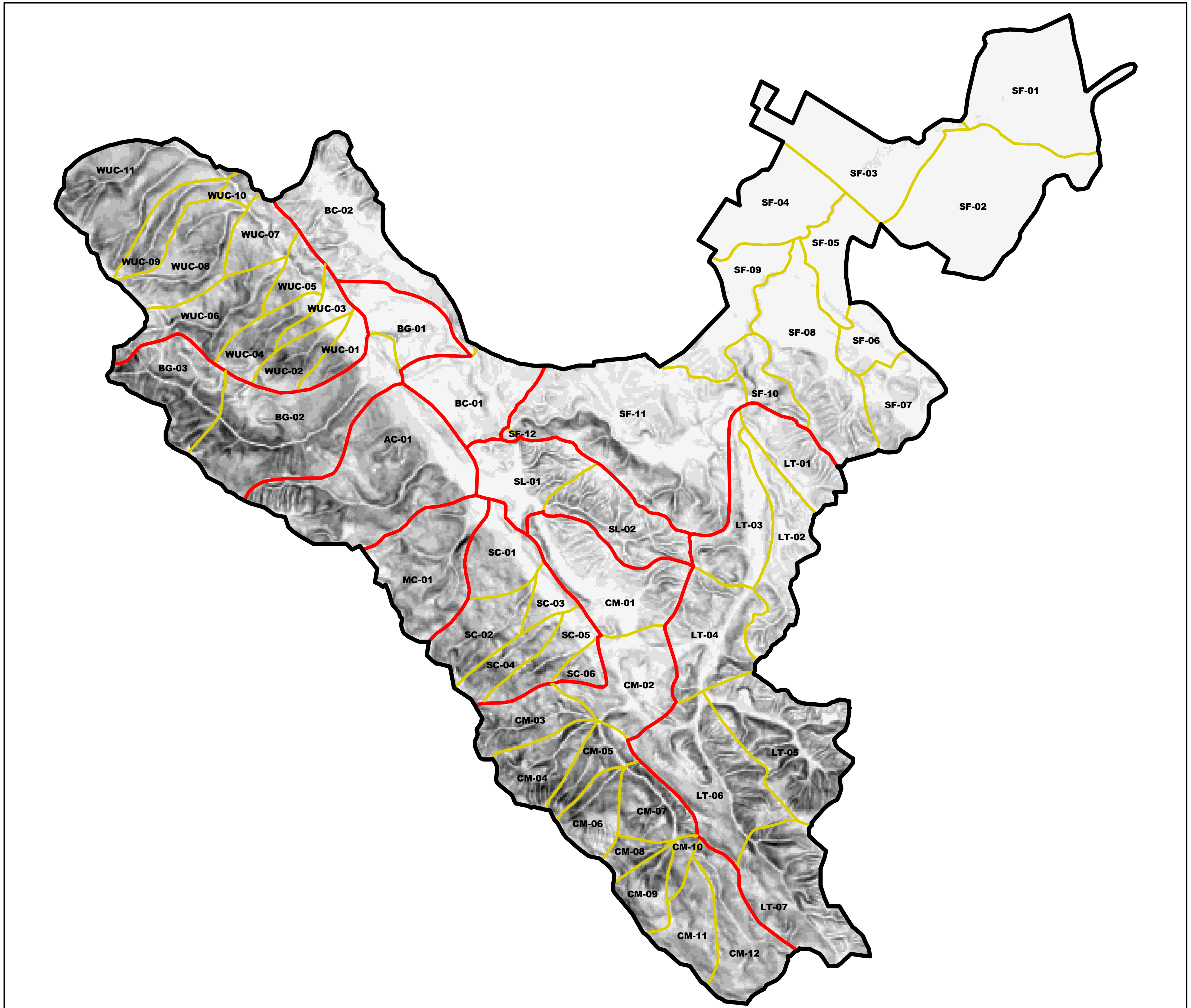

Legend

Percent Slope

0%

50%

100%

CM-03 Sub-sub-watershed label

Sub-sub-watershed boundary

Sub-watershed boundary

Watershed boundary

Source: USGS OF 98-766.

N

3000 0 3000 6000 9000 12000 Feet

Scale: 1 inch = 6000'

Figure 3
Slope
San Francisquito Creek Basin

San Francisquito Creek Watershed Analysis and Sediment Reduction Plan

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Figure 4 San Francisquito Creek Geology Map

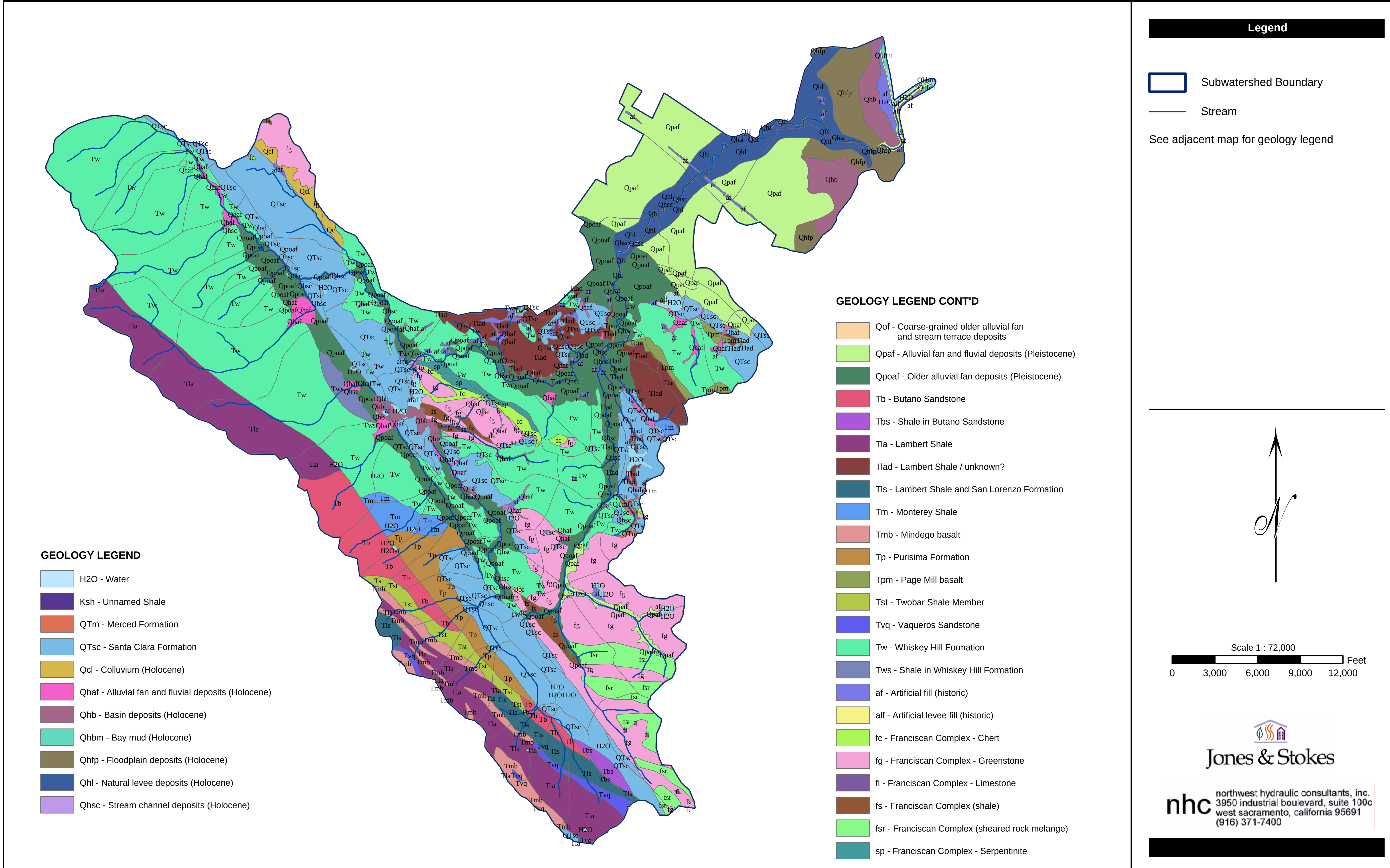

Figure 5 Channel Types using the Montgomery - Buffington Classification - San Francisquito Creek Watershed

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Figure 6 San Francisquito Watershed Jurisdiction Map

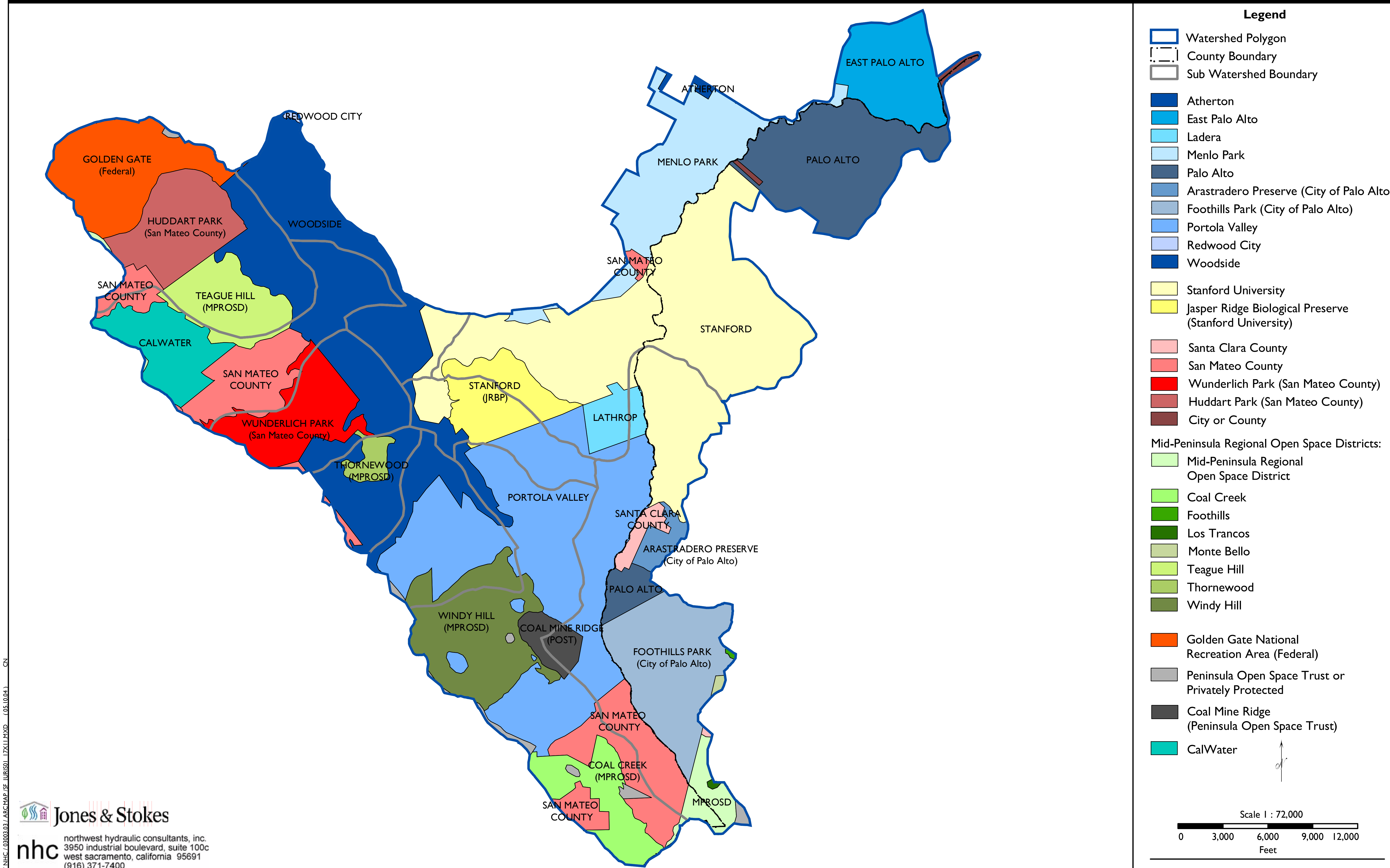

Figure 7 Steelhead Passage Barriers within the San Francisquito Creek Watershed

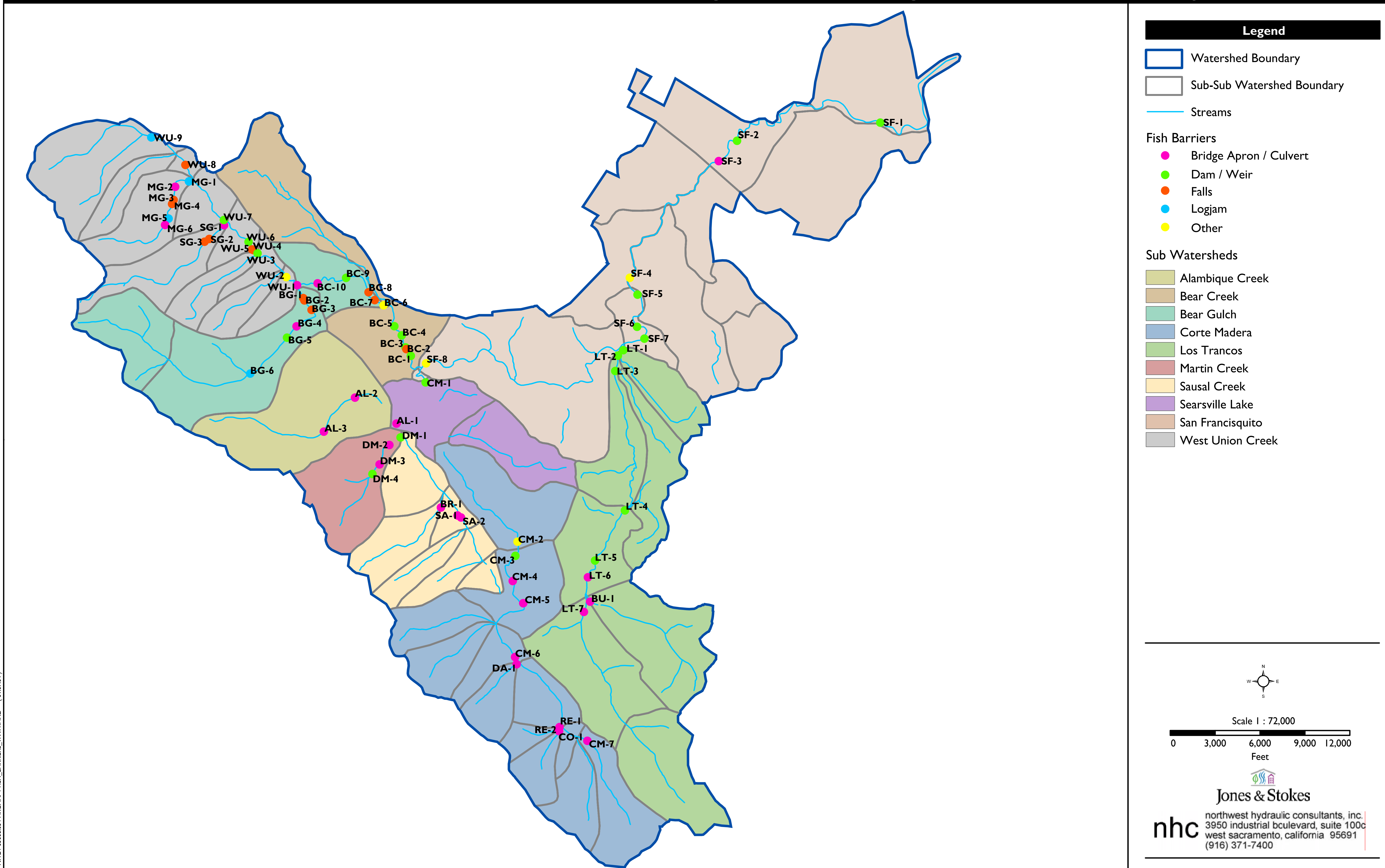

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Figure 8 Road and Stream Intersections - San Francisquito Creek Watershed

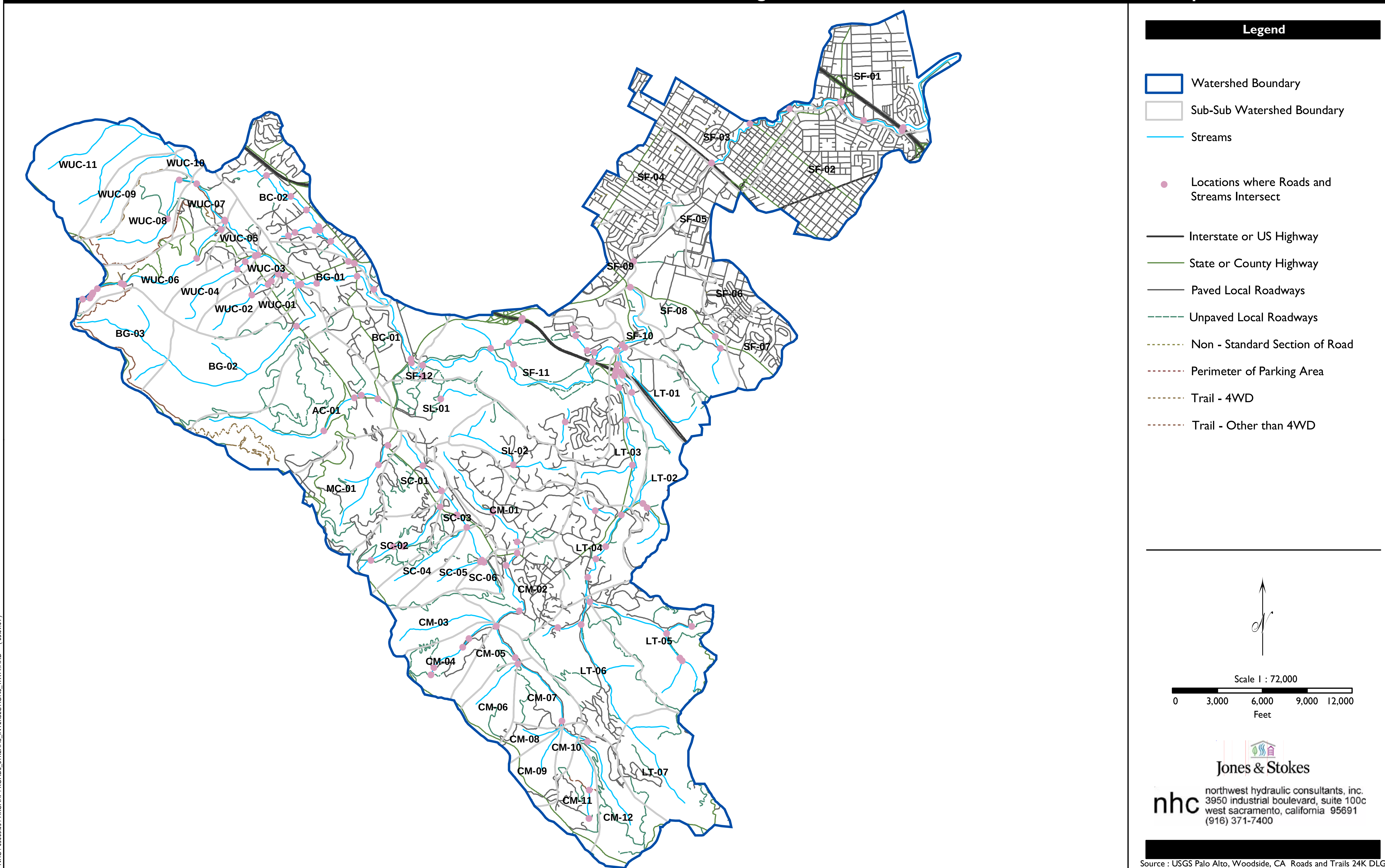

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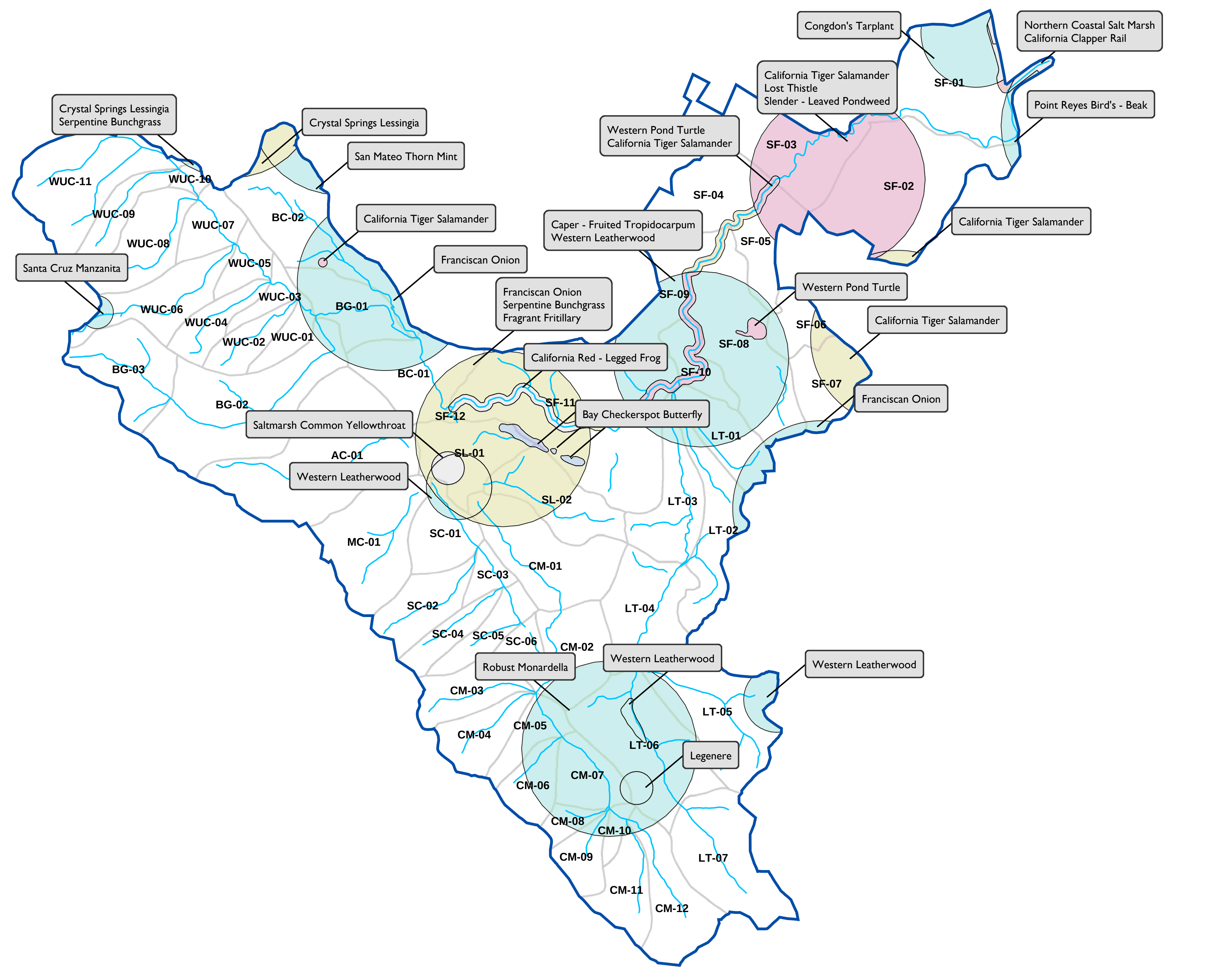
Figure 9 California Natural Diversity Database - San Francisquito Creek Watershed



Legend

- Watershed Boundary
- Sub-Sub Watershed Boundary
- Streams
- Animal
- Vascular Plant
- Animal - Community
- Vascular Plant - Community
- Animal - Plant
- Invertebrate - Plant - Community
- Animal - Plant - Community

Scale 1 : 72,000

0 3,000 6,000 9,000 12,000
Feet

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Source : CNDDB

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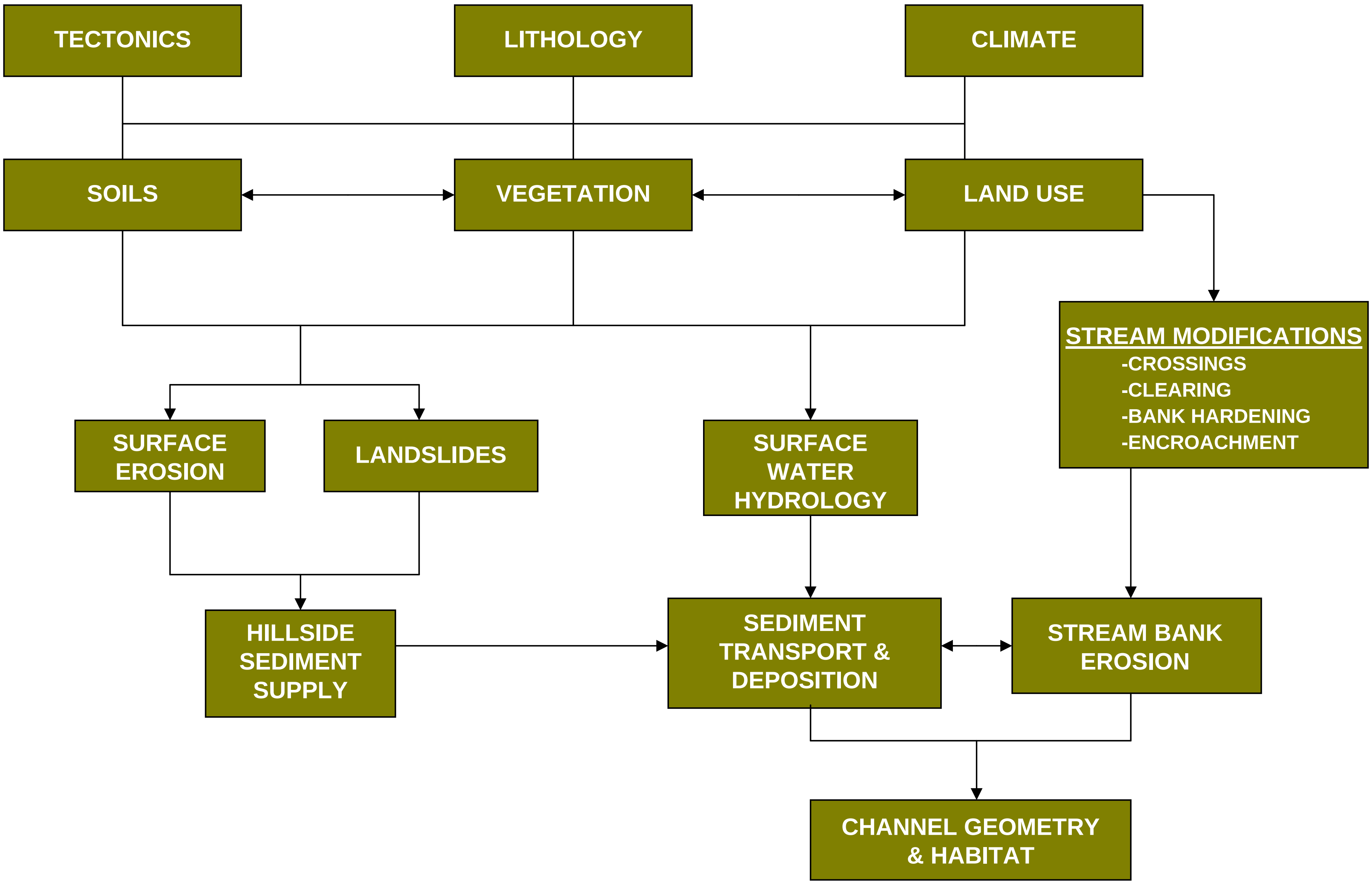

FIGURE 10. Conceptual Model of Erosion in San Francisquito Creek

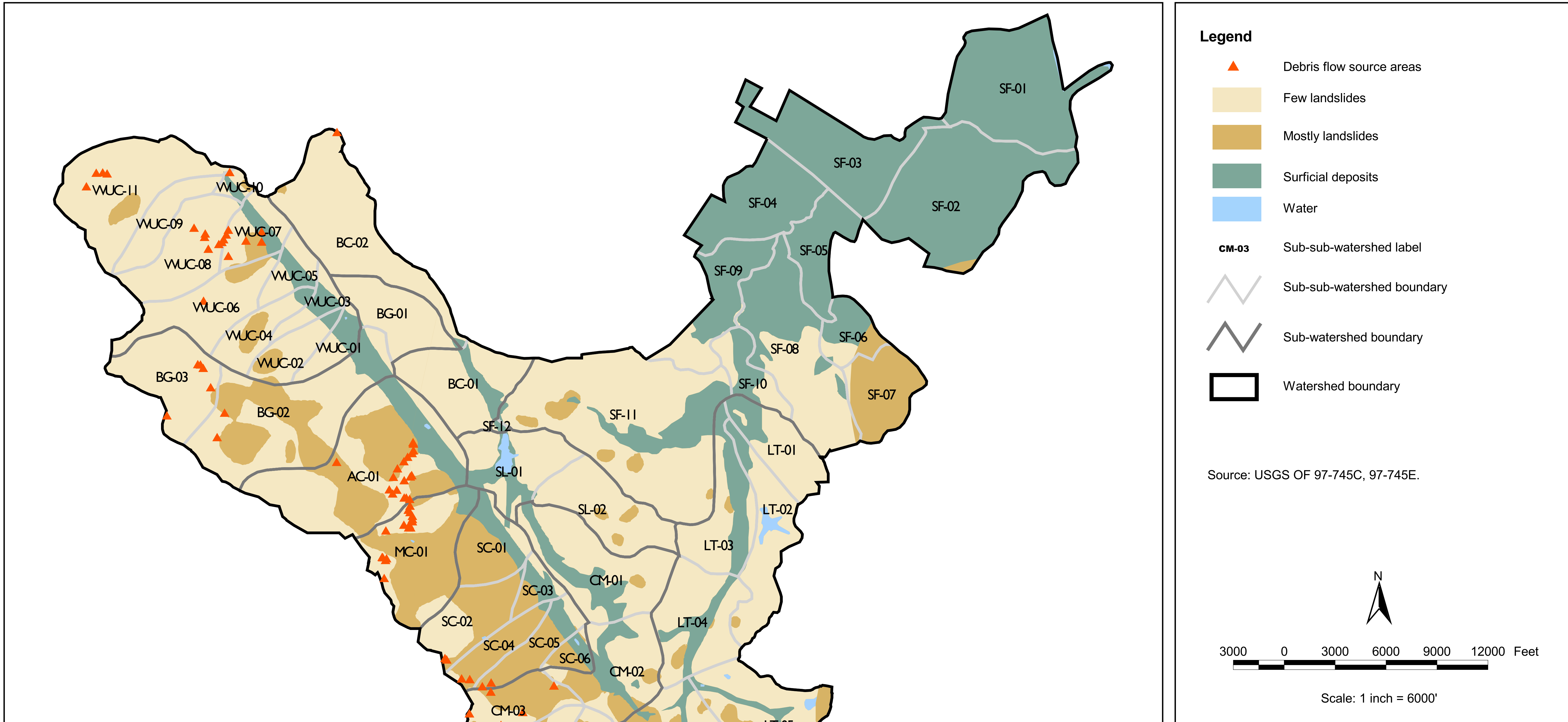

Figure 11
San Francisquito Watershed
Historic Landslide Areas

San Francisquito Creek Watershed Analysis and Sediment Reduction Plan

San Francisquito Creek Joint Powers Authority

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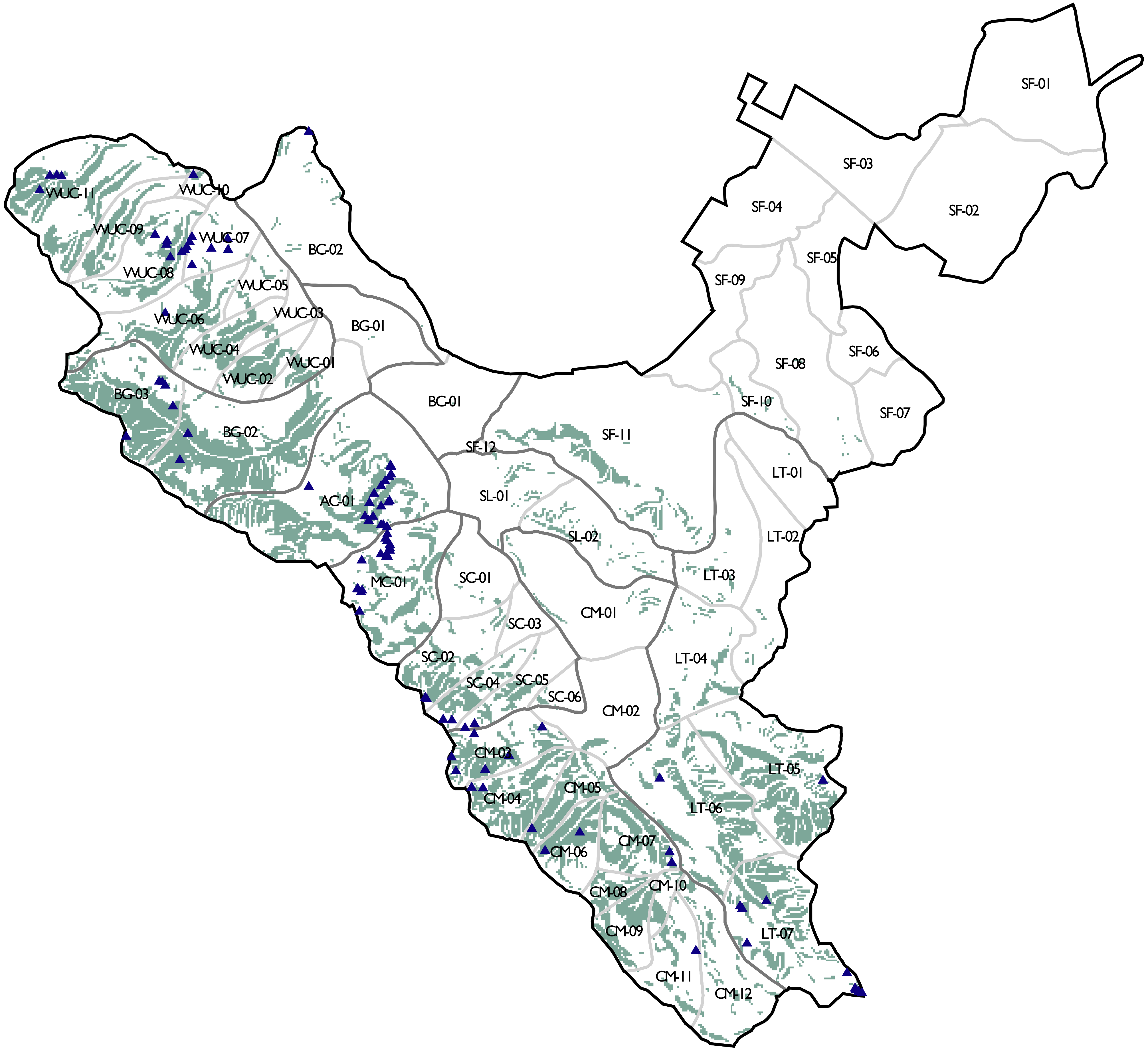

Legend

- ▲ Approximate sources of debris-flows triggered during the storm of January 1982
- Principal predicted debris-flow source areas
- **CM-03** Sub-sub-watershed label
- Sub-sub-watershed boundary
- Sub-watershed boundary
- Watershed boundary

Source: USGS OF 97-745E.

N

3000 0 3000 6000 9000 12000 Feet

Scale: 1 inch = 6000'

Figure 12
Debris-Flows
San Francisquito Creek Basin

San Francisquito Creek Watershed Analysis and Sediment Reduction Plan

San Francisquito Creek Joint Powers Authority

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Figure 14 Average Erosion Rate in Cubic Yards / Acre per year in the San Francisquito Watershed

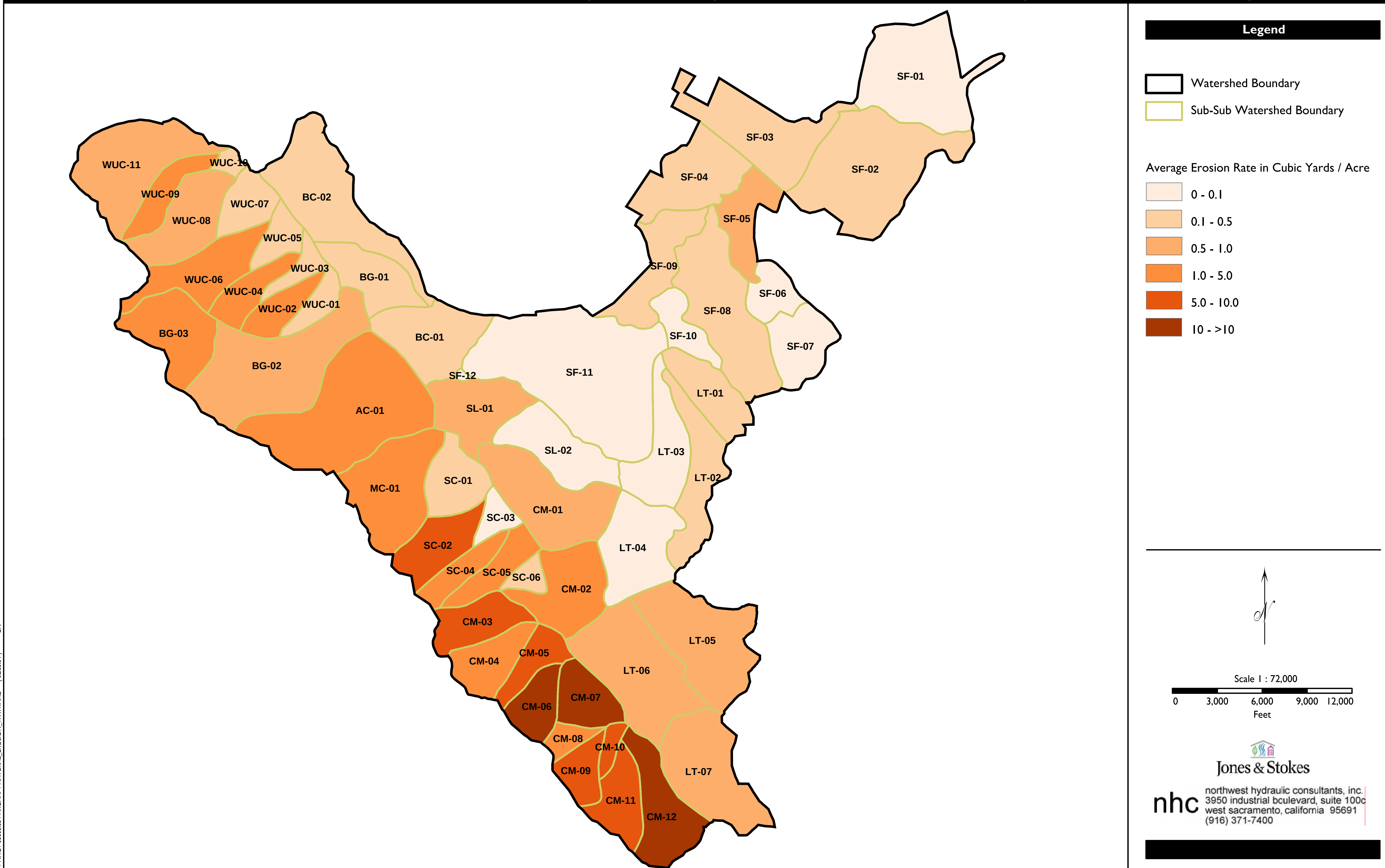

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Figure 15 Average Erosion Rate in Cubic Yards / Acre per year in the San Francisquito Watershed

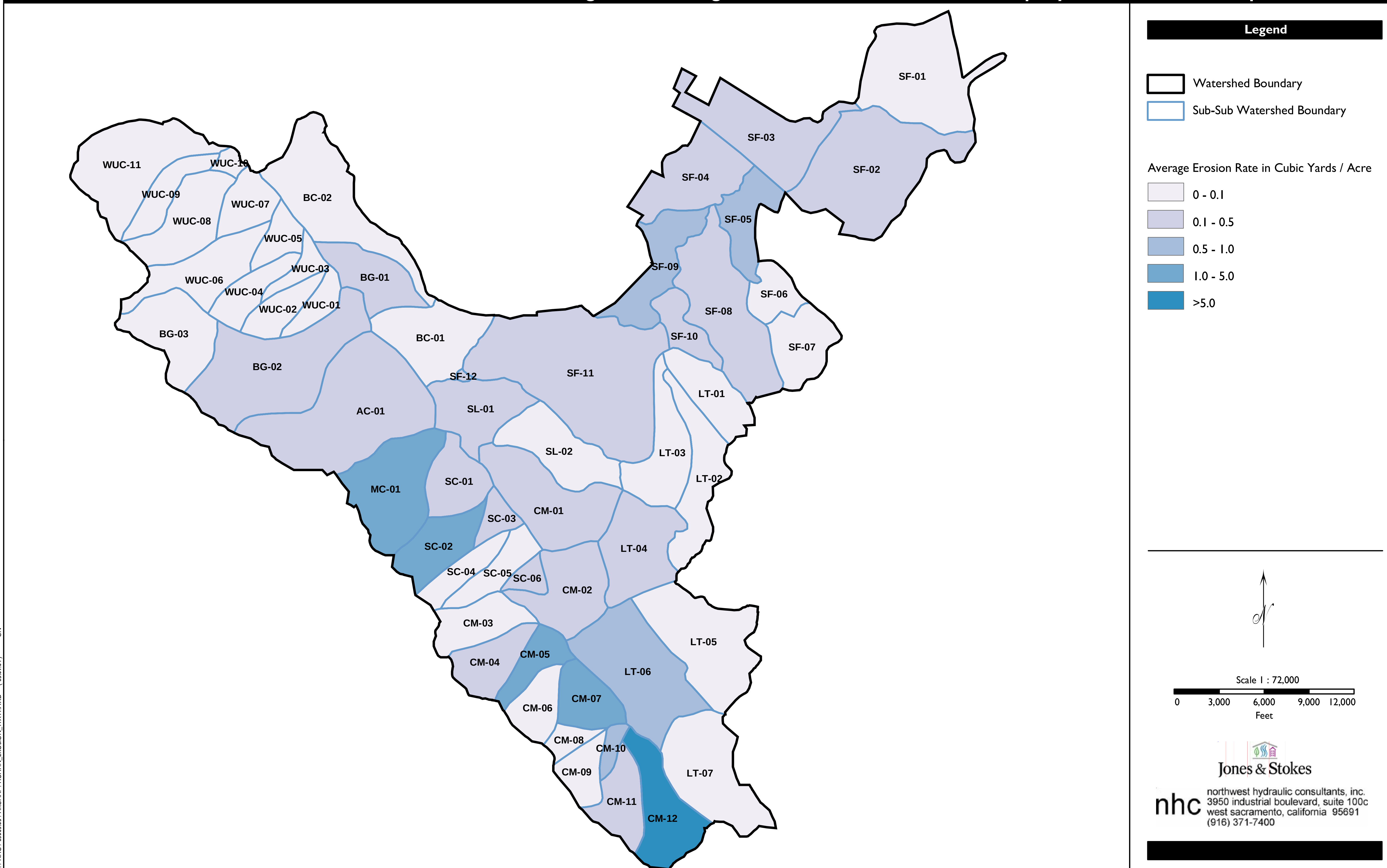

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Figure 16 Human - related Erosion as a Percentage of Total Erosion in the San Francisquito Watershed

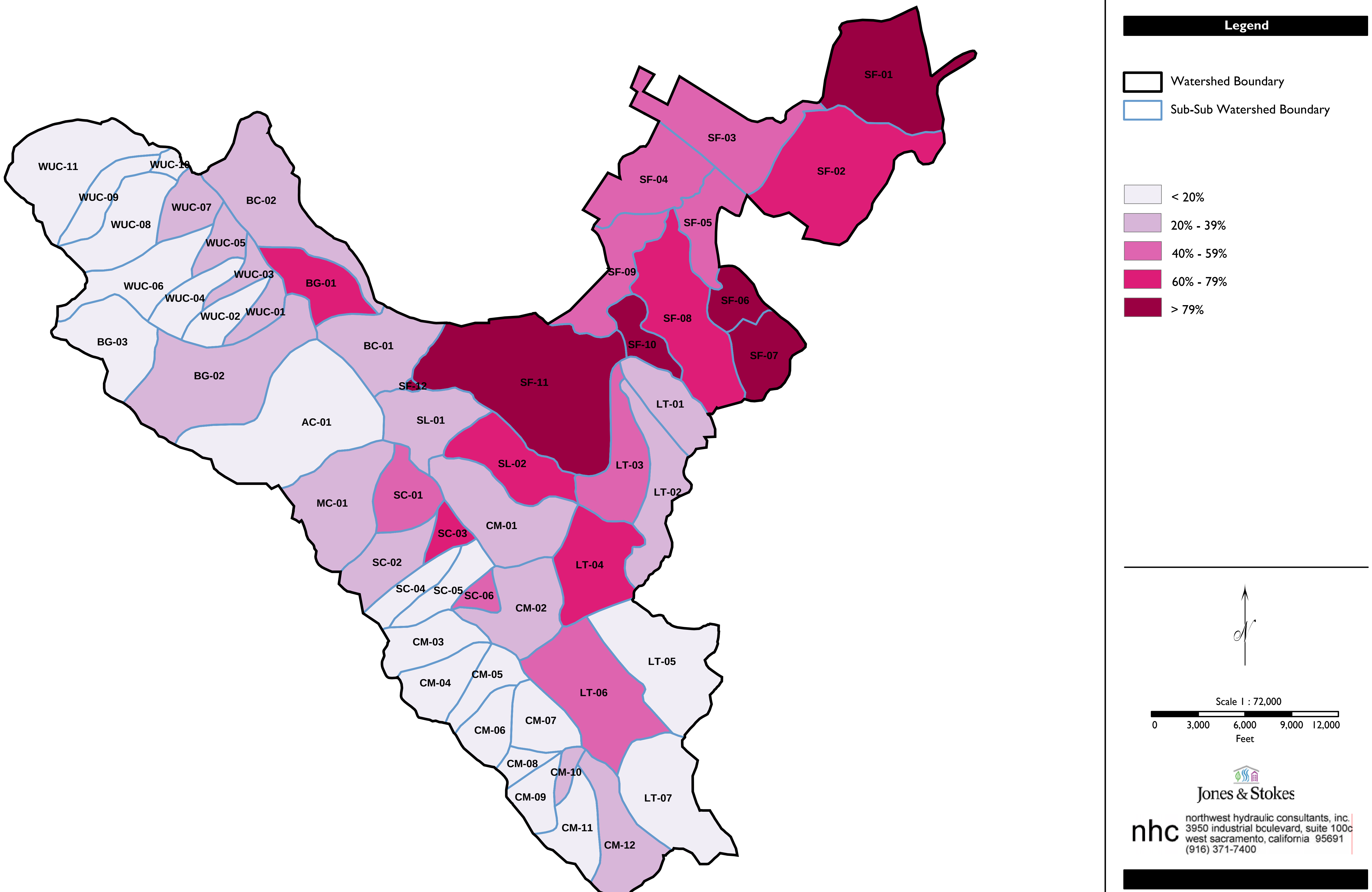

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Figure 17
San Francisquito Creek Watershed
Principal Predicted Debris_Flow Source Areas Per Jurisdiction

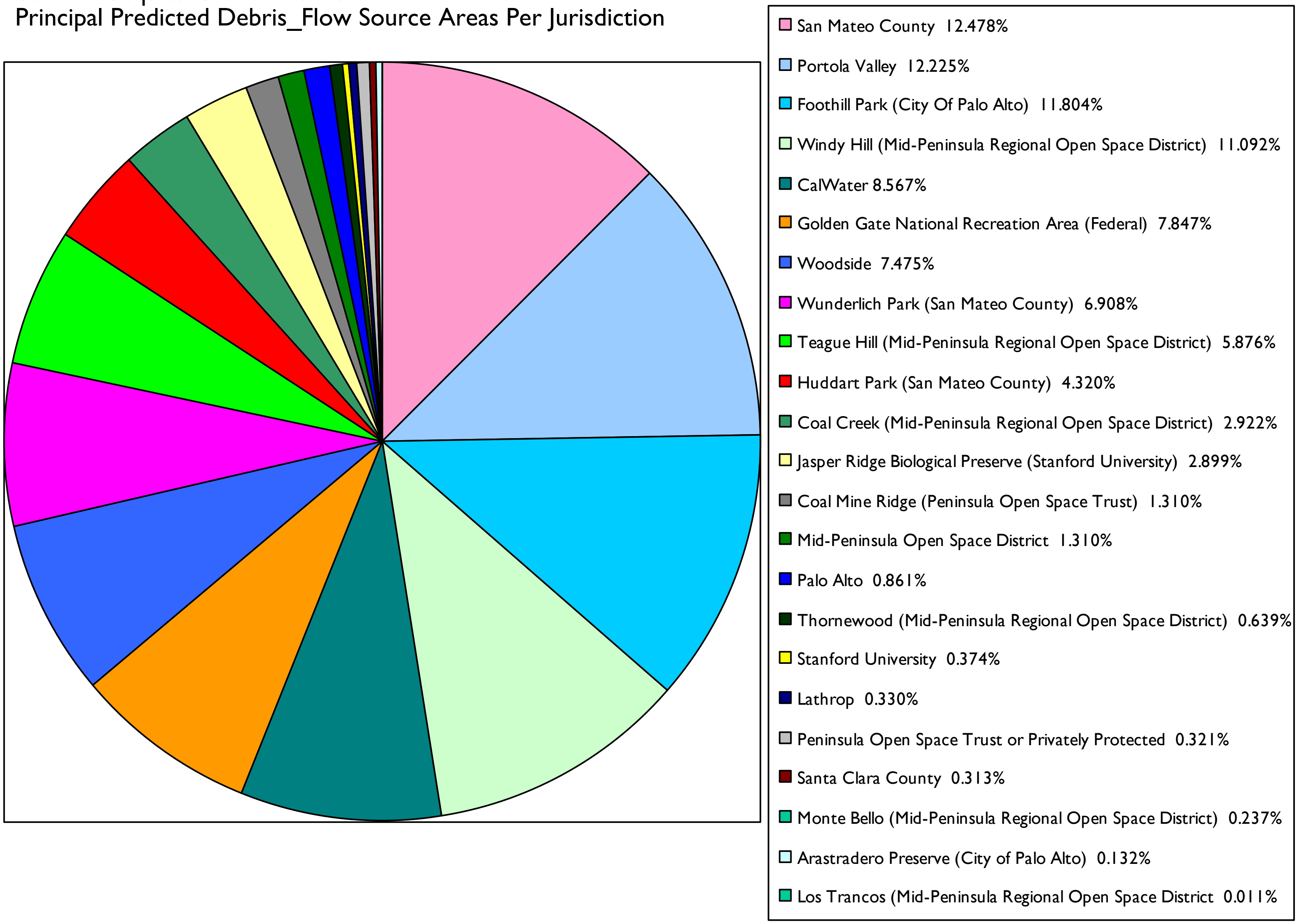
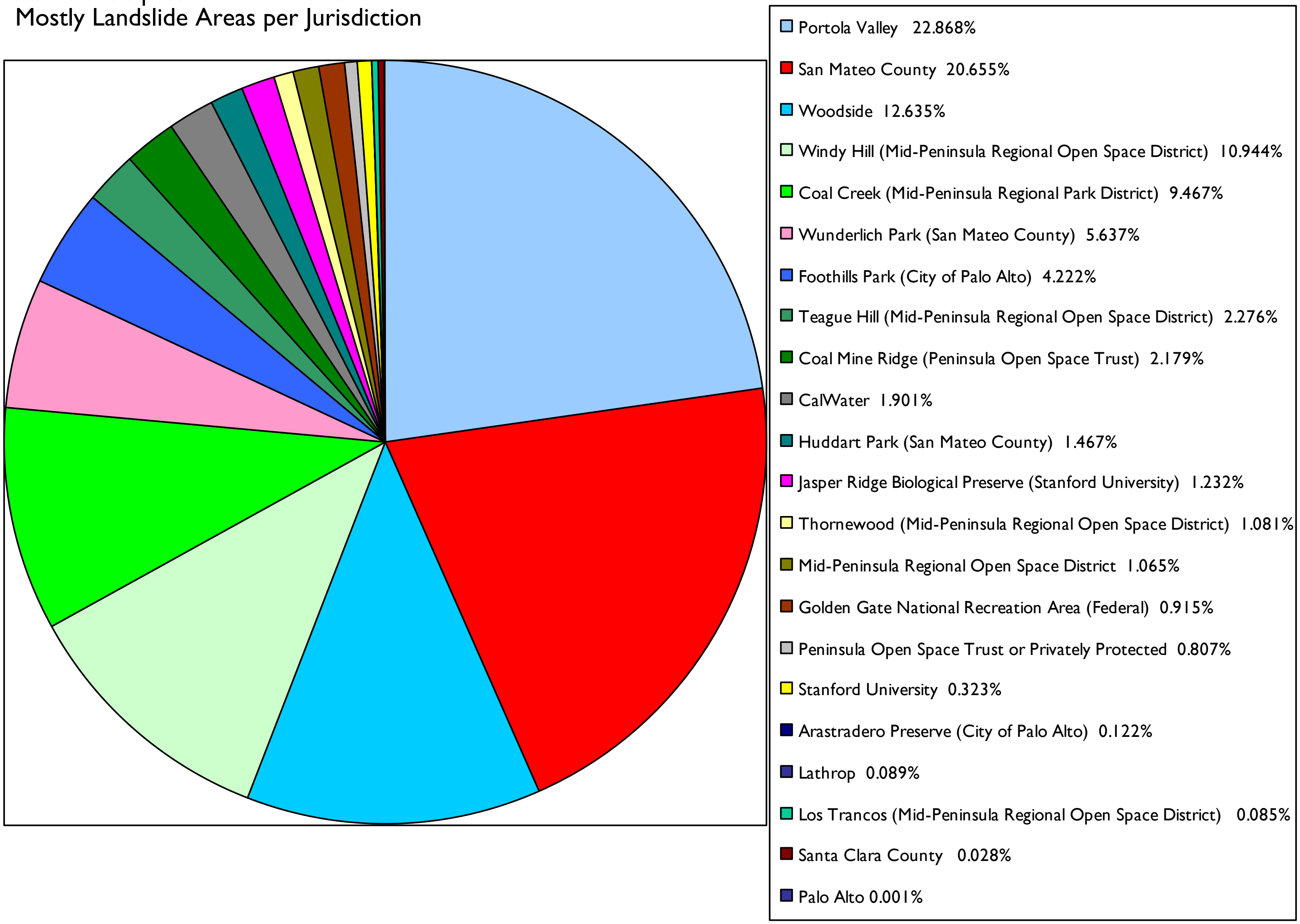
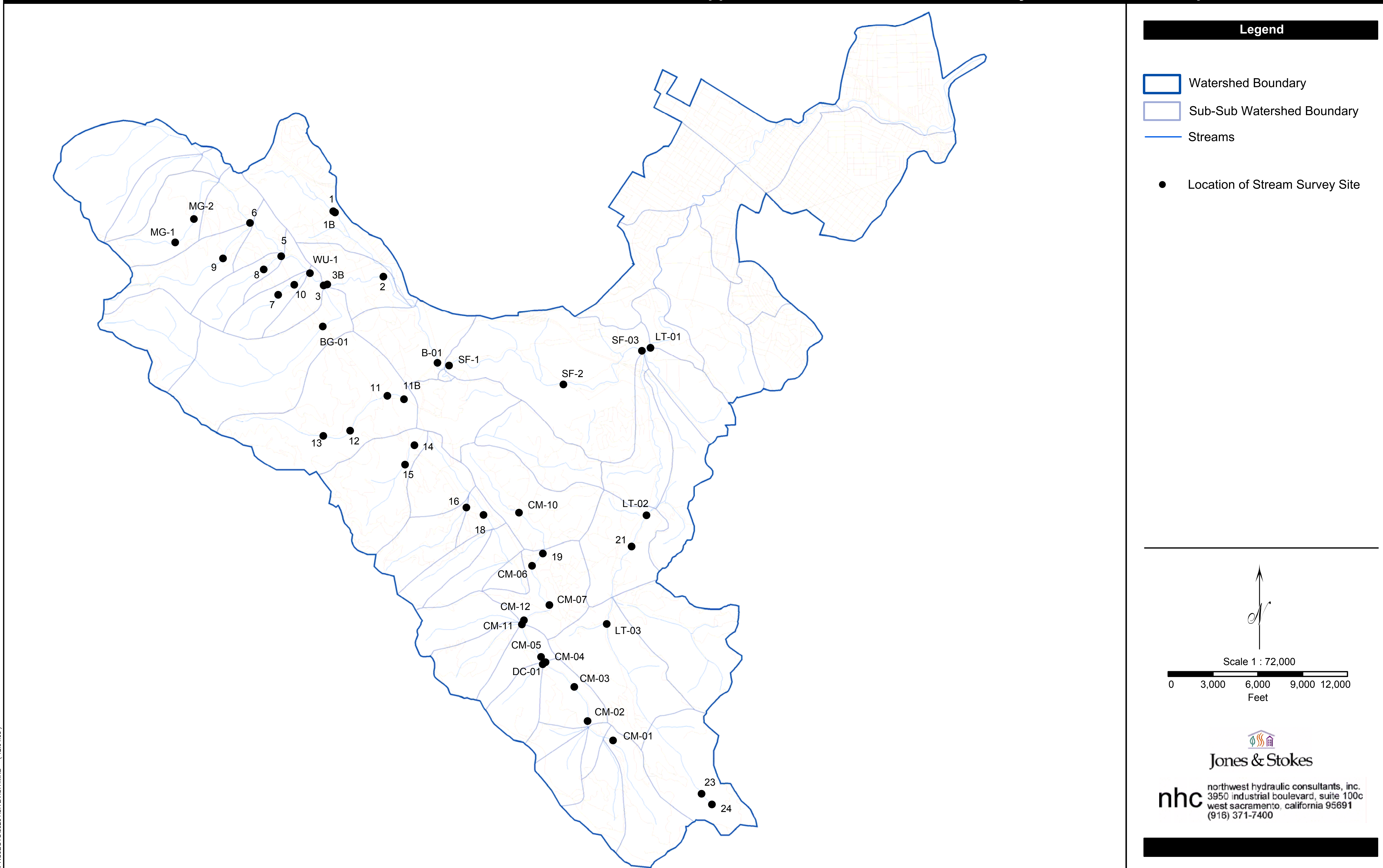


Figure 18
San Francisquito Creek Watershed
Mostly Landslide Areas per Jurisdiction



Appendix A Location of Stream Survey Sites - San Francisquito Creek Watershed



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Appendix A: Summary of Stream Channel Observations
Searsville Lake, Bear, Los Trancos and San Francisquito Creek Subwatersheds

				Channel Character						Bed Material (mm)		Banks		Sediment Transport and Deposition		
Stream	Site Description	Sub-Sub watershed	Site #	Stream Type	Slope (%)	Bankfull Width (ft)	Bankfull Depth (ft)	D_{50}	D_{90}	Description	Comment	Left Bank	Right Bank	Channel Incision	Erosion	Storage and Deposition
Corte Madera Creek Subwatershed																
Corte Madera Creek	downstream of Alpine Road crossing	CM-12	CM-01	step-pool	N/A	12 to 15	3 to 4	N/A	N/A	conglomerate boulders to 500 mm on riffles	boulder steps sit on poorly indurated bedrock	valley wall - sandy colluvium over bedrock	sand over boulders; 3 to 5 ft	Incision of 2 or 3 feet recently; up to 6 feet downstream of culvert outlet	small landslide from stream undercutting; irregular bank erosion; poss avulsion	frequent lateral bars of sand and gravel; pools filled with sand and pebbles up to 1 foot thick
Corte Madera Creek	first bridge downstream of Closed Section of Alpine Road	CM-07	CM-02	pool-riffle	3 to 4	about 25	about 2	N/A	N/A	cobbles and boulders	lateral and point bars	sand over gravel - 2 feet high	sand over gravel - 2 feet high	less than 1 foot recently	bank trimming; roots exposed, minor widening	Minor storage in lateral bars and pools
Corte Madera Creek	second bridge downstream of Closed Section of Alpine Road	CM-07	CM-03	pool-riffle	N/A	25 to 30	N/A	N/A	N/A	cobbles and boulders	lateral bars of gravel and sand	colluvium - 10 feet high	colluvium - 10 feet high; rock from Alpine Road	No recent incision	bank trimming; roots exposed, minor widening	Minor storage in lateral bars and sand in pools
Damiani Creek	Razorback Trail culvert crossing in Windy Hill Open Space Preserve	CM-06	DC-01	step-pool	N/A	15 to 20	about 5	N/A	N/A	mainly gravel to cobble sizes; woody debris	frequent tree fall	open matrix colluvium -- 5 to 8 feet	open matrix colluvium -- 5 to 8 feet	possibly as much as 2 feet recently	mass movement failures along both steep valley side slopes with consequent fluvial bank erosion	none observed, erosion and transport reach
Corte Madera Creek	mouth of Damiani Creek	CM-06	CM-04	step-pool	N/A	about 20	about 5	N/A	N/A	cobbles; gravel and sand	LWD and old stumps in bed	debris flow lobe; 6 feet high	debris flow lobe; 6 feet high	incising into debris flow lobe or deposit; rate slowed by LWD	banks steep and bare	little storage in channel through deposit; storage of coarse material upstream
Corte Madera Creek	bridge over creek to Skyline Ridge	CM-05	CM-05	boulder riffles	N/A	20 to 25	about 3	N/A	N/A	boulder cobble; riffles to 300 mm		alluvium over boulders	alluvium over boulders; toe of Alpine Road fill upstream	Incision of about 5 to 6 feet below bridge apron; maybe one or two feet recent (?); little or no disturbance upstream	eroding fill slope for Alpine Road above bridge	lateral and medial bars; gravel in boulder riffles and in pools
Corte Madera Creek	upstream of the mouth of Hamms Gulch	CM-03	CM-11	pool-riffle	N/A	20 to 25	about 3	N/A	N/A	gravel and cobbles	bed filled with gravel	10 to 15 feet of alluvium	10 feet of alluvium	No recent incision	on outside of bend; erosion/small landslide	section appears to be aggrading; cobble bed filled with gravel and sand
Corte Madera Creek	downstream of bridge to Open Space lands near Willowbrook and Alpine Rds	CM-02	CM-12	pool-riffle	N/A	about 20	3 to 5	N/A	N/A	cobble riffles		20 to 25 feet of alluvium	20 to 25 feet of alluvium	No recent incision; terraces at two levels above channel bed	past erosion opposite bar on shallow bend	cobbles aggrading in stream and on small lateral bars
Corte Madera Creek	Willowbrook Road bridge near Portola	CM-02	CM-07	pool-riffle	N/A	about 20	3 to 5	N/A	N/A	compact cobble and gravel; lateral sand and gravel bars	clasts up to 200 mm moved recently	N/A	N/A	No recent incision	reasonably stable low; developing a sinuous pattern	sand and gravel aggradation
Corte Madera Creek	Bridge at entrance to Windy Hill Open Space Preserve	CM-02	CM-06	pool-riffle	N/A	about 15	3 to 5	N/A	N/A	boulder riffles	riffles seem very compact and stable	alluvium over gravel	alluvium over bedrock; 10 to 20 ft high	recent incision minor; terraces along channel	erosion on bends and opposite bars	plentiful sand and gravel storage on bars, channel margins and in pools
Corte Madera Creek	on Portola Road near Willowbrook Drive	CM-02	19	pool-riffle / plane bed	N/A	20 to 25	3 to 5	N/A	N/A	cobble riffles / sand to gravel in pools	stable transport reach	N/A	moderate to steep soil -- 5 feet	No recent incision	no significant erosion observed	minor deposition in small point bar
Corte Madera Creek	At Westridge Road Bridge	CM-01	CM-10	pool-riffle	N/A	20 to 25	about 3	40	100	bar head material; sand and gravel	clasts up to 150 mm moved recentlly	about 20+ feet	20 feet of dense sand	no recent incision; at least two terraces visible	on outside of bends; gabion protection at some properties	sand and gravel up to foot thick in pools; on bar tops
Bear Creek Subwatershed																
McGarvey Gulch	Huddart County Park at Dean Trail crossing	WUC-08	MG-01	cascade	N/A	10 to 15	about 2	N/A	N/A	gravel to boulder sizes with abundant woody debris	frequent bedrock outcrops; many very large boulders	colluvium and bedrock (steep valley side-slope)	colluvium and bedrock (steep valley side-slope)	No recent incision	soil creep on side-slopes; localized erosion around obstructions (logs, boulders) in channel	except for bedrock and very large boulders, much of the stream bed stores mobilized sediment from previous high flows
McGarvey Gulch	Huddart County Park at Campground Trail crossing	WUC-08	MG-02	step-pool	N/A	10 to 15	about 2	N/A	N/A	mainly cobbles	well-defined channel with mobile bed, no bar forms	open matrix - sand to cobble sizes -- 2 feet	open matrix - sand to cobble sizes -- 2 feet	No recent incision	minor erosion on stream banks; soil creep on side-slopes	little storage, mainly a transport reach
Squealer Gulch	Kings Mountain Road crossing near Huddart Park boundary	WUC-06	9	cascade	N/A	about 10	2 to 3	N/A	N/A	boulder stream bed with interstitial sand to cobble sizes	frequent boulder outcrops create irregular channel bottom	soil overlying colluvium - 8 to 12 feet	soil overlying colluvium - - 6 to 10 feet	recent minor incision	minor to moderate bank erosion	none observed, largely and erosion and transport reach
Squealer Gulch	Huddart Park at Greer Road crossing	WUC-06	6	step-pool	N/A	about 15	2 to 3	N/A	N/A	mainly cobble to boulder sizes with interstitial sand and gravel	no bar forms	gravelly loam -- 10 feet	gravelly loam -- 10 feet	No recent incision	moderate bank erosion along steep, near vertical side-slopes	sediment storage in step-pools
Tripp Gulch	at Patrol Road crossing	WUC-04	8	cascade	N/A	about 10	2 to 3	N/A	N/A	mainly cobble to boulder sizes with interstitial sand and gravel	very steep, stepped reach with very large boulders	open matrix cobbly loam -- 4 to 10 feet	open matrix cobbly loam -- 4 to 10 feet	No recent incision	minor bank erosion on steep bank slopes, soil creep on valley side-slopes	none observed, largely a transport and erosion reach
Tripp Gulch	along Kings Mountain Road near Tripp Road	WUC-04	5	plane-bed (engineered)	N/A	N/A	N/A	N/A	N/A	cobble and boulder bed	narrow channel engineered along roadside	vertical concrete wall (10 ft)	sloped sacrete bank 6 feet high	No recent incision	none observed	none observed, designed as a transport reach
Apple Tree Gulch	Summit Springs Road crossing	WUC-02	7	plane-bed	N/A	about 10	about 2	N/A	N/A	mainly cobbles and small boulders	no bedforms	moderate slope silt to cobble sizes -- 3 to 5 feet	moderate slope silt to cobble sizes -- 3 to 5 feet	No recent incision	no significant erosion observed	possible backwater deposit 3 to 5 ft deep behind culvert at road crossing
Apple Tree Gulch	Tripp Road crossing	WUC-02	10	plane-bed	N/A	10 to 12	about 2	N/A	N/A	sand and gravel with some cobbles	no bedforms	moderately sloped soil -- 5 feet	moderately sloped soil -- 5 feet	No recent incision	no significant erosion observed	transport reach some aggradation between storms evident from partially buried tree trunks in channel
West Union Creek	West Union above Woodside Road to Tripp Road	WUC-01	WU-01	pool-riffle	N/A	N/A	N/A	N/A	N/A	cobble boulder riffles	long riffles and short pools	N/A	sand over gravel; 20 to 30 feet	possible recent minor incision	sacrete wall underscoured; erosion on outside of bends	cobbles bars; minimal sand in pools
West Union Creek	Hwy 84 crossing west of Canada	BG-01	3	pool-riffle	N/A	about 25	about 5	N/A	N/A	gravel and cobble bed; interstitial sand	clasts up to 150 mm moved recently	gradually sloping sandy fill and soil -- 4 feet	moderately sloping silty clay capped with loamy soil -- 10 feet	No recent incision	moderate bank erosion on right bank	significant storage in large point bar and smaller medial bars
Bear Gulch Creek	Highway 84 crossing	BG-01	3B	pool-riffle / plane-bed	N/A	about 40	5 to 7	N/A	N/A	mainly gravel to cobble sizes	few bedforms, small medial bars in otherwise plane-bed	soil and fine sediments	soil with gravel	possible headcut - 2 foot drop at sill along base of bridge	minor erosion along right bank	transport reach, minor storage in medial bar features
Bear Gulch	Bear Gulch at Woodside Road	BG-02	BG-01	step-pool	N/A	N/A	N/A	N/A	N/A	boulders and cobbles	steps appear to be degraded	3 to 5 ft of sand over boulders	wall	incised below bridge apron; elevated flood channel	on outside of bends	very limited; small cobble bars
Bear Creek	bridge at Olive Hill Lane	BC-02	1	pool-riffle / plane-bed	N/A	about 15	2 to 4	N/A	N/A	sand and gravel	moderate size point bar, large bedrock outcrop prevents upstream migration of 6 foot headcut	moderately sloping soil - - 8 to 10 feet	moderately sloping soil - - 8 feet	headcut immediately downstream of study reach stops at bedrock outcrop, 6 foot drop.	minor bank erosion on left bank	minor deposition at small point bar 12 x 4 feet
Bear Creek	just downstream of Site #1 at Olive Hill Lane	BC-02	1B	pool-riffle / plane-bed	N/A	about 15	N/A	N/A	N/A	sand, gravel, and cobble sizes	medial bar, shallow pool, 6 foot headcut	bedrock outcrops covered with soil	N/A	6 foot headcut stopped at bedrock control	moderate erosion on both banks immediately downstream of headcut	minor deposition at small medial bar
Bear Gulch Creek	at Canada Road near Roberts Market	BG-01	2	pool-riffle / plane-bed	N/A	20 - 25	about 5	N/A	N/A	sand and gravel, some cobble	smooth channel bed, left bank abuts concrete retaining wall	vertical concrete wall (10 ft)	moderate to steep soil -- 8 feet	No recent incision	no significant erosion observed	stable transport reach with minor sediment storage in pools
Bear Creek	Bear Creek downstream of Sand Hill Road (Jasper Ridge)	BC-01	B-01	pool-riffle	0.5	about 25	3 to 5	60	100	bar head (mobile) material	cobble riffles up to 250 mm (seem stable)	sand over gravel -- 5 feet	sand over gravel; 10 feet	no recent incision; fan surface is now terrace	around logjam and opposite bars -- minor	deep sand in pool below Sand Hill Road up to 1 foot; small lateral bars.

				Channel Character						Bed Material (mm)		Banks		Sediment Transport and Deposition		
Stream	Site Description	Sub-Sub watershed	Site #	Stream Type	Slope (%)	Bankfull Width (ft)	Bankfull Depth (ft)	D_{50}	D_{90}	Description	Comment	Left Bank	Right Bank	Channel Incision	Erosion	Storage and Deposition
Searsville Lake Subwatershed																
Alambique Creek	Alambique Trail in Wunderlich County Park - 1.5 miles from parking lot	AC-01	13	cascade	N/A	about 15	2 to 3	N/A	N/A	bouldery with sand to cobble sizes in between; woody debris	very irregular, unstable erosive gully	valley wall - colluvium with high soil content	valley wall - colluvium with high soil content	No recent incision	moderate to severe bank erosion, tree fall, soil creep	none observed, erosion and transport reach
Alambique Creek	Highway 84 crossing	AC-01	12	step-pool / cascade	N/A	10 to 15	2 to 3	N/A	N/A	bouldery with sand to cobble sizes in between; woody debris	clasts up to 150 mm moved recently	valley wall - colluvium ranging from soil to boulder sizes	valley wall - colluvium ranging from soil to boulder sizes	No recent incision	soil creep on side-slopes; localized erosion around obstructions (logs, boulders) in channel; small landslide	none observed, largely an erosion and transport reach
Alambique Creek	Portola Road crossing near Highway 84	AC-01	11	steep pool-riffle	N/A	about 15	2 to 3	N/A	N/A	mainly cobble and gravel	well-developed meanders with steep, gravel-cobble point bars	silt to cobble size unsorted deposits	N/A	Minor recent incision	minor bank erosion on both banks	minor storage in coarse-grained point bar deposits
Alambique Creek	upstream of bridge at 1990 Portola Road	AC-01	11B	plane bed	N/A	about 15	2 to 4	N/A	N/A	sand to cobble sizes	plane-bed, no significant bar forms	alluvial sand and gravel matrix	alluvial sand and gravel matrix	No recent incision	minor erosion on stream banks	aggrading reach, only 1 foot remaining between stream bed and top of bridge opening
Martin Creek	Old La Honda Road crossing 0.4 miles from Portola Road	MC-01	15	step-pool	N/A	8 to 12	2 to 4	N/A	N/A	sand and gravel with boulders up to 1200 mm	bed is mobile during high flows, including small boulders	valley wall - colluvium with some bedrock outcrops	colluvium and bedrock (steep valley side-slope)	possible minor incision (1' - 2') and erosion through an abandoned dirt road crossing	minor erosion on stream banks; soil creep on side-slopes	little storage, mainly a transport reach
Martin Creek	Portola Road crossing near Old La Honda Road	MC-01	14	plane bed	N/A	12 to 15	about 3	N/A	N/A	sand to cobble sizes	no significant bar forms	soil overlying sandy colluvium	soil overlying sandy colluvium	No recent incision	none observed	none observed
Bull Run Creek	Wayside Road crossing near church	SC-02	16	step-pool / plane bed	N/A	about 15	about 2	N/A	N/A	sand to small boulder sizes	some plane-bed and some step-pool sections	soil	soil	No recent incision	minor erosion on right bank	little storage, mainly a transport reach
Sausal Creek	Portola Road crossing near Family Farm Road	SC-03	18	plane bed (engineered)	N/A	N/A	N/A	N/A	N/A	sand and gravel	engineered trapezoidal channel	moderately sloped soil -- 6 feet	moderately sloped soil -- 6 feet	No recent incision	none observed	none observed, engineered channel may be maintained
Los Trancos Creek Subwatershed																
Los Trancos Creek	Los Trancos Open Space Preserve - downstream crossing of Franciscan Loop Trail	LT-07	24	cascade	N/A	about 10	1 to 2	N/A	N/A	cobble to boulder sizes (200 - 600 mm)	very steep, stepped bouldery reach	N/A	N/A	No recent incision	moderate bank erosion with soil creep on side-slopes	minor storage in gravel point bar at sharp channel bend
Los Trancos Creek	Los Trancos Open Space Preserve - on Lost Creek Loop Trail next to Los Trancos Creek	LT-07	23	cascade	N/A	10 to 15	1 to 2	N/A	N/A	gravel to cobble sizes with many small boulders, interstitial gravel and sand, and moderate woody debris	bed is mobile during high flows, may include small boulders	sandy colluvium	sandy to gravelly colluvium	No recent incision	minor erosion on stream banks; soil creep on side-slopes	minor storage areas behind areas of coarse woody debris and cascade pools
Los Trancos Creek	second upstream crossing of Los Trancos Road	LT-06	LT-03	plane bed	3 to 4	about 15	3 to 4	N/A	300 to 400	boulder bed; conglomerate	bed filled with sand and pebbles; angular gravel in culvert barrel	N/A	road fill and protection	No recent incision	minor erosion	appears to be aggrading with coarse material; up to 0.2 feet of sand and pebbles
Los Trancos Creek	Country Road crossing off Alpine Road	LT-04	21	plane bed / pool-riffle	N/A	20 to 25	about 3	N/A	N/A	sand to cobble sizes, several boulders	small, alternating gravel bars	N/A	N/A	No recent incision	very minor bank erosion, revetment in some places along banks	stable transport reach with minor sediment storage in small bar features
Los Trancos Creek	Arastradero Road crossing	LT-04	LT-02	pool-riffle	1.5 to 2	24	about 3	40	85	bar head (mobile) material	active transport; material to 150 mm	gravel to 2.5 ft above bed; sand	N/A	No recent incision	opposite bars; on bends. Eroding ditch carries fines to stream	sand in pools up to 0.5 to 1 foot deep; gravel point bars; cobble fill below bridge
Los Trancos Creek	Piers Lane crossing	LT-01	LT-01	bedrock	N/A	N/A	N/A	N/A	N/A	boulders and cobbles over bedrock		N/A	sand over boulders/bedrock	low weir/dam at head of reach; incision into bedrock to match SF Creek (?). Low terraces	minor erosion; inside of bend recently repaired?	sand and gravel to 1 foot in poosl near mouth; backwater deposits.
San Francisquito Creek																
San Francisquito Creek	Downstream of Bear Creek and Concrete Ford -- Jasper Ridge	SF-11	SF-01	bedrock	N/A	N/A	N/A	N/A	N/A	cobbles over bedrock		alluvium over bedrock -- 15 feet	alluvium over bedrock -- 15 feet	incision into bedrock	none observed	gravel and sand to 1 foot in bedrock pools; large gravel bars downstream at powerline crossing
San Francisquito Creek	Bridge crossing at Webb Ranch Home	SF-11	SF-02	pool-riffle	N/A	about 40	about 8	N/A	N/A	gravel/cobble riffles; sandy gravel over bed material	bedrock exposure in bed	dense sand to 20 feet	dense sand to 20 feet	No recent incision	minor erosion	No instream bars; deposit of sandy gravel below bridge on bed
San Francisquito Creek	Above Los Trancos Creek (Alpine Road)	SF-11	SF-03	pool-riffle	N/A	N/A	N/A	N/A	N/A	cobble-boulder riffles	bedrock exposure in bed at bridge	sand over cobbles and boulders	sand over cobbles and boulders	concrete apron on pier has failed; no obvious recent incision	none observed	left barrel of bridge filled with sand and gravel to about 5 feet above bed; minor sand accumulation in pools; junction bar near mouth of Los Trancos of cobbles and gravel

CORTE MADERA D/S OF ALPINE ROAD (CM #1)

LOOKING D/S OVER BOULDER STEP

LOOKING U/S TO BOX CULVERT BELOW ALPINE ROAD

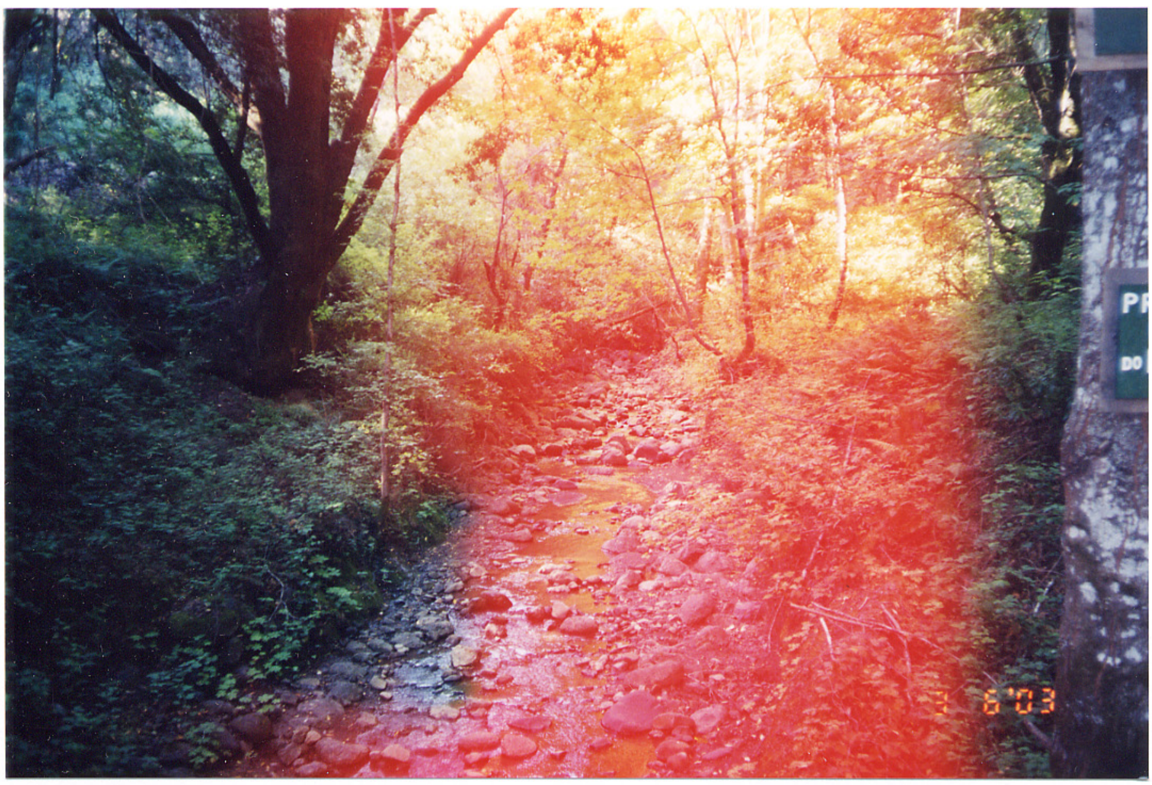
CORTE MADERA AT 1ST PRIVATE BRIDGE (CM #2)

LOOKING D/S FROM TOP OF RIGHT BANK (ALPINE RD)

LOOKING U/S FROM LEFT BANK

CORTE MADERA #3 - AT 2ND PRIVATE BRIDGE D/S OF GATE ON ALPINE ROAD

LOOKING U/S TO AGGRADED SECTION



-TYPICAL COARSE-BEDDED SECTION.

Site DC-01 Damiani Creek at Razorback Trail culvert crossing, looking upstream

Site DC-01 Damiani Creek - view of open matrix cobble and gravel in stream bank, looking upstream

LOOKING U/S TO CONCRETE APRON AT SKYLINE RIDGE BRIDGE

LOOKING D/S BELOW BRIDGE — SACRETE WALL SEDIMENT DEPOSITS

CORTE MADERA AT MOUTH OF DAMIANI CK (CM#5)

VIEW NEAR FRONT OF DF DEPOSIT

NEW CHANNEL OF CM CREEK THROUGH DEPOSIT
- BREACHED LOG JAM

CORTE MADERA U/S OF HAMM'S CK. (CM#11)

LOOKING DOWNSTREAM
FAILURE ON LEFT
BANK

CORTE MADERA CK AT WILLOWBROOK ROAD (CM#7)

LOOKING D/S PAST TYPICAL BAR.

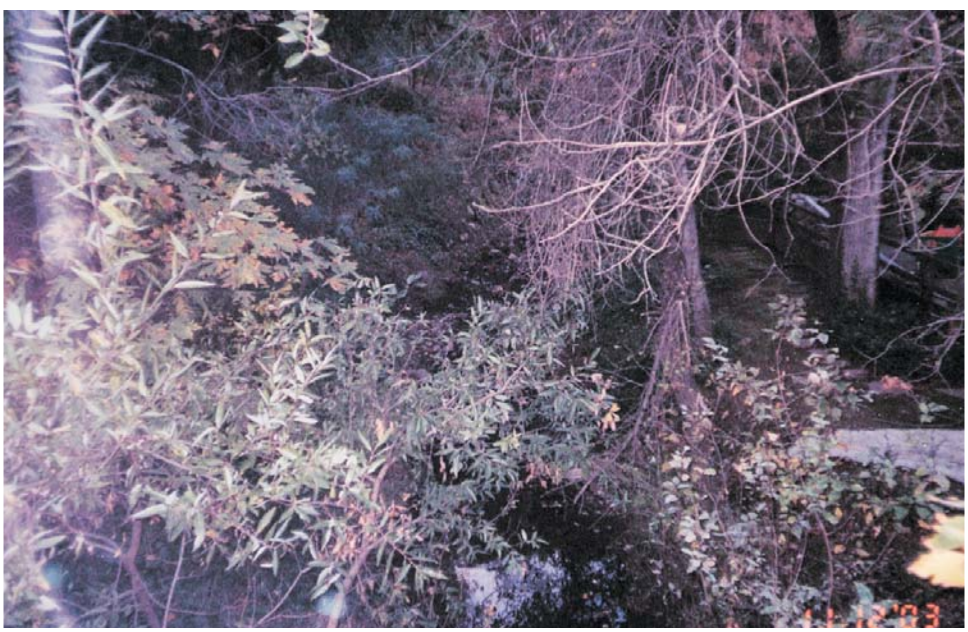
LOOKING U/S TO BRIDGE – AGGRADATION ON LB

CORTE MADERA CK AT WINDY HILL PRESERVE BRIDGE (CM #6)

ERODING RB UPSTREAM OF BRIDGE

LOOKING D/S – MINOR BANK EROSION – LWD JAM.

Site 19 Corte Madera Creek at Portola Road bridge, looking upstream



Site 19 Corte Madera Creek at Portola Road bridge, looking downstream

CORTE MADERA CK D/S OF WESTRIDGE ROAD

D/S VIEW OF ERODING BANK IN LEFT BEND

D/S VIEW OF GABION WALL IN BEND (RIGHT)

Site MG-01 McGarvey Gulch at Dean Trail crossing, looking upstream

Site MG-01 McGarvey Gulch at Dean Trail crossing, looking downstream

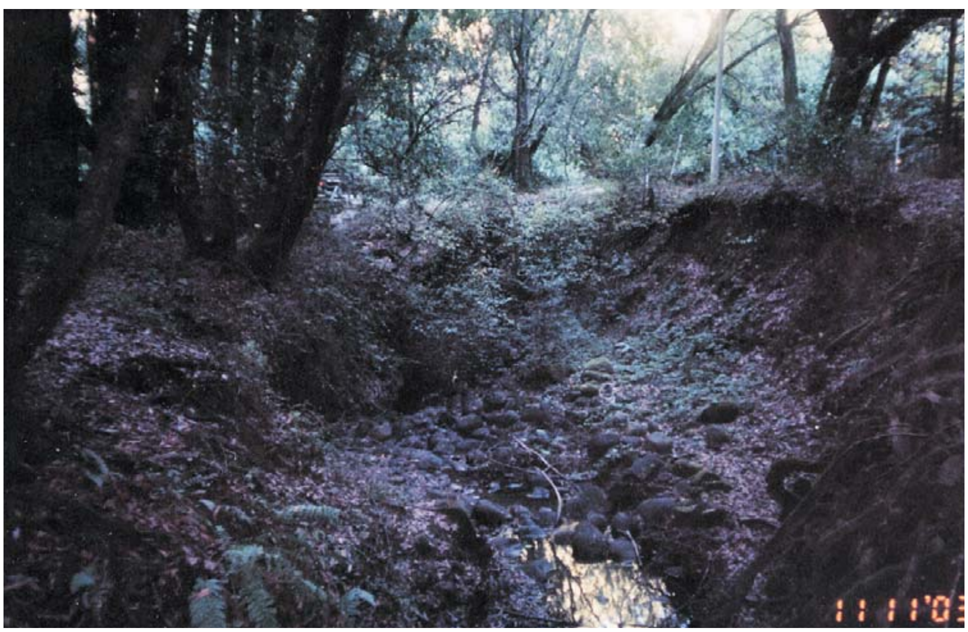
Site MG-02 McGarvey Gulch at Campground Trail crossing, looking upstream

Site MG-02 McGarvey Gulch at Campground Trail crossing, looking downstream

Site 9 Squealer Gulch at Kings Mountain Road crossing, looking upstream

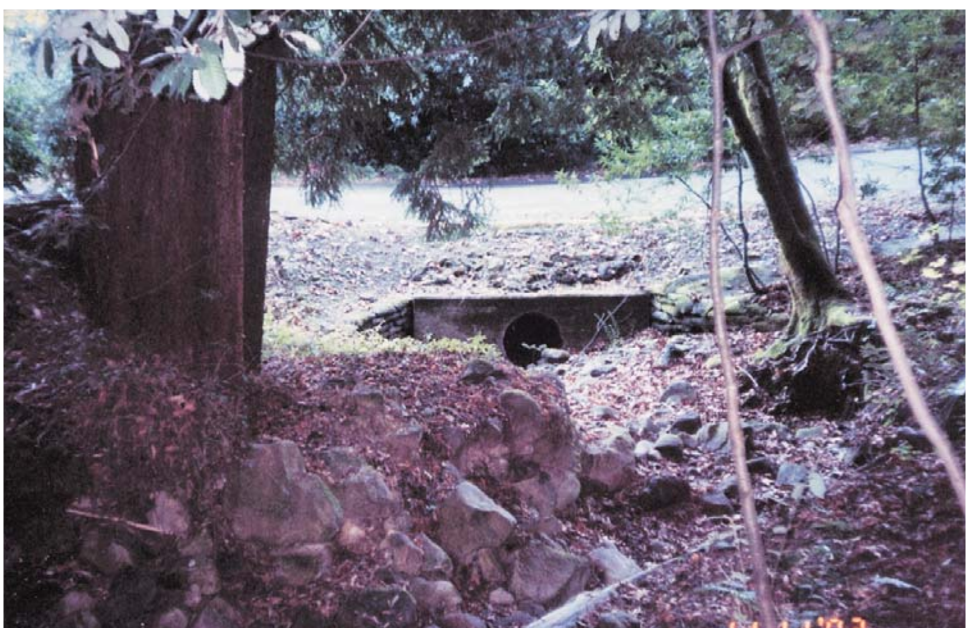
Site 9 Squealer Gulch at Kings Mountain Road crossing, looking downstream at culvert under road

Site 6 Squealer Gulch at trail crossing in Huddart Park near Greer Rd, looking upstream



Site 6 Squealer Gulch at trail crossing in Huddart Park near Greer Rd, looking downstream

Site 8 Tripp Gulch at Patrol Road crossing, looking upstream



Site 8 Tripp Gulch at Patrol Road, looking downstream at culvert under road

Site 5 Tripp Gulch beside Kings Mountain Road near Tripp Road, looking upstream along retaining wall

Site 7 Appletree Gulch at Summit Springs Road, looking upstream

Site 7 Appletree Gulch at Summit Springs Road, looking downstream at culvert under road

Site 10 Appletree Gulch at Tripp Road, looking upstream

Site 10 Appletree Gulch at Tripp Road, looking downstream at culvert under road

WEST UNION CREEK NEAR WOODSIDE ROAD

GENERAL VIEW DOWNSTREAM

GENERAL VIEW UPSTREAM FROM TOP OF LEFT BANK

Site 3 West Union Creek upstream of Highway 84 crossing, looking upstream

Site 3 West Union Creek at Highway 84 west of Canada Rd, looking at large point bar with eroding outer bank

Site 3B Bear Gulch Creek at Highway 84, looking upstream at bridge

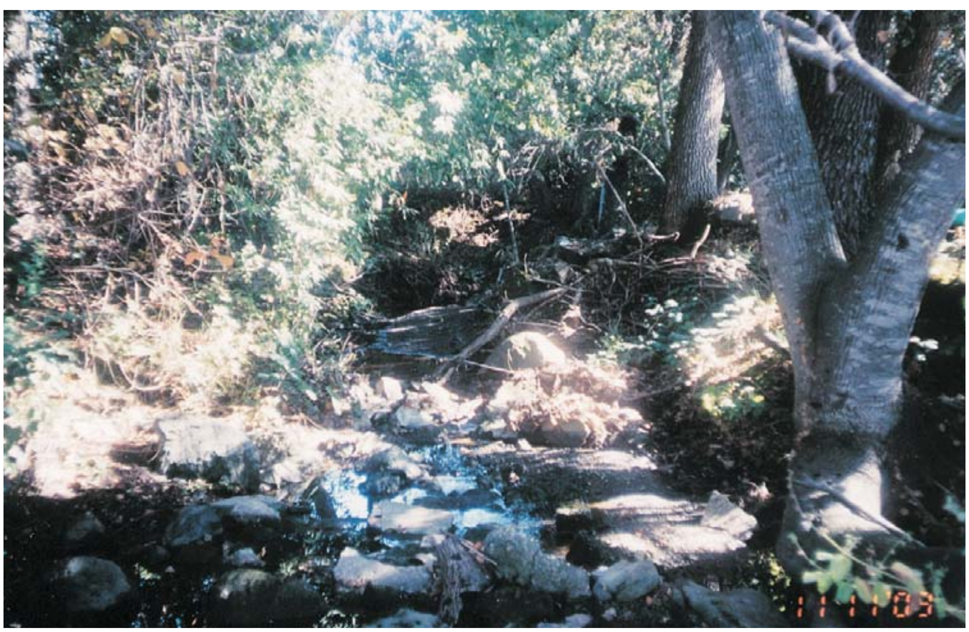
Site 3B Bear Gulch Creek at Highway 84, looking downstream

BEAR GULCH AT WOODSIDE ROAD

LOOKING U/S FROM BRIDGE
ROCK WALL ON RIGHT (RIVER) BANK

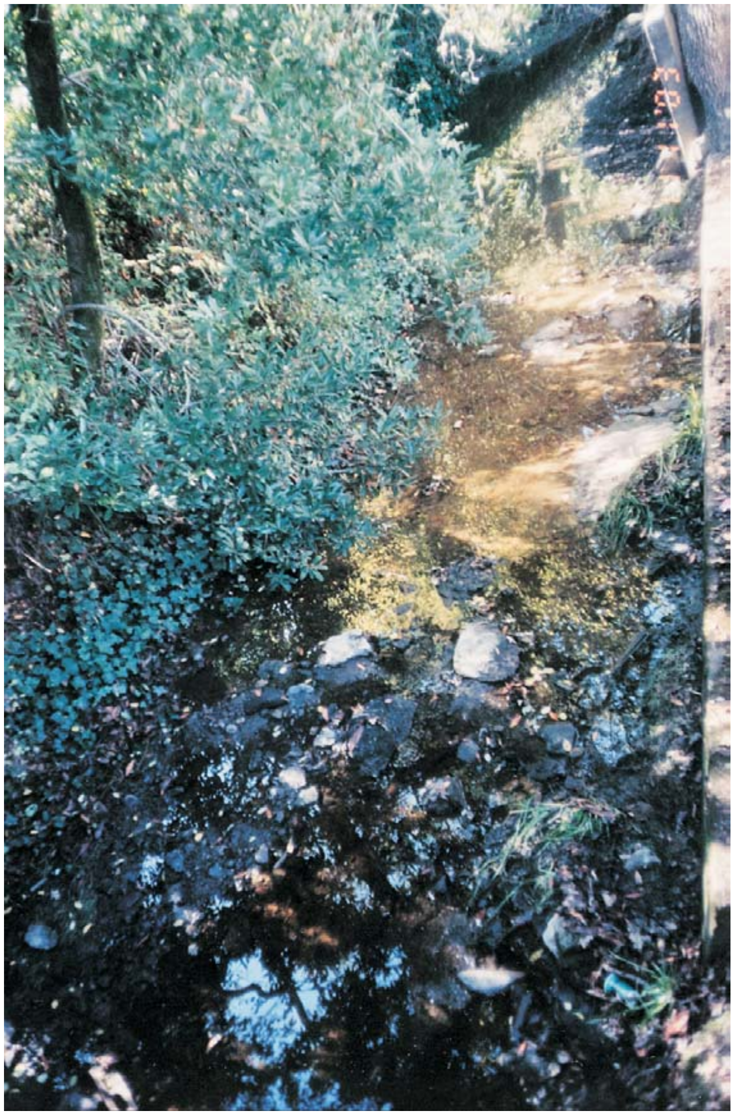
LOOKING U/S ABOUT 100'
ABOVE WOODSIDE ROAD
- ERODING LEFT BANK

Site 1 Bear Creek at Olive Hill Lane bridge, looking upstream at bridge culverts



Site 1 Bear Creek at Olive Hil Lane bridge, looking downstream

Site 1b Bear Creek 150 ft downstream of Olive Hill Lane bridge, looking downstream from top of 6 ft headcut



Site 2 Bear Creek about 50 feet upstream of Canada Road bridge, looking upstream at retaining wall next to Roberts Market

BEAR CREEK D/S OF SAND HILL ROAD

ROLL #1-2

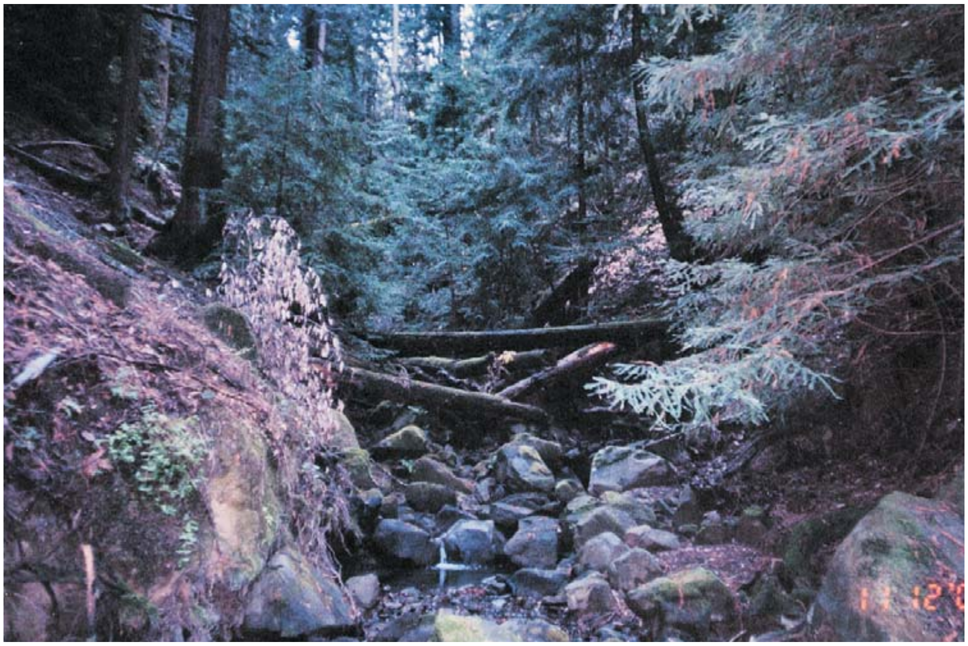
LOOKING D/S ABOUT 200' D/S OF SAND HILL ROAD

ROLL # 1-5

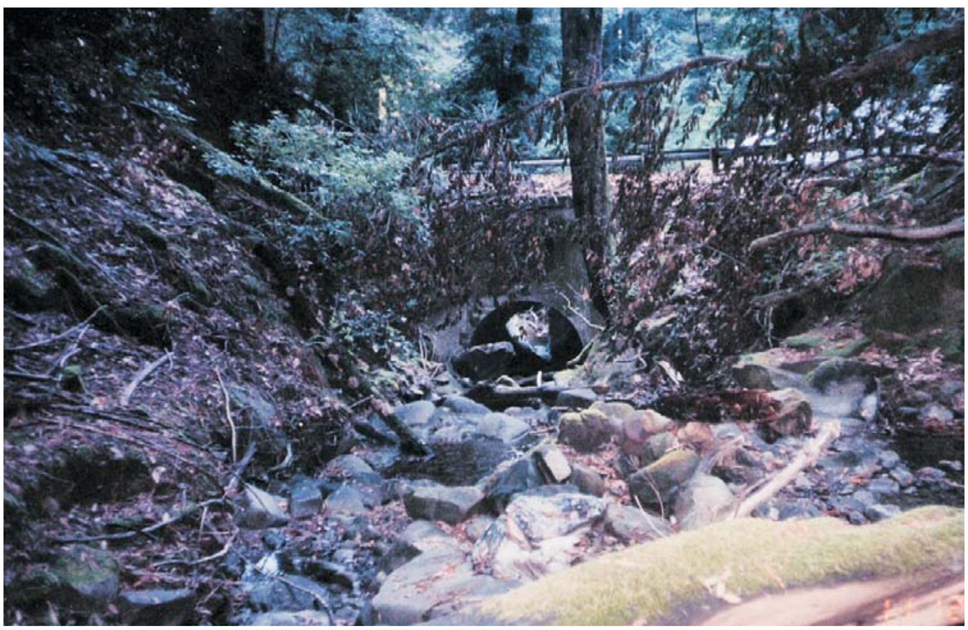
LOOKING U/S TO SAND HILL ROAD - POOL BELOW BRIDGE FILLED WITH SAND + PEBBLES

Site 13 Alambique Creek near Alambique Trail, 1.5 miles from parking lot trail head in Wunderlich Park, looking upstream

Site 13 Alambique Creek near Alambique Trail, about 1.5 miles from parking lot trail head in Wunderlich Park, looking upstream at bank slump failure



Site 12 Alambique Creek at Highway 84 crossing, looking upstream



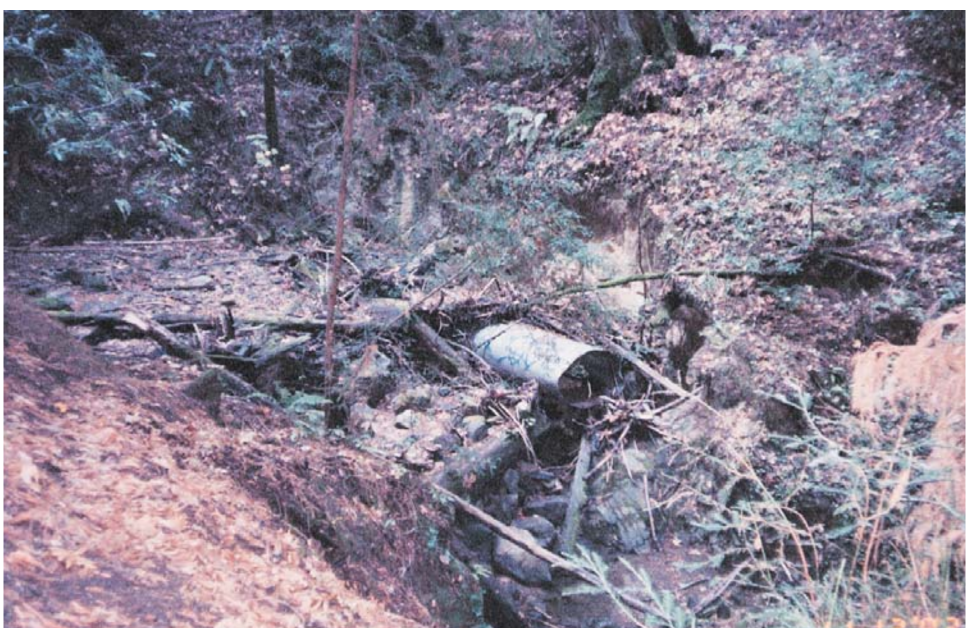
Site 12 Alambique Creek at Highway 84 crossing, looking downstream at culvert under road

Site 11 Alambique Creek at Portola Road crossing near Highway 84, looking upstream

Site 11 Alambique Creek at Portola Road crossing near Highway 84, looking downstream at large point bar and erosion on opposite bank

Site 11B — Alambique Creek at 1990 Portola Road, looking downstream - note sediment accumulation blocking much of bridge opening

Site 15 Martin Creek about 400 ft upstream of Old La Honda Road crossing, looking downstream



Site 15 Martin Creek about 200 ft upstream of Old La Honda Road crossing, looking upstream at erosion of unpaved road crossing

Site 14 Martin Creek at corner of Old La Honda Road and Portola Road, looking upstream

Site 16 Bull Run Creek about 75 ft upstream of Wayside Road crossing, looking downstream

Site 16 Bull Run Creek 200 ft downstream of Wayside Road crossing, looking downstream

Site 18 Sausal Creek just upstream of Portola Road near Family Farm Road, looking upstream at engineered channel

Site 24 — Los Trancos Creek in Lost Trancos Open Space Preserve on downstream crossing of Franciscan Loop Trail, looking upstream

Site 24 — side gully of Los Trancos Creek at Site 24, looking upslope

Site 23 Los Trancos Creek in Los Trancos Creek Open Space Preserve near Lost Creek Loop Trail, looking upstream

Site 23 Los Trancos Creek in Los Trancos Creek Open Space Preserve near Lost Creek Loop Trail, looking upstream

LOS TRANCOS CK AT 2ND CROSSING OF LOS TRANCOS RD

VIEW U/S ABOUT 100 FEET ABOVE BOX CULVERT
NOTE PILES OF SAND + PEBBLES

VIEW D/S JUST BELOW BOX CULVERT.

Site 21 Los Trancos Creek at Country Road crossing off of Alpine Road, looking upstream

Site 21 Los Trancos Creek at Country Road crossing off of Alpine Road, looking downstream

LOS TRANCOS CK AT ARASTRADERO ROAD

LOOKING U/S ABOVE BRIDGE – ERODING BANK ON OUTSIDE OF BEND

LOOKING U/S THROUGH BRIDGE – COBBLE BAR ON RIVER LEFT + SACRETE BAGS

LOS TRANCOS CREEK AT ALPERS LANE

LOOKING D/S FROM ROCK/CONCRETE WEIR ABOVE BRIDGE

LOOKING D/S THROUGH BEDROCK REACH BELOW BRIDGE.

SAN FRANCISQUITO CREEK AT WEBB RANCH

LOOKING D/S FROM BENEATH BRIDGE – SAND IN POOL

PHOTO #1 200' U/S OF BRIDGE – SAND ON FLOODPLAIN AND FILLING CHANNEL.

SAN FRANCISQUITO CK D/S OF BEAR CREEK

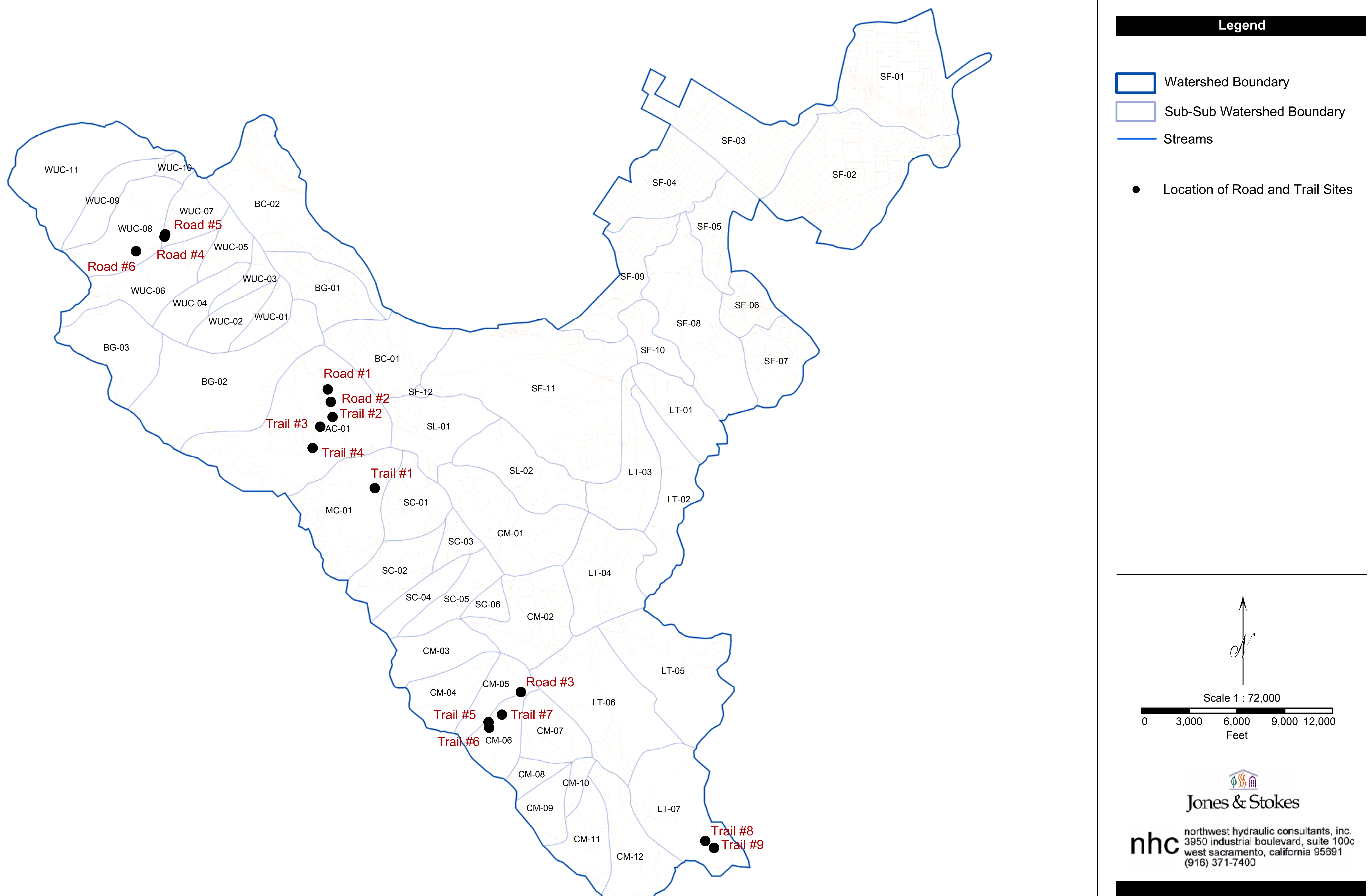
LOOKING D/S PAST CONCRETE FORD - BEDROCK ON RB TO +6 FEET

LOOKING D/S ABOUT 200' D/S OF FORD BEDROCK + COARSE ARMOR.

SAN FRANCISQUITO CREEK AT LOS TRANCOS CK

LOOKING DOWN SF CREEK PAST LOS TRANCOS CREEK.

Appendix B   Location of Trail and Unpaved Road Observation Sites - San Francisquito Creek Watershed



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Appendix B: Summary of Unpaved Road and Trail Observations
Searsville Lake, Bear, and Los Trancos Creek Subwatersheds

Site Location	Sub-Sub watershed	Site #	Type	Width	Left Side Slope(1)	Right Side Slope(1)	Drainage Features	Erosion Features
Corte Madera Creek								
Thornewood Open Space Preserve - unmarked trail on Dennis Martin Creek about 1/8 mile upstream of Old La Honda Road	Dennis Martin Creek (MC-1)	Trail #1	Hiking Trail	about 8 feet	gradual downhill	moderate uphill	large ditch 4 feet wide by 2 feet deep on right side of road	moderate bed and bank erosion in ditch
Wunderlich County Park - Alambique Trail near parking lot	Alambique Creek (AC-1)	Road #1	Unpaved Road	about 10 feet	moderate uphill	moderate downhill	none	none
Wunderlich County Park - Alambique Trail between Meadow Trail and Parking Lot	Alambique Creek (AC-1)	Road #2	Unpaved Road	about 10 feet	moderate uphill	gradual downhill	small ditch 2 feet wide by 6 inches deep on left side of road	very minor bed erosion in ditch
Wunderlich County Park - Alambique Trail between Meadow Trail and Parking Lot	Alambique Creek (AC-1)	Trail #2	Hiking Trail	about 6 feet	steep uphill	gradual downhill	ditch 2 feet wide by 1 foot deep on left side of road, roots exposed	moderate bed and bank erosion in ditch
Wunderlich County Park - Alambique Trail between Meadow Trail and Parking Lot	Alambique Creek (AC-1)	Trail #3	Hiking Trail	about 6 feet	stream crossing about 8 feet wide	stream crossing about 8 feet wide	culvert (about 18 inch diameter) conveys flows under trail	minor bed and bank erosion on downstream side of culvert crossing
Wunderlich County Park - Alambique Trail upslope from Meadow Trail	Alambique Creek (AC-1)	Trail #4	Hiking Trail	about 6 feet	steep uphill	steep downhill	culvert (about 24 inch diameter) conveys flows under trail	headcut at downstream face of culvert about 4 feet deep by 3 feet wide by 10 feet long
Windy Hill Open Space Preserve - Razorback Trail about 1 mile from Skyline Blvd	Damiani Creek (CM-6)	Trail #5	Hiking Trail	about 4 feet	steep downhill	steep uphill	none	very minor erosion on upslope side of trail
Windy Hill Open Space Preserve - Razorback Trail about 1.5 miles from Skyline Blvd	Damiani Creek (CM-6)	Trail #6	Hiking Trail	about 4 feet	steep downhill	steep uphill	none	small landslide on upslope side of trail about 25 feet long by 20 feet wide by 4 feet deep
Windy Hill Open Space Preserve - Razorback Trail within 1 mile of Alpine Road	Damiani Creek (CM-6)	Trail #7	Hiking Trail	about 5 feet	steep uphill	steep downhill	culvert (about 12 inch diameter) conveys flows from small drainage under trail	very minor erosion on upslope side of trail; minor bed erosion at downstream face of culvert
Windy Hill Open Space Preserve - Razorback Trail near Alpine Road	Damiani Creek (CM-6)	Road #3	Unpaved Road	about 12 feet	gradual uphill	gradual downhill	water bars across road; small ditch 1 feet wide by 6 inches deep on left side of road drains into a culvert (about 12 inch diameter) that conveys flows under the road	minor erosion in ditch
Bear Creek								
Huddart County Park - Archery Fire Road about 1/4 mile west of Miwok Picnic Area	McGarvey Gulch (WUC-8)	Road #4	Unpaved Road	about 12 feet	moderate downhill	steep uphill	small ditch 1.5 feet wide by 6 inches deep on right side of road drains into a culvert that crosses under the road	minor erosion along roadside ditch; right side slope erosion about 30 feet long by 4 feet high
Huddart County Park - Archery Fire Road about 1/4 mile west of Miwok Picnic Area	McGarvey Gulch (WUC-8)	Road #5	Unpaved Road	about 12 feet	steep downhill	steep uphill	small ditch 1.5 feet wide by 6 inches deep on right side of road drains into a culvert that crosses under the road	very minor erosion along roadside ditch; sideslope erosion at downstream face of culvert about 20 feet long by 10 feet wide by 4 feet deep
Huddart County Park - Dean Trail at McGarvey Gulch	McGarvey Gulch (WUC-8)	Road #6	Unpaved Road	about 15 feet	stream crossing about 30 feet wide	stream crossing about 30 feet wide	culvert (about 30 inch diameter) conveys McGarvey Creek flows under the road	Instream bed and bank erosion on McGarvey Creek
Los Trancos Creek								
Los Trancos Open Space Preserve - Franciscan Loop Trail near Lost Creek Trail	Los Trancos Creek (LT-7)	Trail #8	Hiking Trail	about 4 feet	gradual uphill	gradual downhill	none	none
Los Trancos Open Space Preserve - Franciscan Loop Trail near Page Mill Trail	Los Trancos Creek (LT-7)	Trail #9	Hiking Trail	about 5 feet	stream crossing about 6 feet wide	stream crossing about 6 feet wide	culvert (about 18 inch diameter) conveys Los Trancos Creek flows under the trail	minor bank erosion in stream; small headcut (about 1 foot high) at downstream face of culvert

(1) = all side slope descriptions are made looking in the downhill direction of the road or trail

Trail Site #1 Thornewood Open Space Preserve - unmarked trail on Dennis Martin Creek about 1/8 mile upstream of Old La Honda Road

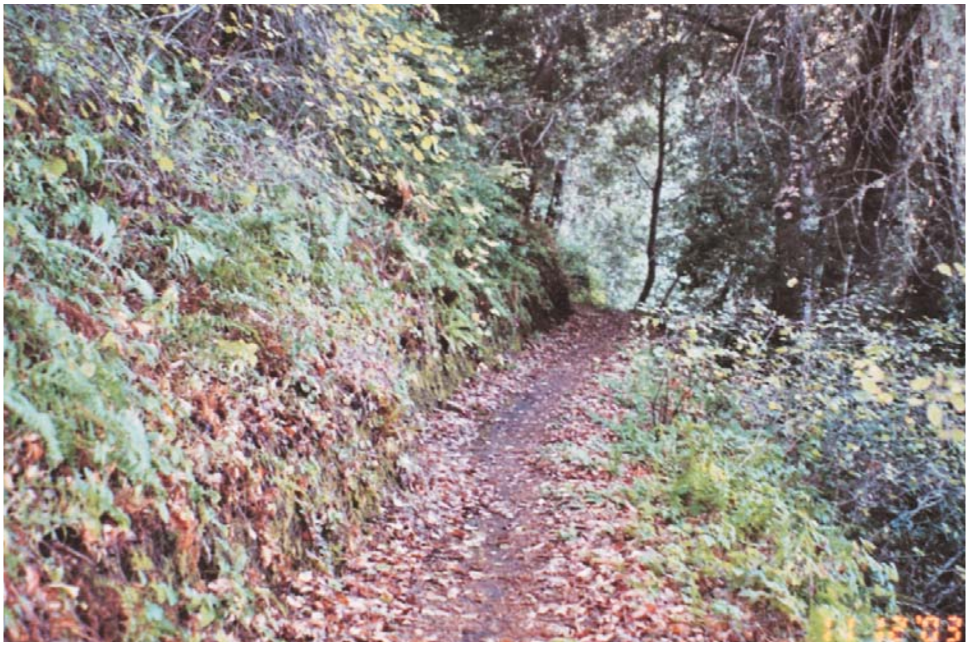
Road Site #1 Wunderlich County Park - Alambique Trail near parking lot

Road Site #2 Wunderlich County Park - Alambique Trail between Meadow Trail and parking lot

Trail Site #2 Wunderlich County Park - Alambique Trail between Meadow Trail and parking lot

Trail Site #3 Wunderlich County Park - Alambique Trail between Meadow Trail and Parking Lot

Trail Site #4 Wunderlich County Park - Alambique Trail upslope from Meadow Trail



Trail Site #5 Windy Hill Open Space Preserve - Razorback Trail about 1 mile from Skyline Blvd.

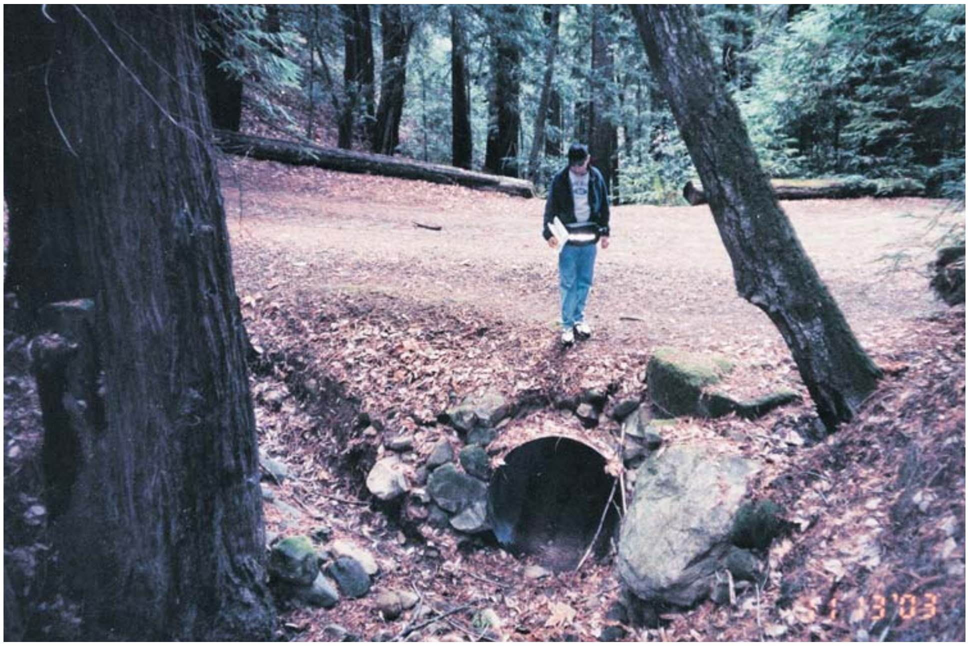
Trail Site #6 Windy Hill Open Space Preserve - Razorback Trail about 1.5 miles from Skyline Blvd.

Trail Site #7 Windy Hill Open Space Preserve - Razorback Trail within 1 mile of Alpine Road

Road Site #3 Windy Hill Open Space Preserve - Razorback Trail near Alpine Road

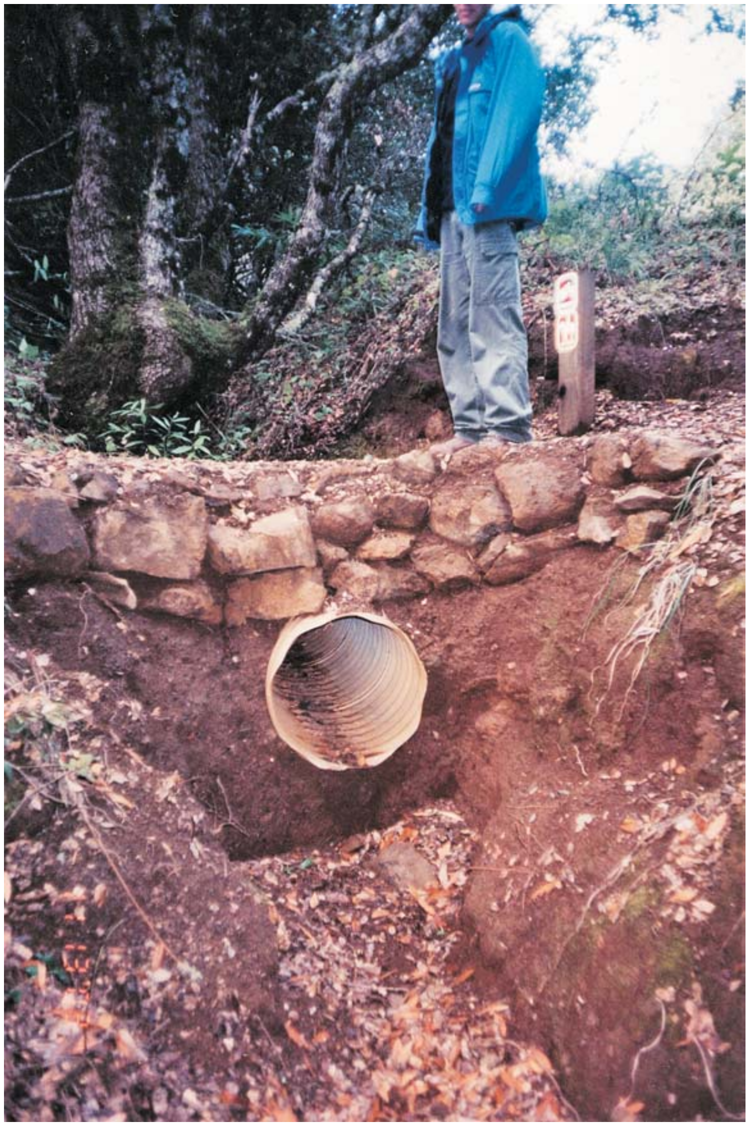
Road Site #4 Huddart County Park - Archery Fire Road about 1/4 mile west of Miwok Picnic Area

Road Site #5 Huddart County Park - Archery Fire Road about 1/4 mile west of Miwok Picnic Area



Road Site #6   Huddart County Park - Dean Trail at McGarvey Gulch

Trail Site #8   Los Trancos Open Space Preserve - Franciscan Loop Trail near Lost Creek Trail



Trail Site #9 Los Trancos Open Space Preserve - Franciscan Loop Trail near Page Mill Trail

APPENDIX C – ESTIMATING EROSION VOLUMES IN SEARSVILLE LAKE, LOS TRANCOS AND BEAR SUBWATERSHEDS

C.1. Searsville Lake

OVERVIEW

Sources in the Searsville Lake watershed that contribute sediment to streams can be divided into two broad categories; discrete sources, such as landslides and gully erosion, and chronic sources, such as bank erosion, sheetwash or surface erosion, and other hillslope erosion processes. As described earlier, landslides are thought to be the dominant erosion process and the greatest effort has applied to documenting this source, with less effort applied to those sources that are thought to be less important overall. The nature of each source, how we identified them in the watershed, and the estimated rates of erosion for the 1995 to 2000 period are described below and summarized in Table C-1. Tables in the main text summarizes erosion volumes contributed to streams from 1995 to 2000 and indicate the range of uncertainty in these estimates and the likely grain sizes of the erosion products.

LANDSLIDES

The inventory of landslides in the Searsville watershed was prepared from two different sources. Frey (2001) mapped landslides along stream channels and classified them as either small or large; the surface area of small landslides was measured whereas large landslides were simply noted. Her surveys followed the large flood of 1998 and her measurements are thought to be fairly representative of the total number of landslides that occurred along valley bottoms near streams from 1995 to 2000, although a few that occurred after her survey may not be included. We estimated the volumes eroded from her small landslides by multiplying the surface area by an average depth of 4 feet, typical for the soil slips or small landslides measured in the Santa Cruz Mountains by Ellen and Weiczorek (1988). Field inspection confirmed that average depths were about 4 feet, but they varied considerably from one slide to another. The eroded material is typically sand with small quantities of gravel and up to 25% silt and clay (see Wentworth et al 1985; Ellen and Weiczorek 1988). We assumed that all the sediment from these landslides entered streams.

Frey identified considerably fewer large landslides than small ones. We do not have a good indication of the size of these landslides so we assumed that their area averaged about twice that of the small landsides, or about 0.08 acres. We assumed the same depth, so the large landslides produced an average sediment volume of 600 yd^3, about double that of the average small landslide. There is considerable uncertainty in the estimated volumes for each landslide and for the total volume from this source. We assumed that all the sediment from these landslides entered streams.

Large landslides on slopes away from stream channels were measured from 2000 stereo air photos (Historic Conditions Memorandum). The inventory focused on landslides with disturbed areas that exceeded 500 yd^2 (0.10 acres) as this appeared to be about the minimum size that would be clearly visible through the forest cover, given the air photo scale. This minimum size is much larger than the average size of the small landslides identified by Frey (2001). We deleted any landslides from the air photo inventory that appeared to match or correspond to sites where Frey had identified landslides, however, for the most part, the landslides she identified could not be identified on the 2000 air photos. We assumed that the landslides that were bare of vegetation on the 2000 air photos occurred during the 1998 storm or at least after 1995 and were part of the yield from 1995 to 2000. We have assumed that these landslides primarily contributed sand and coarser material, with up to 25% silt and clay.

The surface area of each landslide was estimated from the air photos and an eroded volume calculated based on an estimated average landslide depth of 5 ft, typical for the medium and large landslides observed in the Santa Cruz Mountains by Ellen and Weiczorek (1988). The portion of the landslide volume entering a stream was estimated from the general appearance of the landslide and its deposit, if visible. These landslides were divided into natural and man-made types, the latter including those landslides that initiated adjacent to road prisms, where they may have been caused by slope loading or drainage diversion, or those that initiated in areas disturbed by development or other land uses.

Two large landslides were examined during field inspections. The Alpine Road landslide on upper Corte Madera Creek is a large failure that was also described by Frey (2001) and Kittleson *et al* (1996). It appears to be a deep-seated rotational failure that has a displaced volume of over 10,000 yd^3 and that has confined Corte Madera Creek along its toe. The slide initiated well before 1995 although it has continued to be active since then. We included a contribution to Corte Madera Creek of 10,000 yd^3 from this landslide for 1995 to 2000. As noted, this may over-estimate the actual contribution to the creek since 1995. Bank erosion and small landslides along the toe of the failure and their volumes are also incorporated in the budget.

A large debris flow fan has been deposited in Corte Madera Creek at the mouth of Damiani Creek. Frey (2001) notes that much of this deposit formed during the storms of 1998. However, field inspection of vegetation on and near the deposit indicates that it may have been in place for much longer. It appears that much of the coarse sediment carried down Damiani Creek remains in the fan; however, fine sediment was likely carried downstream. We did not include the debris flow volume in the 1995-2000 sediment budget but erosion of the landslide deposit by Corte Madera Creek is included under stream erosion.

STREAM EROSION

Stream erosion is subdivided into bank and bed erosion. Frey (2001) reported bank erosion for all major streams, identifying the percentage of stream reaches that exhibited either moderate or severe bank erosion. We have assumed that all of the observed erosion occurred after 1995 and most occurred during the 1998 flood. Based on field inspections of Corte Madera Creek and its tributaries, we estimated that banks were about 3 feet high;

severe erosion was assumed to consist of 2 feet of retreat on each bank; moderate erosion to consist of 0.67 feet of erosion on each bank. These values likely overestimate the erosion that actually occurred. We have assumed that all the material eroded from banks entered the stream and that the sediment was dominantly sand and gravel, typical of the observed alluvial deposits. The main body of the report describes how natural and human-related erosion were distinguished.

Frey (2001) also noted areas of channel incision in her description of each stream. For the tributaries to Corte Madera Creek and other streams in the Searsville Watershed, we assumed that incision averaged about 1 foot, or 0.3 yd^3/yd, assuming that channel bottoms average about eight feet wide. It was assumed that all material entered the stream and that it was nearly entirely coarse sediment – gravels and cobbles. The record of incision on the tributaries may not be complete, and it is likely that only the more significant incised sections were identified. Incision along Corte Madera Creek was estimated from field inspections in the summer of 2003. The main body of the report describes how natural and human-related incision were distinguished.

STREAM DEPOSITION

Frey (2001) also mapped areas of deposition or aggradation along streams. In steep tributaries, deposition primarily occurred upstream of logjams or in sheltered locations along the channel. Along Corte Madera Creek and other large streams, deposition consisted of sand and gravel in pools and on bar tops, often up to 1 foot or so thick. Based on field inspections, we have assumed that deposition averages about 0.5 feet over the lengths of stream identified as aggrading by Frey (2001), or about 0.15 yd^3/yd, assuming an eight-foot bottom width. The above estimate is likely too high for the tributaries and may be too low for some sections of Corte Madera Creek. Gravel accumulation along Corte Madera Creek is not well documented and is not included in the above estimates.

Deposition is subtracted from total erosion to provide net transport from the subwatershed or sub-subwatershed. Net transport can be negative in some lower reaches of some subwatersheds, indicating net storage of sediment within the sub-subwatershed (see Table C-1).

ROAD EROSION

Erosion along roads is from chronic sheetwash on natural or gravel road surfaces, on cut and fill slopes, and from ditch erosion. Sediment is eroded from paved roads, natural or gravel surfaced roads and trails; often, trails are old roads. The length of existing roads in the individual sub-subwatersheds, both paved and unpaved, is from Appendix E of the Historic Conditions Memorandum. Trails in the Searsville Watershed are included in this inventory as unpaved roads.

Erosion rates for unpaved roads are higher than for paved roads; however, the erosion rates for unpaved roads vary widely depending on climate and the frequency and type of traffic (see Reid and Dunne 1996). Road surfacing, maintenance practices, spacing of drainage structures, road slope and other factors also affect erosion from individual roads

(McCashion and Rice 1983, Reid and Dunne 1984, Rice 1999). Reid and Dunne (1984) provide annual erosion rates for gravel-surfaced logging roads in mountainous watersheds, for different types and frequency of traffic, based on sediment transport measurements. Very high erosion rates occur on road segments with frequent traffic by logging trucks; much lower rates were observed for abandoned roads and those with only light vehicle traffic (McCashion and Rice 1983; Reid and Dunne 1984).

There are no studies of erosion from roads in the San Francisquito Creek watershed. Pacific Watershed Associates (2003) examined erosion along paved and unpaved (assumed mostly natural surface) roads and trails in San Mateo County Parks in Pescadero Watershed in the Santa Cruz Mountains. Predicted future surface erosion from the unpaved roads to streams averaged about 40 yd^3/mi per year over the road network, with most of the erosion expected from that part of the network where long-term lowering of ditches, cut slopes, and road surfaces is assumed to average 0.2 feet/year. Pacific Watershed Associates also estimated surface erosion from trails in the County Parks in the Pescadero Watershed. For the total length of 34.4 miles of trail, erosion averaged about 1.7 yd^3/mile per year, assuming a 6-foot wide trail prism and averaging lowering of 0.2 feet/year at those sites that appeared to have chronic erosion. The blended average erosion rate for all their unpaved roads and trails is 23 yd^3/mile per year.

The estimated average erosion from Reid and Dunne (1984) for light traffic on gravel-surfaced roads is much less than that estimated by Pacific Watershed Associates – only 3.8 tonnes/km per year (5 yd^3/mi per year, assuming 1.5 tonnes/m^3). The volume entering streams would be even less than their quoted erosion value because of deposition between roads and streams. It is our view that the average road erosion quoted by Pacific Watershed Associates would over-estimate contributions to streams if applied in the Searsville Lake watershed. Rainfall is less in Searsville Watershed, roads and trails are often distant from streams, there are relatively few stream crossings on mid and upper slopes (see Figure 8), and many roads and trails have no ditches or drainage structures to convey sediment to streams.

We have adopted an average value that is half of their blended erosion rate (11 yd^3/mile per year) and applied it to all unpaved roads in the Searsville Watershed, including both roads and trails. The sediment eroded from roads that reaches steams is assumed to be mostly silt and clay but may include some sand and is all assumed to be human-related.

Our estimate for surface and ditch erosion from unpaved roads and trails in the Searsville Watershed is likely conservative, particularly when applied to trails. However, a conservative value seems appropriate because some erosion processes along roads are not included in the above total, such as erosion from cut or fill failures, or failure of stream crossings. Some erosion from small failures on cut and fill slopes, which are less than the minimum area included in the air photo inventory, was observed. Field inspections indicate that cut slope failures are unlikely to enter streams as they are intercepted by road surfaces, however, some of these sediments may be later eroded by sheetwash or removed by maintenance activities. Erosion of road crossings is also not included in the above estimate. As noted earlier, there are relatively few crossings by unpaved roads in

Searsville Watershed and past failures of these crossing may not have provided a large contribution to erosion.

Large fill and road surface failures seem to be uncommon. Landslide maps prepared for Portola Valley and Woodside (Rodine 1975; Cummings and Spangle & Associates 1975; Dickinson et al 1992) show few active landslide scarps originating in road prisms, other than in subdivisions along Bull Run and Sausal Creeks, suggesting roads and trails are reasonably stable. Note that these maps do not include all of unpaved roads and trails in the Searsville Lake Watershed.

Erosion along paved roads results from sheetwash on cut and fill slopes, failures on cut and fill slopes, and ditch erosion. Reid and Dunne (1984) estimated that paved road erosion averages 2 tonnes/km per year (2.8 yd^3/mi per year, assuming 1.5 tonnes/m^3) and we have adopted their value for paved roads in the Searsville Lake watershed. Sediment that reaches streams is assumed to be mostly silt and clay with some sand and to all be human-related.

Road erosion in the individual sub-subwatersheds is estimated from the above average annual rates applied to the measured lengths of paved and unpaved roads. Some road segments produce much more sediment than some others; consequently, the average values may result in over- or under-estimating actual road erosion. For instance, significant erosion has been observed on Alpine Road (cut and fill slopes), Highway 84 (debris flows observed during 1982 storm on cut and fill slopes) and on Kings Mountain Road (ditch erosion) and these paved roads are expected to contribute substantially more sediment than other paved road segments. Little is known about which unpaved roads and trails are significant contributors.

SURFACE EROSION

In the Searsville Watershed, surface erosion (sheetwash) is relatively rare on undisturbed, forested slopes and is usually confined to those sites where vegetation and soils are removed or disturbed, or soils are compacted, and overland flow occurs. Such sites include landslide scars, construction sites, range and agricultural lands, fire-damaged areas, and roads and urban developments. Roads are addressed separately in preceding sections. Erosion rates from these processes have not been measured in the Searsville Lake Watershed.

Erosion from landslide scars occurs by surface wash of areas of bare earth exposed by sliding, where vegetative re-growth is still in the early stages, and retreat of slide scarps along the headwall and margins of the slide. We have based our estimates of surface erosion rates on Lehre (1982) who conducted a 3-year study of erosion rates on Lone Tree Creek, a small, mountainous, forested watershed in Marin County. He observed surface erosion of between 2 and 5 mm/year on fresh landslides. We have assumed that surface erosion would average 3 mm/year, equivalent to 16 yd^3/acre per year for fresh or recent landslide scars. This rate was applied to the area of the small and large landslides of Frey and the landslides identified from the air photo inventory. We assumed surface erosion mobilized mostly fine sediment, with some sand, and that all sediment was carried to a stream. Surface erosion from human-related landslides was assigned to the human-related surface erosion category.

Lehre also observed average head scarp retreat of 0.017 yd^3/yd. In Searsville watershed, head scarp widths were estimated from landslide areas by assuming that the ratio of landslide length to width was 5. This rate was applied to the width of the small and large landslides of Frey and the landslides identified from the air photo inventory. We assumed surface erosion mobilized mostly fine sediment, with some sand, and that all sediment was carried to a stream. Scarp retreat from human-related landslides was assigned to the human-related surface erosion category. We assumed scar erosion mobilized mostly fine sediment, with some sand, and all sediment was carried to a stream.

Lehre (1982) also estimated the average rate of surface erosion from grasslands and denuded hillslopes in Lone Tree Creek to be 4 $tonnes/km^2$ per year (9 yd^3/mi^2 per year, assuming 1.5 $tonnes/m^3$). We have applied this average rate to all the area in each sub-subwatershed around Searsville Lake, rather than just grasslands, to account for past human disturbance of hillslopes, some contributions from construction sites, or other activities not explicitly incorporated above. We assume that all this eroded material enters streams and that it consists almost entirely of silt and clay.

While there are considerable uncertainties regarding the applicability of Lehre's estimates to the Santa Cruz Mountains, the total yields from these surface processes are relatively insignificant and it was not judged necessary to refine them further.

CONSTRUCTION SITES

Erosion from construction sites can be substantial, if no sediment and water management controls are in place (see Knott 1973). However, we have assumed that all winter construction and re-construction completed between 1995 and 2000 was well managed and contributed little sediment to creeks in the Searsville Watershed.

GULLIES AND ZERO ORDER STREAMS

Frey (2001) mapped gully intersections with stream channels in the Searsville Lake watershed. However, it is unclear if she identified all gullies or only included eroding gullies. A brief inspection of large-scale maps shows that the stream network included in the GIS database of San Francisquito Creek includes very few small gullies or zero-order channels and swales. Measurements from large-scale maps suggest that the drainage density including these channels may typically be from 4 /mi to 5/mi, whereas drainage densities calculated from the stream lengths in the GIS database are typically around 2/mi (Historic Conditions Memorandum). Consequently, we estimating the length of gullies and zero-order channels in each sub-subwatershed by calculating the total length of the channel network for each sub-subwatershed areas from its area and an estimated density of 4/mi and then subtracting the stream length measured in the GIS database.

Lehre (1982) estimated a gully sidewall erosion rate of 0.013 m^3/m per year (0.016 yd^3/yd per year), combining retreat rates observed on vegetated and bare walls. We have adopted his erosion rate for gullies in the Searsville Lake watershed even though it is uncertain if his rate is applicable there.

Field and air photo inspection suggests that a number of the small gullies and zero-order channels have been disturbed by drainage diversion, road construction or other human activities. We have assumed that about one-third of the gully erosion in each sub-subwatershed results from human disturbance. This is a very rough estimate and is likely to over-estimate disturbance in some watershed and underestimate it in others. The sediment derived from gully erosion was assumed to be about half sand and half silt and clay and to all enter a stream.

SOIL CREEP

Soil creep includes all processes that cause soil to move downslope under gravity, such as animal burrows, frost heave, soil expansion and contraction from wetting and drying or other processes, and plastic flow. Creep occurs at slow rates on most slopes and it is most significant in moving sediment to colluvial banks along steep streams. This sediment is then eroded during floods, and the streambank erosion at the slope toe helps maintain creep. Creep rates are usually not well known and are thought to vary widely. Lehre (1982) estimated creep rates of 11 to 27 yd^3/mi^2 (5 to 12 $tonnes/km^2$ per year) directly to stream banks in Lone Tree Creek; Reid and Dunne (1996) quote typical rates of 10^{-3} m^3/m of stream bank per year, or up to 17 yd^3/ mi^2 for colluvial stream banks. Much higher rates occur at deep-seated landslides or other unstable sites. Brown and Jackson (1973) quote an estimated annual contribution to streams of 1 ton/50 feet in the Moraga Valley in the Oakland Hills.

We have not included soil creep as a sediment source in our short-term budget because its contributions are later mobilized by bank erosion and we wish to avoid counting the same sediment contribution twice. However, in the long-term, creep and other slope processes carry the sediment downslope that is moved to streams by landslides and erosion of colluvial bank deposits.

C.2. Los Trancos

OVERVIEW

Sediment sources in the Los Trancos watershed that contribute to streams can be divided into two broad categories; discrete sources, such as landslides and gully erosion, and diffuse sources, such as bank erosion, sheetwash or surface erosion, and other hillslope erosion processes. The nature of each source, how we identified them in the watershed, and the estimated rates of erosion for the 1995 to 2000 period followed the procedures adopted for Searsville Lake Watershed, with the exceptions described below. Erosion estimates are summarized in Table C-2. Tables in the main text summarize erosion volumes contributed to streams between 1995 and 2000 and indicate the range of uncertainty in these estimates and the likely grain sizes of the erosion products.

LANDSLIDES

The area or volume of sediment contributed by streamside landslides in Los Trancos Watershed has not been measured. We attempted to correlate the small landslide volumes for in Searsville Lake Watershed to the erosivity index described below and to other physical characteristics of the sub-subwatersheds. However, we were unable to construct a satisfactory predictive relationship in the Searsville Watershed that could be applied to the Los Trancos sub-subwatersheds. Instead, we estimated the volume of streamside landslides by balancing erosion and sediment transport, calculating the small landslide contribution as the remainder. Estimated erosion was about equal to transport in Los Trancos and the volume from small and large streamside landslides was arbitrarily set to zero. This was consistent with field observations of the main channel of Los Trancos Creek. We saw no evidence of small landslides entering the creek from steep lower valley slopes, which are mostly distant from the creek. However, streamside landslides may be more important in the upper watershed, which was not inspected.

STREAM EROSION

We also did not have any information on where bank erosion occurred in Los Trancos watershed or the severity of the erosion that occurred. To correct this deficiency, we correlated the percentage stream length with severe or moderate bank erosion observed in Searsville Lake Watershed to an erosivity index constructed by adding the percentages of erosive geology, stream length with erosive slope, and stream length near a landslide zone listed in the sub-subwatershed characteristics included in the Historic Conditions Memorandum. The relationships showed reasonably high correlations and they were applied to estimate the percent severe and moderate in the sub-subwatersheds in the sub-subwatersheds. Once the eroding bank lengths were predicted, erosion volumes were calculated as described previously (Table C-2).

The extent of channel incision was based on existing reports and field inspections (see main text). We observed no recent incision along Los Trancos Creek, other than its lowest 500 feet or so. One small tributary to Los Trancos Creek in Los Trancos Woods (LT-06) showed one or two feet of recent incision that is included in the gully erosion estimates.

STREAM DEPOSITION

The volumes of coarse sediment deposited along Los Trancos Creek and its tributaries were estimated from existing reports and field observations. We observed accumulation of cobble, gravel and sand along much of Los Trancos Creek in LT-03, LT-04 and LT-06. Deposition volumes were estimated by assuming that deposition averaged 0.25 feet over the stream bottom over about half of the stream length in each of these sub-subwatersheds. Deposition is also reported in a marsh or wetland in Buckeye Creek (LT-05); however, we did not inspect this creek to confirm if this occurs and have not included this area is our total.

C.3. Bear Subwatershed

OVERVIEW

Sediment sources in the Bear Creek watershed that contribute to streams can be divided into two broad categories; discrete sources, such as landslides and gully erosion, and diffuse sources, such as bank erosion, sheetwash or surface erosion, and other hillslope erosion processes. The nature of each source, how we identified them in the watershed, and the estimated rates of erosion for 1995 to 2000 followed the procedures adopted for Searsville Lake Watershed, with the exceptions described below. Erosion volumes are summarized in Table C-2. Tables in the main text summarize erosion volumes contributed to streams between 1995 and 2000 and indicate the range of uncertainty in these estimates and the likely grain sizes of the erosion products.

LANDSLIDES

The area or volume of sediment contributed by streamside landslides in Bear Watershed has not been measured. We attempted to correlate the small landslide volumes in Searsville Lake Watershed to the erosivity index described below and to other physical characteristics of the sub-subwatersheds. However, we were unable to construct a satisfactory predictive relationship in the Searsville Watershed that could be applied to the Bear sub-subwatersheds. Instead, we estimated the volume of small landslides by roughly balancing erosion and transport volumes, calculating the small landslide contribution as the remainder. On this basis about 10,000 yd^3 was assigned to this process, distributed roughly evenly over the eight steeper sub-subwatersheds – Bear (BG-02 and 03), Appletree, Tripp, Squealer, and McGarvey Gulches and upper West Union Creek (WUC-9 and WUC-11) (see Table C-2).

STREAM EROSION

We also did not have any information on where bank erosion occurred in Bear sub-subwatersheds or the severity of the erosion that occurred. To correct this deficiency, we correlated the percentage stream length with severe or moderate bank erosion observed in Searsville Lake Watershed to an erosivity index constructed by adding the percentages of erosive geology, stream length with erosive slope, and stream length near a landslide zone listed in the sub-subwatershed characteristics included in the Historic Conditions Memorandum. The relationships showed reasonably high correlations and they were applied to estimate the percent severe and moderate bank erosion in the Bear sub-subwatersheds. Once the eroding bank lengths were predicted, erosion volumes were calculated as described previously.

Observations by Smith and Harden (2001) indicated long-term incision on Bear Creek and West Union Creek but they identified no evidence of recent incision (see main text). However, they identified incision along Bear Gulch downstream of the CalWater diversion (BG-01 and much of BG-02) as a result of interception and removal of coarse material load. We have assumed that incision of about one foot occurred along half of the stream channel in these two sub-watersheds from 1995 to 2000 (Table C-2).

STREAM DEPOSITION

Volumes of coarse sediment deposited along Bear Creek and its tributaries were estimated from existing reports and field observations. Smith and Harden (2001) reported sporadic accumulation of sand and fine sediment along Bear Creek and West Union Creek. We have assumed that deposition covers about one-quarter of the length of stream in BC-01, BG-01, BC-02, WUC-03, WUC-05 and WUC-07 to a depth of about 0.25 feet. Some deposition likely also has occurred in the steep upper tributaries but it is not included in our sediment sources.

Appendix C-1: Sediment Budget Searsville Lake Watershed
Years 1995 to 2000

Sub-Watershed	CM1	CM2	CM3	CM4	CM5	CM6	CM7	CM8	CM9	CM10	CM5/7	CM11	CM12		AC1	MC1	SC1	SC2	SC3	SC4	SC5	SC6	SL1	SL2		
PHYSICAL CHARACTERISTICS	Corte Madera	Corte Madera	Hamms	Jones	Creek A	Damiani	Creek B	Rengstorff	Coal	Corte Madera	Middle CM	Creek C	Uppe Corte M	*Subtotal*	Alam-bique	Martin	Upper Sausal	Bull Run	Unnamed	Neils	Bozzo	Sausal	West Ridge	West Ridge	*Subtotal*	***Grand Total***
Area (acres)	811	589	378	361	251	283	337	117	237	86	-	357	560	*4,367*	1492	790	381	409	138	231	280	107	523	556	*4,907*	***9,274***
Stream Length (feet)	8810	7459	6976	5905	3497	3969	5682	2808	3215	1446	12100	5745	7253	*74,865*	13524	8420	4798	8151	3414	5938	5864	2060	3082	11049	*66,300*	***141,165***
Road Length paved (mi)	10.4	9.5	0	2.7	0.9	0.9	2.2	1.1	1.8	0.5	-	2.6	3.1	*36*	7.2	8.9	4.6	2.9	2.3	0.5	0.7	0.7	2.6	4.4	*35*	***71***
Road Length native (mi)	1	2	1.4	1.8	0.6	0.8	1.7	0	0.1	0.2	-	1.8	3.7	*15*	11.6	2.9	1.6	3.6	0.8	1.2	0.8	0.5	3.5	0.9	*27*	***43***
Total Road Length (mi)	11.4	11.5	1.4	4.5	1.6	1.8	3.8	1.2	1.8	0.7	-	4.4	6.8	*51*	18.8	11.8	6.3	6.6	3.1	1.6	1.6	1.3	6.1	5.3	*63*	***113***
STREAM EROSION																										
Percent Severe Bank Erosion (%)	0.398	0.386	0.447	0.434	0.479	0.588	0.374	0.25	0.421	0.559	0.237	0.633	0.934		0.197	0.141	0.069	0.148	0.005	0.162	0.162	0.069	0.005	0.005		
Percent Moderate Bank Erosion (%)	0.183	0.304	0.391	0.361	0.273	0.163	0.549	0.15	0.269	0	0.304	0.303	0.061		0.215	0.42	0.176	0.45	0.005	0.177	0.177	0.176	0.01	0.01		
Incised Length (feet)	0	1640	0	984	0	0	656	0	0	0	4000	984	0	*8,264*	6560	4592	0	1000	0	1000	1000	0	0	0	*14,152*	***22,416***
Incised Volume (yd^3)	0	492	0	295	0	0	197	0	0	0	2680	295	0	*3,959*	1968	1378	0	300	0	300	300	0	0	0	*4,246*	***8,205***
Net Stream Erosion (yd^3)	1564	1870	1520	1533	765	998	1359	323	628	323	4195	1924	2754	*19,757*	3324	2206	217	1149	9	790	784	93	9	33	*8,614*	***28,372***
Human-Caused Component (yd^3)	391	468	0	0	191	0	340	0	0	81	1049	0	0	*2,519*	0	552	0	287	0	0	0	47	0	17	*902*	***3,421***
STREAM DEPOSITION																										
Percent Aggraded (%)	1	1	0.382	0.315	0.602	0.588	0.689	0.5	0.539	0.5	0.642	0.732	1		0.336	0.3	0.4	0.45	0.4	0.458	0.458	0.71	0.224	0.224		
Net Stream Storage (yd^3)	(1322)	(1119)	(400)	(279)	(316)	(350)	(587)	(211)	(260)	(108)	(1165)	(631)	(1088)	*(7,835)*	(682)	(379)	(288)	(550)	(205)	(408)	(403)	(219)	(104)	(371)	*(3,608)*	***(11,444)***
LANDSLIDE EROSION																										
No of Small Landslides	8	8	38	30	22	51	19	5	18	4	11	45	81	*340*	47	25	0	34	0	12	14	0	1	0	*133*	***473***
Area of Small Landslides (acres)	0.3	0.3	1.4	1.0	0.9	1.8	1.0	0.2	1.1	0.2	0.5	2.0	9.2	*20*	3.27	2.16	0	1.26	0	0.46	0.5	0	0.17	0	*8*	***28***
Small Landslide Erosion (yd^3)	2,000	2,065	9,033	6,323	6,065	11,678	6,400	1,290	6,904	1,161	3,123	12,775	59,294	*128,111*	21098	13936	0	8130	0	2968	3226	0	1097	0	*50,455*	***178,566***
Human-caused Component (yd^3)	500	516	0	0	1,516	0	1,600	0	0	290	781	0	0	*5,204*	0	3484	0	2032	0	0	0	0	0	0	*5,516*	***10,720***
No of Big Landslides	0	1	0	0	1	0	7	0	0	0	-	1	11	*21*	0	3	0	6	0	0	0	0	0	0	*9*	***30***
Big Landslide Erosion (yd^3)	0	600	0	0	600	0	4,200	0	0	0	-	600	6,600	*12,600*	0	1800	0	3600	0	0	0	0	0	0	*5,400*	***18,000***
No Air Photo Landslides - Natural	0	0	0	1	3	3	7	0	1	0	-	0	7	*22*	0	0	0	0	0	0	0	0	0	0	*0*	***22***
Area of Natural Landslides (acres)	0.0	0.0	0.0	0.1	0.5	1.2	1.9	0.0	0.1	0.0	-	0.0	2.4	*6.1*	0	0	0	0	0	0	0	0	0	0	*0*	***6***
AP Landslide Erosion - Natural (yd^3)	0	0	0	598	3,984	9,363	15,538	0	598	0	-	0	19,323	*49,403*	0	0	0	0	0	0	0	0	0	0	*0*	***49,403***
No Air Photo Landslides - ManMade	0	0	0	0	0	0	1	0	0	0	-	0	3	*4*	0	0	0	0	0	0	0	0	0	0	*0*	***4***
Area of ManMade Landslides (acres)	0	0	0	0	0	0	0.3	0	0	0	-	0	3.5	*3.8*	0	0	0	0	0	0	0	0	0	0	*0*	***4***
AP Landslide Erosion - ManMade (yd^3)	0	0	0	0	0	0	2,390	0	0	0	-	0	28,287	*30,677*	0	0	0	0	0	0	0	0	0	0	*0*	***30,677***
SURFACE EROSION (yd^3)																										
Paved Road Erosion	146	133	0	38	13	13	31	15	25	7	-	36	43	*500*	101	125	64	41	32	7	10	10	36	62	*487*	***987***
Unpaved Road and Trail Erosion	55	110	77	99	33	44	94	0	6	11	-	99	204	*831*	638	160	88	198	44	66	44	28	193	50	*1,507*	***2,338***
Scar Erosion -- Natural	25	26	112	84	115	238	233	16	92	14	-	158	927	*2,040*	262	173	0	101	0	37	40	0	14	0	*626*	***2,665***
Scar Erosion -- Man-made	0	0	0	0	0	0	24	0	0	0	-	0	281	*304*	0	0	0	0	0	0	0	0	0	0	*0*	***304***
Slide Scarp Retreat -- Natural	2	2	4	4	4	6	6	2	4	1	-	5	12	*50*	6	5	0	4	0	2	2	0	1	0	*21*	***71***
Slide Scarp Retreat -- Man-Made	0	0	0	0	0	0	2	0	0	0	-	0	6	*8*	0	0	0	0	0	0	0	0	0	0	*0*	***8***
Sheet Erosion	57	41	27	25	18	20	24	8	17	6	-	25	39	*307*	105	56	27	29	10	16	20	8	37	39	*345*	***652***
GULLY EROSION																										
Estimated Gully Length (ft)	17,953	11,978	5,498	6,008	4,786	5,370	5,439	1,053	4,606	1,392	-	6,036	11,227	*81,346*	35,712	17,650	7,775	5,346	1,140	1,685	3,376	1,471	14,177	7,299	*95,631*	***176,977***
Gully Wall Erosion (yd^3)	479	319	147	160	128	143	145	28	123	37	-	161	299	*2,169*	952	471	207	143	30	45	90	39	378	195	*2,550*	***4,719***
Human-caused Component (yd^3)	158	105	48	53	42	47	48	9	41	12	-	53	99	*716*	314	155	68	47	10	15	30	13	125	64	*842*	***1,557***
TOTAL HUMAN-CAUSED	1,307	1,374	152	215	2,728	124	5,466	33	88	407	1,829	214	28,959	*41,066*	1,158	4,531	248	2,634	96	104	103	104	390	231	*9,599*	***50,665***
TOTAL NATURAL	3,020	3,793	10,767	8,649	11,741	25,123	24,979	1,650	8,307	1,154	5,488	15,570	89,110	*203,862*	25,328	14,400	356	10,759	29	3,827	4,113	73	1,374	147	*60,406*	***264,268***
TOTAL EROSION	4,327	5,166	10,919	8,864	11,724	22,502	30,445	1,683	8,395	1,562	7,318	15,784	118,069	*246,758*	26,486	18,931	603	13,393	125	3,931	4,216	177	1,765	378	*70,005*	***316,763***
ADJUSTED FOR DEPOSITION	3,005	4,048	10,519	8,585	11,408	22,152	29,858	1,472	8,135	1,453	6,152	15,153	116,981	*238,923*	25,805	18,552	316	12,843	(80)	3,523	3,813	(42)	1,661	7	*66,397*	***305,319***
eroded material as % of total	1.4%	1.6%	3.4%	2.8%	3.7%	7.1%	9.6%	0.5%	2.7%	0.5%	2.3%	5.0%	37.3%		8.4%	6.0%	0.2%	4.2%	0.0%	1.2%	1.3%	0.1%	0.6%	0.1%		
Natural Erosion (yd^3/acre)	0.74	1.29	5.70	4.79	9.36	17.75	14.82	2.82	7.01	2.68		8.72	31.82	9.34	3.40	3.65	0.19	5.26	0.04	3.31	2.94	0.14	0.53	0.05	2.46	5.70
Man-Made Erosion (yd^3/acre)	0.32	0.47	0.08	0.12	2.17	0.09	3.24	0.06	0.07	0.95		0.12	10.34	1.88	0.16	1.15	0.13	1.29	0.14	0.09	0.07	0.19	0.15	0.08	0.39	1.09
Total Erosion (yd^3/acre)	1.07	1.75	5.78	4.91	11.53	17.84	18.07	2.88	7.08	3.63		8.84	42.17	11.22	3.55	4.79	0.32	6.55	0.18	3.40	3.01	0.33	0.67	0.14	2.85	6.79

Appendix C-2: Sediment Budget Los Trancos & Bear Creeks
Years 1995 to 2000

	LT1	LT2	LT3	LT4	LT5	LT6	LT7		BC-1	BC-2	BG-1	BG-2	BG-3	WUC-1	WUC-2	WUC-3	WUC-4	WUC-5	WUC-6	WUC-7	WUC-8	WUC-9	WUC-10	WUC-11		
Subwatershed	*Los Trancos*	*Los Trancos*	*Los Trancos*	*Los Trancos*	*Buckeye Ck*	*Los Trancos*	*Los Trancos*	*Subtotal*	*Bear Creek*	*Bear Creek*	*Bear Gulch*	*Bear Gulch*	*Bear Gulch*	*West Union*	*Appletree Gulch*	*West Union*	*Tripp Gulch*	*West Union*	*Squealer Gulch*	*West Union*	*McGarvey Gulch*	*West Union*	*West Union*	*West Union*	*Subtotal*	*TOTAL*
PHYSICAL CHARACTERISTICS																										
Area (acres)	405	555	534	649	920	1000	807	4,870	618	964	428	1239	583	170	242	139	271	192	528	281	543	272	64	875	7,409	12,279
Stream Length (feet)	8771	13049	16010	10225	15138	14723	9313	87,229	5537	19115	8838	17713	12092	1558	6556	2215	7313	3179	12872	3895	9343	7468	2068	16781	136,543	223,772
Road Length paved (mi)	3.7	2.7	6.7	8.0	5.1	6.4	3.4	36	7.8	18.2	5.9	2.3	0.6	1.7	1.0	1.7	0.9	2.1	4.3	2.2	0.6	0.1	0.0	0.8	50	86
Road Length native (mi)	0.8	1.0	1.2	1.4	4.3	3.6	2.5	15	1.6	0.7	0.5	4.2	2.8	0.7	0.1	0.0	0.0	0.2	2.1	2.1	3.9	0.7	0.1	0.2	20	35
Total Road Length (mi)	4.5	3.7	7.9	9.4	9.4	10.0	5.9	51	9.4	18.9	6.4	6.5	3.4	2.4	1.1	1.7	0.9	2.3	6.4	4.3	4.5	0.8	0.1	1.0	70	121
STREAM EROSION																										
Percent Severe Bank Erosion (%)	0.042	0.036	0.028	0.013	0.005	0.032	0.162		0.074	0.031	0.079	0.256	0.249	0.024	0.252	0.025	0.344	0.073	0.188	0.088	0.214	0.169	0.076	0.230		
Percent Moderate Bank Erosion (%)	0.092	0.083	0.070	0.042	0.021	0.077	0.232		0.136	0.075	0.142	0.316	0.310	0.062	0.313	0.064	0.387	0.135	0.256	0.153	0.280	0.238	0.138	0.294		
Incised Length (feet)	0	0	0	0	0	0	0	0	0	0	4419	8857	0	0	0	0	0	0	0	0	0	0	0	0	13,276	13,276
Incised Volume (yd^3)	0	0	0	0	0	0	0	0	0	0	663	1328	0	0	0	0	0	0	0	0	0	0	0	0	1,991	1,991
Net Stream Erosion (yd^3)	228	296	291	96	62	302	820	2,095	239	380	1068	3702	1579	25	866	36	1289	136	1297	197	1061	683	91	2037	14,687	16,782
Human-caused Component (yd^3)	0	0	73	24	0	75	0	172	60	95	764	1328	0	6	0	9	0	34	0	0	0	0	0	0	2,297	2,469
STREAM DEPOSITION																										
Percent Aggraded (%)	0	0	0.5	0.5	0.5	0	0		0.25	0.25	0.25	0	0	0.25	0	0.25	0	0.25	0	0	0	0	0	0		
Net Stream Storage (yd^3)	0	0	(736)	(470)	(696)	0	0	(1,903)	(202)	(440)	(203)	0	0	(36)	0	(51)	0	(73)	0	0	0	0	0	0	(1,005)	(2,908)
LANDSLIDE EROSION																										
No of Small Landslides	0	0	0	0	0	0	0	0	0	0	0	5	6	0	5	0	5	0	6	0	5	6	0	6	44	44
Area of Small Landslides (acres)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.000	0.000	0.000	0.175	0.210	0.000	0.175	0.000	0.175	0.000	0.210	0.000	0.175	0.210	0.000	0.210	1.5	2
Small Landslide Erosion (yd^3)	0	0	0	0	0	0	0	0	0	0	0	1129	1355	0	1129	0	1129	0	1355	0	1129	1355	0	1355	9,936	9,936
Human-caused Component (yd^3)																										
No of Big Landslides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Big Landslide Erosion (yd^3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No Air Photo Landslides - Natural	0	0	0	0	1	4	4	9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	10
Area of Natural Landslides (acres)	0	0	0	0	0.25	0.53	0.25	1.0	0.00	0	0	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	1
AP Landslide Erosion - Natural (yd^3)	0	0	0	0	1991	4281	1991	8,264	0	0	0	0	597	0	0	0	0	0	0	0	0	0	0	0	597	8,861
No Air Photo Landslides - ManMade	0	0	0	2	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Area of ManMade Landslides (acres)	0	0	0	0.07	0	0.44	0	0.5	0	0	0	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	1
AP Landslide Erosion - ManMade (yd^3)	0	0	0	597	0	3584	0	4,182	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4,182
SURFACE EROSION																										
Paved Road Erosion	52	38	94	112	71	90	48	504	109	255	83	32	8	24	14	24	13	29	60	31	8	1	0	11	703	1,207
Unpaved Road and Trail Erosion	44	55	66	77	237	198	138	814	88	39	28	231	154	39	6	0	0	11	116	116	215	39	6	11	1,095	1,909
Scar Erosion -- Natural	0	0	0	0	20	42	20	82	0	0	0	14	23	0	14	0	14	0	17	0	14	17	0	17	129	211
Scar Erosion -- Man-made	0	0	0	6	0	36	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
Scarp Erosion -- Natural	0	0	0	0	2	2	2	6	0	0	0	1	2	0	1	0	1	0	2	0	1	2	0	2	12	18
Scarp Erosion -- Man-made	0	0	0	1	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Sheet Erosion	28	39	38	46	65	70	57	342	43	68	30	87	41	12	17	10	19	14	37	20	38	19	5	62	521	863
GULLY EROSION																										
Estimated Gully Length (ft)	4,594	5,266	1,612	11,192	15,222	18,277	17,318	73,481	14,857	12,697	5,286	23,174	7,147	4,052	1,430	2,372	1,630	3,157	4,552	5,378	8,576	1,508	44	12,094	107,954	181,435
Gully Wall Erosion (yd^3)	123	140	43	298	406	487	462	1,959	396	339	141	618	191	108	38	63	43	84	121	143	229	40	1	323	2,879	4,838
Human-caused Component (yd^3)	37	42	13	90	122	146	139	588	119	102	42	0	0	32	11	19	13	25	36	43	69	12	0	97	621	1,209
TOTAL HUMAN-CAUSED	161	174	283	952	494	4,202	380	6,647	419	558	947	1,679	203	113	48	62	45	113	249	209	330	71	10	180	5,236	11,883
TOTAL NATURAL	314	395	249	281	2,359	4,894	3,156	11,646	457	522	402	4,136	3,747	94	2,037	72	2,464	161	2,756	297	2,366	2,084	92	3,636	25,323	36,969
TOTAL EROSION	475	568	532	1,233	2,853	9,095	3,536	18,293	876	1,080	1,349	5,815	3,950	207	2,085	133	2,509	274	3,005	506	2,696	2,155	103	3,817	30,559	48,852
ADJUSTED FOR DEPOSITION	475	568	(205)	763	2,157	9,095	3,536	16,390	674	640	1,146	5,815	3,950	171	2,085	82	2,509	201	3,005	506	2,696	2,155	103	3,817	29,554	45,944
Total erosion as % of Watershed Total	2.6%	3.1%	2.9%	6.7%	15.6%	49.7%	19.3%		1.8%	2.2%	2.8%	11.9%	8.1%	0.4%	4.3%	0.3%	5.1%	0.6%	6.2%	1.0%	5.5%	4.4%	0.2%	7.8%		
Natural Erosivity (yd^3/acre)	0.77	0.71	0.47	0.43	2.56	4.89	3.91	2.39	0.74	0.54	0.94	3.34	6.43	0.55	8.42	0.51	9.09	0.84	5.22	1.06	4.36	7.66	1.44	4.16	3.42	3.01
Human-Related Erosivity (yd^3/acre)	0.40	0.31	0.53	1.47	0.54	4.20	0.47	1.36	0.68	0.58	2.21	1.35	0.35	0.66	0.20	0.44	0.16	0.59	0.47	0.74	0.61	0.26	0.16	0.21	0.71	0.97
Total Erosivity (yd^3/acre)	1.17	1.02	1.00	1.90	3.10	9.10	4.38	3.76	1.42	1.12	3.15	4.69	6.78	1.22	8.62	0.96	9.26	1.43	5.69	1.80	4.96	7.92	1.60	4.36	4.12	3.98

Table D-1: Potential Practices for the Recommended Management Measures

Management Measure	***Management Practices***	***Sources***
Landslide Initiation at Roads	-Road re-alignment -Road decommissioning -Drainage system improvement	See Weaver and Hagans 1994; Atkins *et al* 2001; SCVURPPP (2003a)
Existing Landslide Scars or Unstable slopes and zero order channels	-Drainage system improvement -Geotechnical slope stabilization practices for important sources (site-specific engineering plans) - Revegetation and bioengineering (blankets, fabrics, berms, seeding, staking, pole drains, etc) -Removal and storage of landslide debris	See above; San Mateo County (2001) provides BMPs for bio-engineering and debris removal and storage
Emergency sediment management	See list above	See above
Hydromodification	Practices consist of either on-site controls or regional facilities -On-site includes bio-retention, swales, maintaining infiltration, soil amendments, cisterns, vaults, wetlands and ponds and other features -Regional facilities include detention, retention or bypass diversions	On-site suitable for redevelopment controls. See GeoSyntec (2003), EPA (2002) for discussion of measures and practices.
Stream bank erosion	-Bank stabilization and revegetation plans -Biotechnical or bioengineering stabilization (few techniques are successful for the incised, active streams in the watershed)	See **nhc** *et al* (2003) for example of a plan. Schiechtl and Stern (1997) provide an overview; San Mateo County (2001) and SCVURPPP (2003a)
Channel incision	-Add coarse sediment to the stream -Grade control or profile adjustment -Floodplain restoration or creation -Channel restoration, including adding large woody debris -Transportation facility modification or reconstruction	Few guidelines available; site engineering plans recommended
Sediment Trapping or Removal	-Return coarse sediment to the stream	Few guidelines available

Management Measure	***Management Practices***	***Sources***
Stream maintenance procedures	-Removal of vegetation -Management of LWD	See SCVWD (2002); San Mateo County (2001); SCVURPPP (2003a) for BMP
Surface erosion from roads and trails	-Road deactivation or decommissioning (water bars or other features) -Stabilization of cut banks and ditches; revegetation -Repair of crossings; removal of fills and stream or gully crossings	See Weaver and Hagans 1994; Pacific Watershed Associates (2003) for a local example. See also SCVURPPP (2003a)
Land surface erosion from urban areas	-Temporary BMP for construction -Re-grading -Drainage improvements -Vegetative buffers -Water quality inlets -Slope buffers -Sediment traps	See City of Palo Alto for BMP and plans for construction. Handbooks from CASQA website
Gully and zero order stream erosion	-Reduced grazing in agricultural areas -Gully stabilization and grade control -Drainage modifications -Revegetation	See Atkins *et al* (2001)