CHAPTER 3: HYDROLOGY, GEOMORPHOLOGY & WATER QUALITY

3.0 Introduction

This chapter describes the natural processes and human impacts that have influenced the landscape from which the District's water supply flows. The chapter begins with an overview of landscape evolution, describing the natural processes and human activities that have contributed to shaping the landscape. The chapter then provides an overview of the geology and soil types. Finally, the chapter discusses human impacts and land use activities in terms of their impacts to water quality.

Hydrology is the study of the distribution of water on and near the earth's surface. Because the amount of water is finite, it constantly moves through the hydrologic cycle in processes known as precipitation, infiltration, percolation and groundwater storage, evaporation and transpiration, and surface water runoff.

Geomorphology is the study of landforms, their origin and evolution, and the processes that shape them. Landforms can be characterized by their elevation, slope, orientation, stratification, rock exposure, and soil type. The science of geomorphology seeks to explain why landscapes appear the way they do, and it seeks to use this information to predict future changes. Landscapes include landforms, climatic factors, flora and fauna, and the built environment.

Scientists predict that climate change will increasingly impact the hydrologic cycle, but the degree and severity of the impacts of climate change on local watersheds and water supplies is not known. Scientific research applicable to the central California coast indicates that climate change will bring increasingly higher temperatures, more extreme droughts and more intense rainfall. All of these factors are expected to impact the local region's water resources. Chapter 7: Local Climate Change Assessment presents a more detailed discussion of the impacts of climate change, as well as potential adaptation and mitigation actions.

3.1 Overview of landscape evolution

This section begins with an overview of the geologic processes that formed and continue to shape the Santa Cruz Mountains as a region. It then describes the three geologic areas of the San Lorenzo River watershed, and their soil types. Finally, it summarizes the role of human influences on the landscape, resulting from land use changes that began about 200 years ago.

3.1.1 Geologic formation of the Santa Cruz Mountains

According to the theory of plate tectonics, the earth's crust is formed by a number of rigid plates, which move under (a process known as subduction) and against each other, causing major dynamic events, such as uplift of mountain ranges, and earthquakes (Harden, 1998). About 145 million years ago, the Farallon Plate began to collide with the North American Plate, resulting in the subduction of the Farallon plate. During this subduction, parts of the Farallon plate were scraped off onto the North American Plate in a process called accretion (Sloan, 2006). This accretion took place over a period of about 100 million years, producing the Mesozoic rocks in today's Bay Area (Sloan, 2006).

About 28 million years ago, the subduction of the Farallon Plate was complete, bringing the Pacific Plate into direct contact with the North American Plate. Movement between these two plates no longer involved subduction. Instead, the Pacific Plate slipped northward against the North American Plate, in a roughly parallel fashion, along the San Andreas Fault, which extends from Cape Mendocino to the Gulf of California. About 3-4 million years ago, the Pacific Plate shifted slightly to move obliquely to the North American Plate (Harden, 1998). This shift caused the two plates to converge, and this tectonic compression of the earth's crust caused the uplift of the Coast Ranges of California, including the Santa Cruz Mountains. This compression continues today, and the Coast Ranges continue to be uplifted. For example, the 1989 Loma Prieta earthquake caused the Santa Cruz Mountains west of the San Andreas Fault to rise approximately 1.2 meters (Harden, 1998).

This uplift exposed older geologic units--predominately marine sedimentary rocks--to weathering, to surface erosion, and to erosion from mass wasting and landslides. Recent geologic and climatic conditions, associated with the end of the last ice age, formed stream valleys and drainage networks, through surface erosion and mass wasting. This weathering produced soil, a mix of inorganic minerals and organic matter. These initial soils formed the basis of life for surface vegetation, microbes, and bacteria. Alluvium or "geologic erosion" from these natural processes line most stream valleys in the San Lorenzo River watershed.

3.1.2 Geologic formation of the San Lorenzo River watershed

Within the San Lorenzo River watershed, movement along local fault zones formed three distinctive geologic areas (Hecht & Kittleson, 1998; Swanson Hydrology & Geomorphology, 2001), each with different soil types. The Ben Lomond Mountain geologic unit, on the west side of the watershed, is the source of all of the District's surface water. The District's ground water is supplied from a different geologic area, with different soil types. These geologic areas are depicted in Figure 3-10, and described in detail in Section 3.3, Geology and Hillslope Geomorphology.

3.1.3 Human impacts from land use changes

Landscape evolution of the region and the San Lorenzo River watershed also reflects very recent and profound changes in human land use patterns.

Changes in land-use practices that occurred between 1800 and 1910 caused significant impacts to vegetation, as well as geomorphic and hydrologic processes. Plants that existed prior to introduction of European land uses in the early 1800s were adapted to existing climatic and prehistoric land-use conditions. These conditions have been described by early expeditions of white settlers and explorers, and included the practice of setting fires by Native Americans.

Most of the forested land within the San Lorenzo River watershed was clearcut. Streams were diverted, and roads were built. Today, these are known as "legacy" conditions. Effects of legacy land use were immediate and profound, and some effects are ongoing. Legacy roads and railroad grades caused chronic erosion. As hillslope erosion increased, more sediment was delivered to stream valleys, deepening alluvial deposits and filling stream channels with sediment. Streams would eventually flush out the excess sediment, but higher, unconsolidated stream banks, more prone to erosion, would result. As the human population grew within the watershed, roads and development also increased. The continued use of logging roads as residential access roads created chronic sources of erosion and sedimentation. The pervasive road network, especially unpaved and poorly maintained roads, continues today as the most persistent sources of sedimentation to streams (Santa Cruz County Planning Department, 1998, CCRWQCB staff report for TMDL, 2002). As previously mentioned, county and state agencies have initiated grant-based programs to address some of the problems of these poorly constructed and maintained roads.

3.2 Hydrologic processes

This section summarizes available information for the larger San Lorenzo River watershed, as well as information specific to the District's water supply sub-watersheds and aquifers. Hydrological processes include precipitation, evapotranspiration, streamflow and diversions, groundwater storage, and recharge.

3.2.1 Precipitation in the San Lorenzo River watershed

Three precipitation measurement stations in the watershed have relatively long records: the Santa Cruz and Ben Lomond 4 NOAA stations and the station near the crest of Ben Lomond Mountain now maintained by the nearby Lockheed facility. The available monthly records of these three stations extend back to 1931, 1973, and 1959, respectively. Annual rainfall at Santa Cruz, Ben Lomond, and Lockheed averages approximately 30, 50, and 55 inches per year (in/yr), respectively. Monthly rainfall records maintained by the District since 1981 at its office in Boulder Creek correlate reasonably well with the Ben Lomond 4 annual record. Average rainfall at both stations is about 50 in/yr. (Johnson, 2008. In progress).

Mean annual rainfall exceeds 60 inches along the crest of Ben Lomond Mountain. Figure 3.1 shows mean annual precipitation on Ben Lomond Mountain and the San Lorenzo River watershed to the east of the ridge. The highest rain per day recorded since 1972 for Ben Lomond was 11.46 inches on January 4, 1982 (Ben Lomond Station 040673, 2003). In 1982, the calendar year of highest recorded precipitation for the watershed, the District recorded 111.48 inches, as shown in Table 3-1. The driest recorded year for the watershed was during the drought of the late 1970s, with 22.14 inches of rainfall recorded by the District during the water year 1976-77 year, as shown in Table 3-1.

Approximately 90 percent of annual rainfall occurs between November and April. During the rainy season, six to ten consecutive days of rainfall is not unusual for the San Lorenzo River watershed (Swanson Hydrology & Geomorphology, 2001).

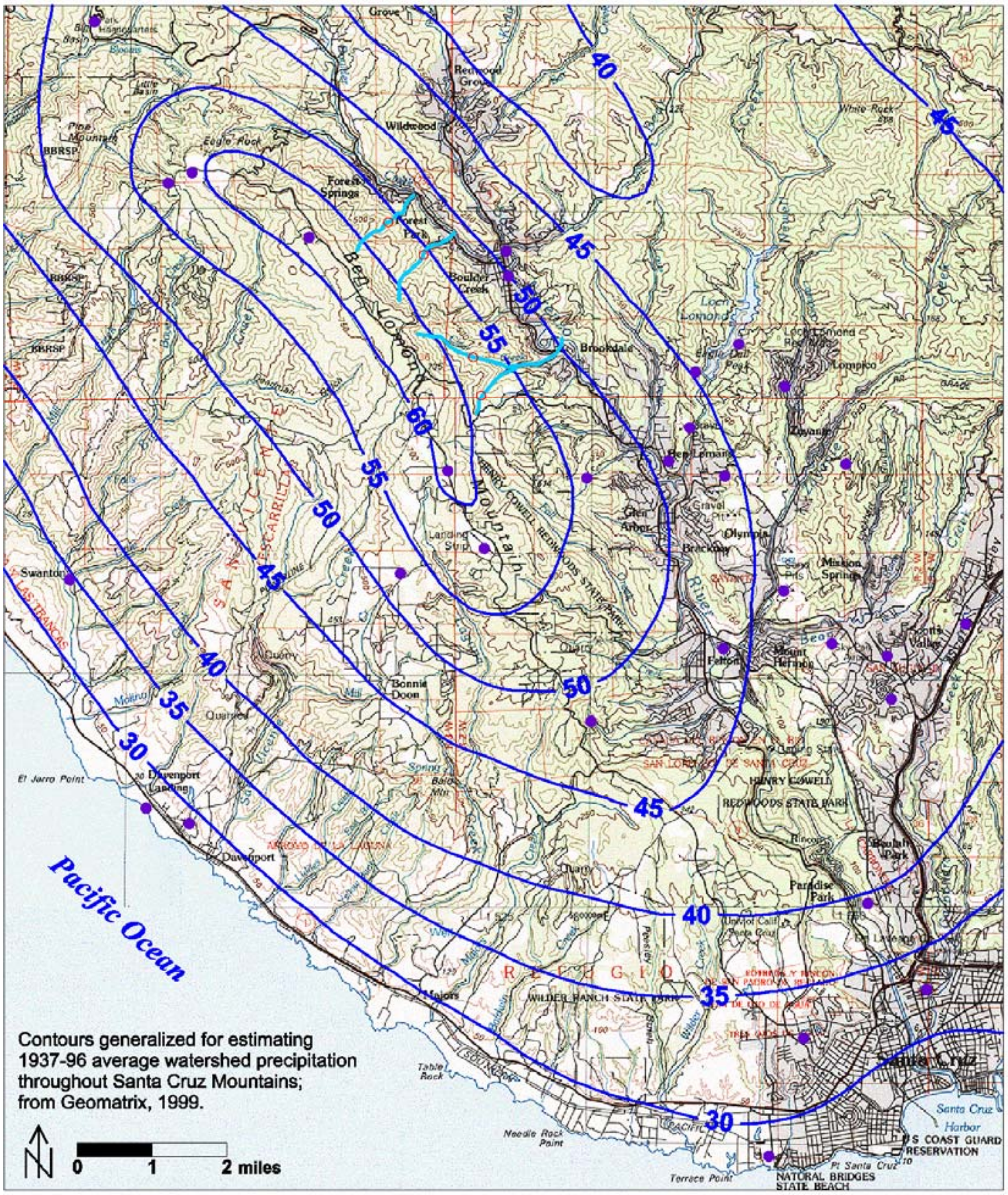
A prolonged 19-year drought occurred in water years 1917-1935, with 80 percent or less of average rainfall. Significant droughts also occurred in water years 1975-77 and 1987-94, with approximately 60 and 75 percent of average rainfall, respectively. Water year 2006-2007 was the driest since 1994.

Coastal fog delivers an unknown amount of moisture, mostly during the summer months. Singer (In Swanson Hydrology & Geomorphology, 2001) cited research (Jacobs, et al. 1985) regarding fog drip data collected on similar ridgetop redwood forests that were different distances from the ocean. In the Muir Woods area, during a six-week period in September – October, Jacobs et al. (1985) recorded 4.38" of fog drip precipitation on the first inland ridge (less than one mile from the ocean) and only 0.24" of fog drip precipitation on the third inland ridge (slightly less than three miles from the ocean). Singer suggested that:

> Valleys that trend north-to-south with bordering ridgelines more than 1500 – 1700 feet high can block the direct incursion of fog. Such is the case in the San Lorenzo Valley, where stratus must move up the valley from the south because of Ben Lomond Mountain (2600’ elevation) to the west. Consequently Boulder Creek has fewer overcast or fog days than Felton. If the roof of the stratus layer is high enough, stratus fog can enter the upper San Lorenzo Valley by spilling over Waterman Gap (1267’ elevation) from the Pescadero Drainage, as we have observed on numerous occasions (Swanson Hydrology & Geomorphology, 2001).

Because no known local studies have been conducted on fog drip, it is unknown how much fog drip contributes to the local water supply. Based on studies of other areas, Swanson Hydrology & Geomorphology (2001) estimated that fog drip provides a small but significant amount of precipitation, probably 5 or less inches annually, to the City of Santa Cruz watershed lands, which are similar in vegetation, elevation and orientation to SLVWD’s watershed lands.

Figure 3.1. Mean annual precipitation (inches/year) on Ben Lomond Mountain



Contours generalized for estimating 1937-96 average watershed precipitation throughout Santa Cruz Mountains; from Geomatrix, 1999.

● Precipitation station

○ District stream diversion

Source: Johnson, 2002

Table 3-1. Monthly rainfall record for Ben Lomond 4 NOAA Station, Water Years 1973-2007 (Inches)

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total	Percent of Avg	
1973				14.55	19.08	5.57	0.13	0.00	0.00	0.00	0.00	0.33			
1974	4.62	14.73	9.11	7.55	2.40	13.00	4.15	0.00	0.35	1.66	0.00	0.00	57.57	116%	100%
1975	2.78	2.30	7.26	1.70	10.80	12.25	3.68	0.04	0.19	0.13	0.79	0.03	41.95	85%	
1976	6.76	0.67	0.81	0.31	4.56	2.12	2.60	0.03	0.20	0.03	1.73	1.78	21.60	44%	42%
1977	0.45	2.97	3.65	2.87	1.99	3.83	0.37	1.29	0.03	0.05	0.00	2.47	19.97	40%	
1978	0.59	5.76	10.61	24.77	10.27	9.89	6.95	0.02	0.04	0.02	0.00	1.79	70.71	143%	119%
1979	0.00	5.50	1.82	12.88	13.26	6.13	1.60	1.14	0.00	0.30	0.04	0.02	42.69	86%	
1980	5.65	3.47	11.02	13.55	19.20	2.90	3.98	0.71	0.27	0.66	0.01	0.02	61.44	124%	
1981	0.08	0.25	6.31	12.14	3.89	9.85	0.15	0.13	0.00	0.00	0.00	0.22	33.02	67%	
1982	2.83	13.33	10.42	23.02	6.91	13.98	8.34	0.04	0.26	0.01	0.08	1.27	80.49	162%	
1983	4.07	13.14	9.20	15.16	20.35	22.61	8.62	1.05	0.04	0.00	0.34	1.07	95.65	193%	
1984	1.29	16.50	13.34	0.77	3.08	3.10	1.47	0.16	0.34	0.03	0.00	0.17	40.25	81%	
1985	3.60	14.81	3.65	1.46	5.56	9.61	0.68	0.16	0.27	0.17	0.03	0.68	40.68	82%	
1986	1.31	7.73	6.13	10.64	24.20	14.43	0.76	0.51	0.00	0.05	0.06	1.38	67.20	136%	
1987	0.14	0.11	3.12	5.85	9.86	7.02	0.63	0.00	0.11	0.02	0.00	0.00	26.86	54%	71%
1988	1.58	4.33	12.07	5.64	0.88	0.06	4.30	1.31	0.11	0.02	0.00	0.01	30.31	61%	
1989	0.39	6.95	9.44	1.16	2.23	11.34	1.20	0.25	0.07	0.00	0.11	1.15	34.29	69%	
1990	3.75	2.03	0.06	4.61	4.89	2.52	0.42	5.76	0.01	0.00	0.08	0.17	24.30	49%	
1991	0.67	0.47	2.52	0.70	5.32	20.52	0.99	0.17	0.46	0.02	0.11	0.05	32.00	65%	
1992	3.53	2.24	6.55	3.92	16.95	6.16	0.68	0.06	0.93	0.02	0.05	0.02	41.11	83%	
1993	4.08	0.51	13.36	20.98	12.24	3.06	1.73	1.03	0.66	0.00	0.00	0.05	57.70	116%	
1994	0.75	3.78	6.65	3.86	11.36	0.97	3.23	2.42	0.04	0.00	0.00	0.03	33.09	67%	
1995	1.32	10.61	5.54	26.51	1.17	15.88	5.14	1.78	1.11	0.01	0.00	0.00	69.07	139%	126%
1996	0.00	0.39	12.24	17.48	16.39	5.61	3.64	5.35	0.04	0.00	0.00	0.00	61.14	123%	
1997	2.64	9.23	24.51	18.41	0.29	1.66	0.82	0.16	0.25	0.00	0.73	0.00	58.70	118%	
1998	0.81	13.08	5.55	19.34	27.98	5.89	4.05	6.00	0.07	0.00	0.00	0.03	82.80	167%	
1999	1.14	8.59	2.45	11.04	11.79	6.84	3.82	0.04	0.29	0.00	0.04	0.27	46.31	93%	
2000	0.44	6.06	0.95	19.14	20.77	2.93	3.86	1.22	0.20	0.00	0.13	0.54	56.24	114%	
2001	6.34	1.68	1.26	10.22	11.38	3.85	*2.36*	0.00	0.12	0.00	0.01	0.07	37.29	75%	90%
2002	1.19	10.87	20.21	4.93	3.23	5.41	0.45	*1.00*	0.00	0.00	0.03	0.00	47.32	96%	
2003	0.00	7.43	24.77	2.52	3.15	2.44	7.52	1.10	0.08	0.00	0.00	0.00	49.01	99%	
2004	*0.00*	4.49	19.39	6.14	11.33	1.65	0.80	0.05	0.00	0.01	0.00	0.20	44.06	89%	
2005	8.70	4.24	15.49	11.83	8.05	10.36	4.35	2.47	1.26	0.00	0.00	0.11	66.86	135%	143%
2006	0.22	4.02	25.95	7.20	5.90	16.84	13.58	0.91	0.00	0.00	0.00	0.00	74.62	151%	
2007	1.19	3.90	7.12	1.31	11.59	0.43							*25.54*	*52%*	
Avg	2.14	6.06	9.19	9.83	9.78	7.45	3.15	1.07	0.23	0.09	0.13	0.41	49.54	99%	99%
Min	0.00	0.11	0.06	0.31	0.29	0.06	0.13	0.00	0.00	0.00	0.00	0.00	19.97	40%	42%
Max	8.70	16.50	25.95	26.51	27.98	22.61	13.58	6.00	1.26	1.66	1.73	2.47	95.65	193%	143%
% of Avg	4.3%	12%	19%	20%	20%	15%	6.4%	2.2%	0.5%	0.2%	0.3%	0.8%	100%		

Italics indicate estimates

Sources: www.ncdc.noaa.gov/coop-precip/california.txt; www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?cabenl+nca

Station elevation 450 ft msl.

3.2.2 Streamflow in the San Lorenzo River watershed

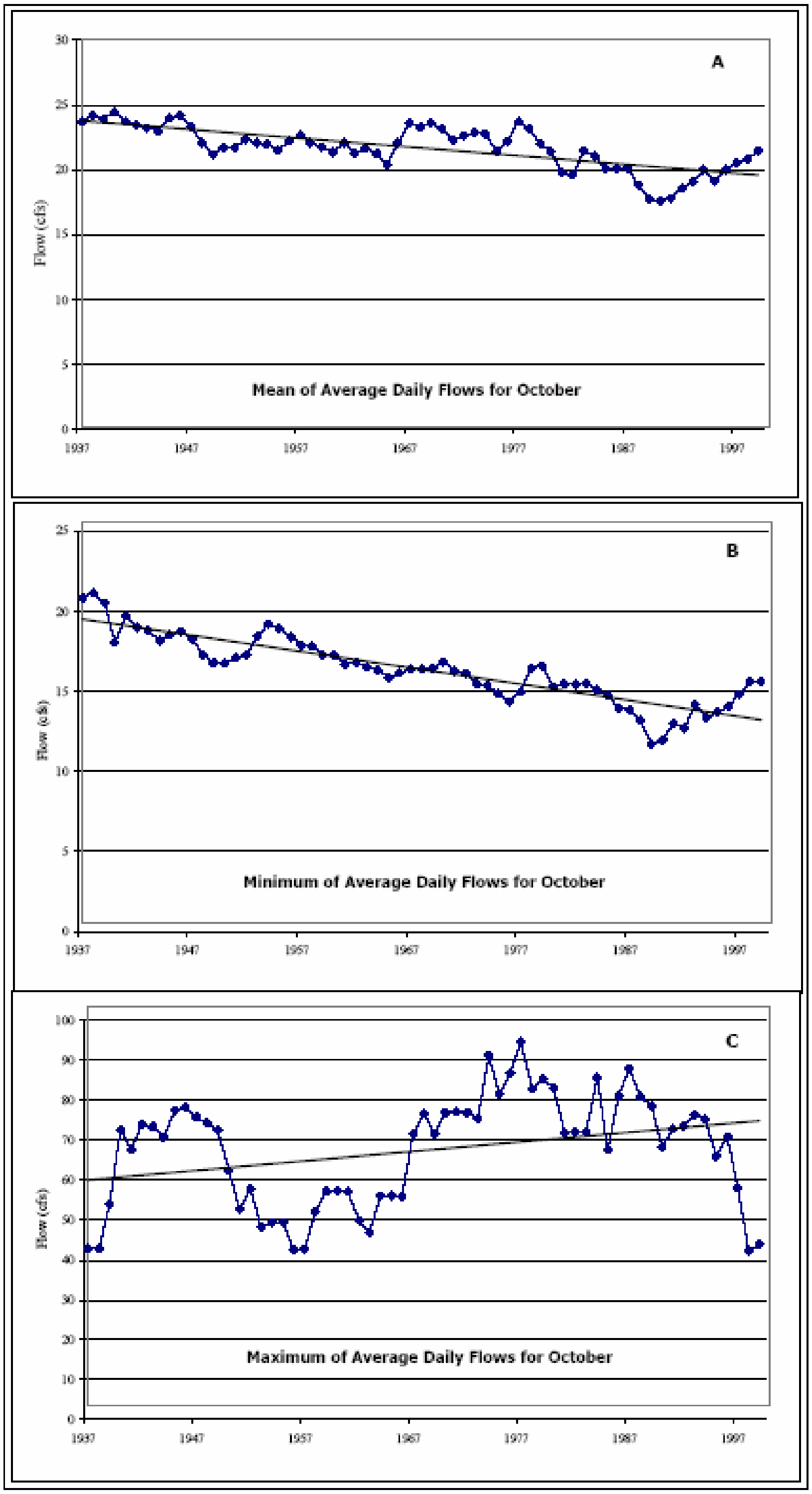
Streamflow is directly related to rainfall. Winter streamflow generally does not markedly increase until soil saturation occurs, after the initial rains of the season, with the highest flows typically occurring from late December through March. Once soils have reached saturation level, streamflow responds quickly to rainfall. Streamflow peaks in great spikes periodically in response to episodic storm events.

As shown in Figure 3.2, Alley ET. al (2004) found that mean streamflows in the San Lorenzo River, measured at the USGS Big Trees station during October, decreased 17.2% between 1937 and 1997, while minimum baseflow decreased 32.1%. (October is typically the month with the lowest streamflows.) They suggested that these decreases were the result of increased surface diversions and well pumping over the same period, in addition to a possible reduction in late season rainfall.

> The impact of surface diversions, reservoir construction, and well pumping becomes clearer after reviewing the December trends [as shown in Figure 3-3]. Mean and maximum streamflow falls 36.2% and 46.2%, respectively. The magnitude of these reductions, particularly for the mean value, is significantly higher than all other months except for April. A viable explanation for the observed flow reductions is that groundwater pumping has reduced groundwater storage to a level where the response time between winter rains and release of water to stream channels has increased. Historically, rains in October and November would percolate into groundwater reservoirs, allowing rains in December through March to contribute more directly to runoff. The capture of initial runoff in Loch Lomond before it spills would also contribute partially to a reduced December maximum flow after 1960 (Alley et. al, 2004).

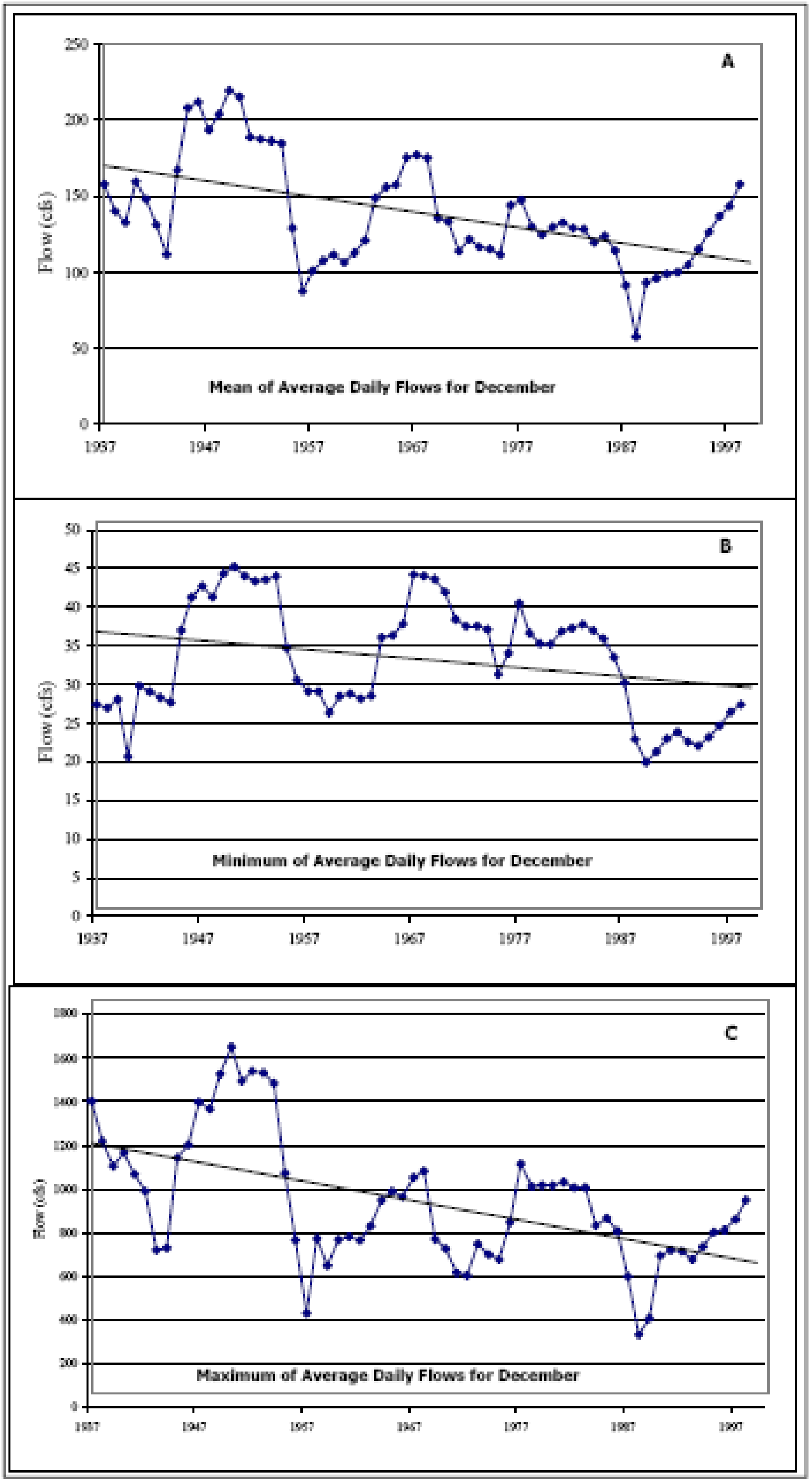
Decreased water flows affect aquatic habitat and every species that relies on such habitat qualities. Management practices to maximize summer flows would considerably benefit the production of yearling sized juvenile salmonids, thereby directly increasing the number of returning adults for the spawning population. For more information about how reduced streamflows affect salmon and steelhead, refer to “Appendix A: Fisheries.”

Figure 3.2. San Lorenzo River average daily flows for the month of October, 1937-1997, measured at Big Trees



Source: Alley et al., 2004.
11-year moving average for October, with trend line for the last 60 years. A) Mean of Average Daily Flows, B) Minimum of Average Daily Flows, C) Maximum of Average Daily Flows.

Figure 3.3 San Lorenzo River average daily flows for the month of December, 1937-1997, measured at Big Trees



Source: Alley et al., 2004

11-year moving average for December, with trend line for the last 60 years. The 1955 Water Year was removed from the analysis due to extremely high flows that acted as an outlier. A) Mean of Average Daily Flows, B) Minimum of Average Daily Flows, C) Maximum of Average Daily Flows.

3.2.3 Precipitation and streamflow in District water supply streams

Surface water streamflow depends largely on precipitation. The District's monthly diversions from Foreman Creek typically peak in March, in response to peak-seasonal rainfall. Diversions from the other streams typically peak in June as seasonal water demand surpasses the Foreman Creek diversion. Total diversions typically peak in May.

Table 3.2 shows the average precipitation and streamflow for the District's surface water supply creeks on Ben Lomond Mountain.

Table 3.2 Average precipitation and streamflow for District surface water supply creeks

Watershed Upstream of SLVWD Intake	Estimated Average Precipitation (inches/yr)	Estimated Stream Discharge from Watershed Precipitation		Estimated Evapo-transpiration (inches/yr)	Est. Add'l Ground-water Discharge* (ac-ft/yr)	Estimated Total Average Discharge		Estimated 1984-1997 Range in Monthly Discharge Min - Max		Estimated Peak Discharge 1/4/82**
		(inches/yr)	(ac-ft/yr)			(ac-ft/yr)	(cfs)	(cfs)		
Peavine Ck	60.2	29.2	588	30.9	159	750	1.0	0.1	10	120
Silver Ck	58.3	28.0	74	30.3	21	94	0.1	-	-	20
Foreman Ck	60.0	29.1	1,169	30.9	230	1,400	1.9	-	-	230
Clear Ck	60.3	29.3	1,071	31.0	200	1,270	1.8	0.2	17	210
Sweetwater Ck	60.3	29.3	524	31.0	70	590	0.8	0.1	8	100
Total or Average	60.1	29.2	3,425	30.9	680	4,100	5.7	0.5	55	680

*Recharge from outside watershed.

**Estimated from Boulder Creek gaged 1/4/82 peak based on ratio of watershed areas.

Source: Geomatrix Consultants, March 1999

3.2.4 Groundwater pumping and streamflow in the San Lorenzo River watershed

The San Lorenzo River Salmonid Enhancement Plan, (Alley et al., 2004) addressed groundwater extraction as another significant, yet difficult to track, source of flow reduction.

> Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation (Alley et al., 2004).

According to Santa Cruz County, since 1986, the decline of groundwater levels has significantly reduced water levels in the Santa Margarita sandstone aquifer in the Pasatiempo Unit and Camp Evers areas, reducing baseflow in Bean Creek, Carbonera Creek, and the San Lorenzo River. The decline has also reduced available water supplies for the District, and other water agencies including Scotts Valley Water District, the City of Santa Cruz, and Mt. Hermon Association, Inc. (Todd Engineers, 2004; Watkins-Johnson, 1993).

It seems reasonable to assume that overdraft of the Scotts Valley groundwater basins has reduced summer baseflows to creeks draining the area underlain by the Santa Margarita, but a District draft hydrological study of Bean Creek has not confirmed this assumption (Johnson, 2002). As a result, the District's consulting hydrologist theorized that the perching layer beneath the channel causes flows from upper Bean Creek, and groundwater discharge from the north, to mostly ride along the top of this layer, at least until bypassing the pumping depression. This theory could also account for flow declines in late fall and early winter, which are shown in Fig. 3.2. Increasingly depressed groundwater levels in the Santa Margarita may increasingly "suck up" early season stormflows in creeks flowing above it, but this action occurs during a season when the flows average greater than baseflow. Since more data is available for Bean Creek than for Newell, Zayante, Carbonera, Creeks, it offers the best opportunity for quantitative analysis of potential flow impacts.

3.2.5 District groundwater storage and recharge

The District's wells draw from the Lompico Sandstone aquifer and the Santa Margarita Sandstone aquifer. The Santa Margarita Sandstone aquifer supplies the District's Olympia and Quail Hollow well fields.

3.2.5.a The northern service area

Groundwater recharge to the Olympia wells is derived primarily from percolating rainfall. Groundwater occurs under unconfined conditions in the Olympia area, even where the aquifer is overlain by mudstone. (Unconfined conditions means that the groundwater aquifer does not have a confining layer between it and the surface. Unconfined aquifers usually receive recharge water directly from the surface, from precipitation or from a body of surface water connected with it.) Because of the synclinal fold, the aquifer becomes unsaturated to the north and south and is not in direct hydraulic contact with either Bean Creek or upper Zayante Creek. The aquifer base also rises to the west where the sandstone has been mostly eroded away along Zayante Creek. As such, the aquifer is generally not in direct contact with the portion of Zayante Creek nearest to the wellfield, with the exception of an approximately 700-foot long stretch where a thin band of sandstone crosses the creek between the Olympia and Quail Hollow areas.

The recharge area for the Olympia wellfield is rural and undeveloped, and much of the aquifer lies beneath less permeable mudstone. An old quarry immediately west of the wells serves as a stormwater retention basin that recharges the aquifer, and receives stormwater from a relatively undeveloped area, as shown in Figure 3.4.Where the aquifer is exposed to the surface, it has a high percolation capacity.

Figure 3.4. The old Olympia quarry immediately west of the District's Olympia wells

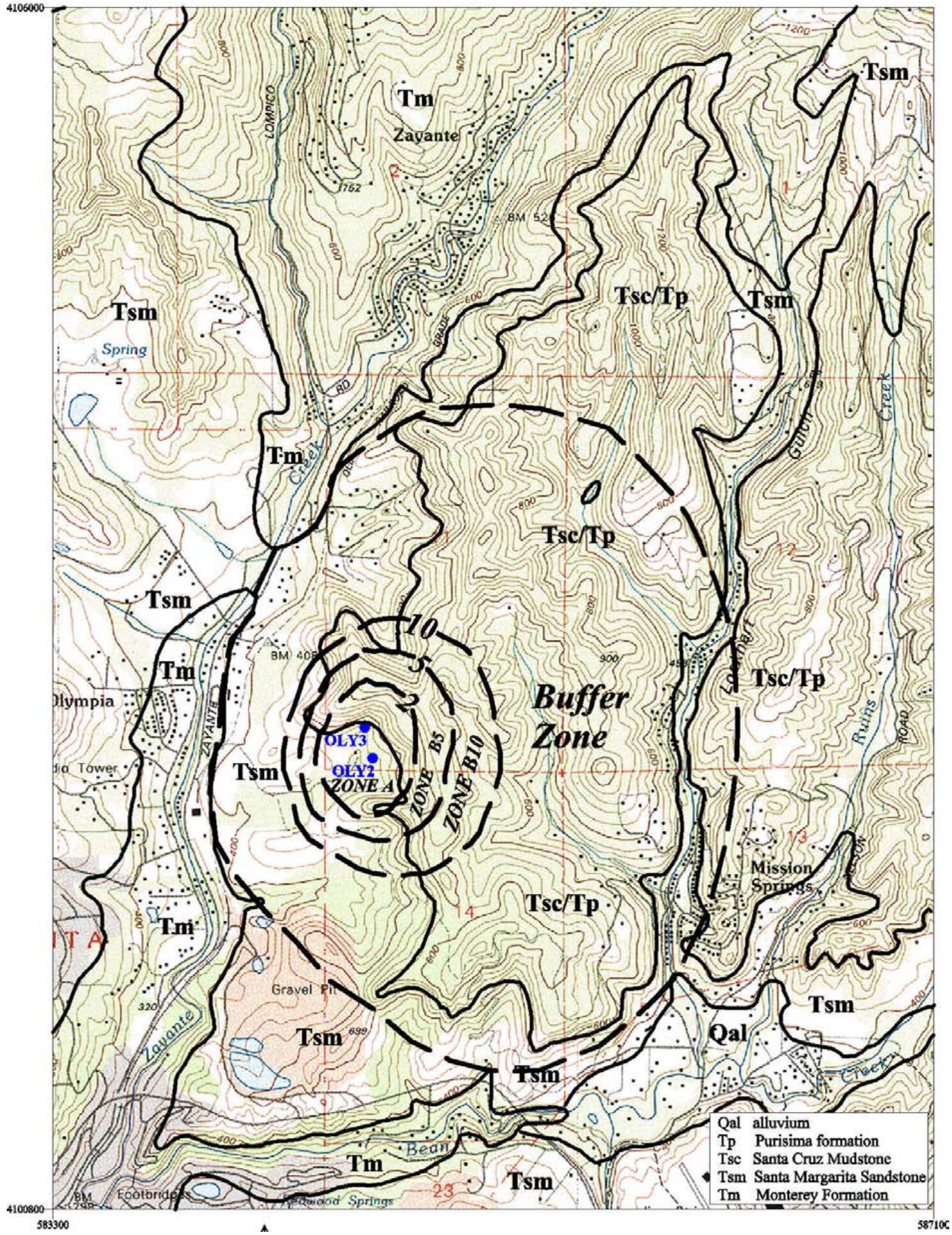
Herbert 2006

The Olympia quarry serves as a stormwater retention basin that receives stormwater and recharges the aquifer. Where the aquifer is exposed to surface, it has a high percolation capacity.

Figure 3. 5 shows the recharge area and protection zones for the Olympia well field. The protection zones are delineated by a District consultant (Johnson, 2005), following Department of Health Services (DHS) guidelines (California Department of Health Services, 1999) for preparing the Drinking Water Source Assessment (DWSAP). DHS considers these protection zones as critical for wellhead protection. Zones A, B5, and B10 are areas within which ground water is estimated to travel to the well within 2, 5, and 10 years, respectively.

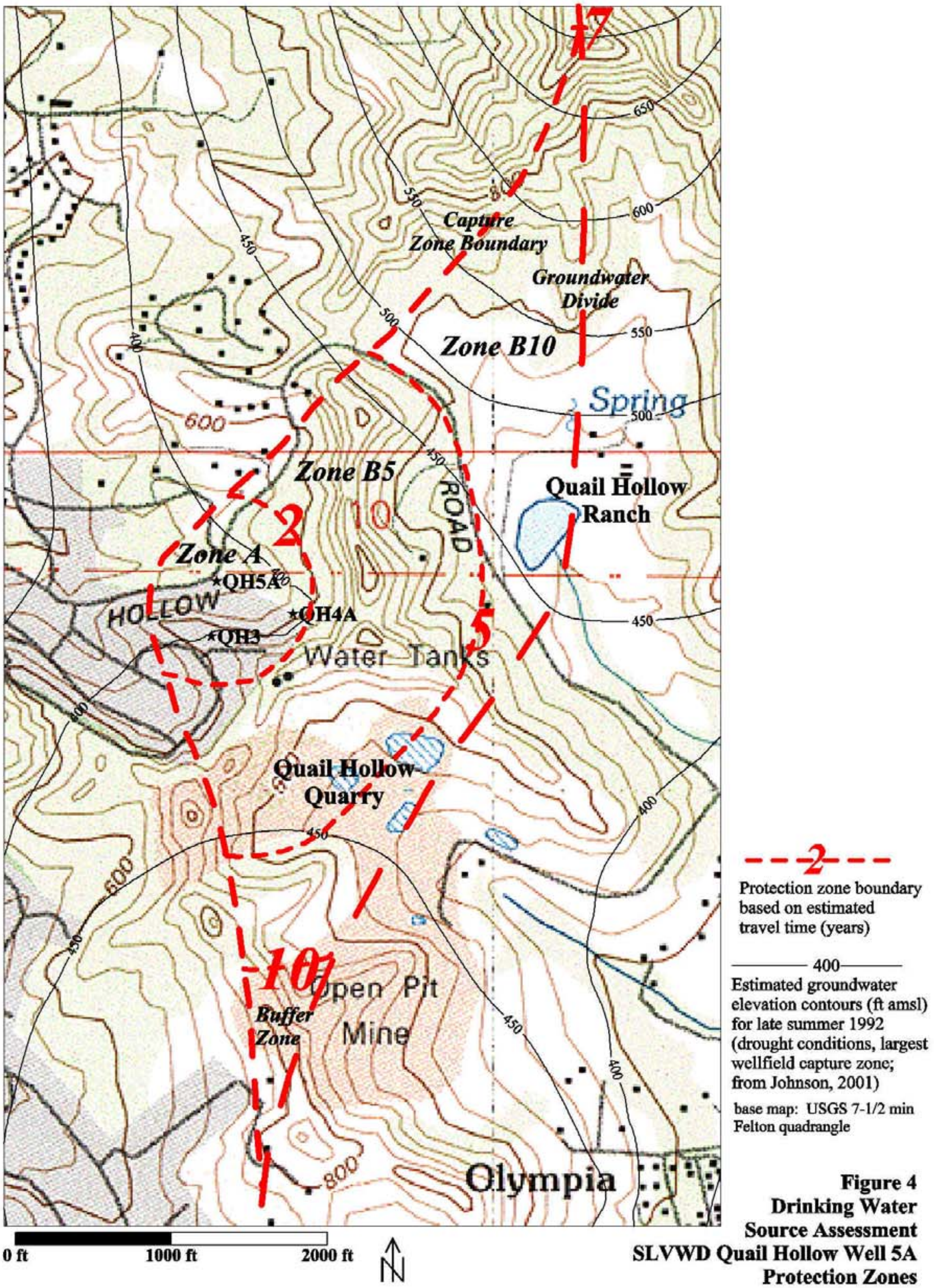
Similarly, Figures 3.6 and 3.7 show the recharge area and protection zones for Quail Hollow Well 5A and 4A, respectively. The Quail Hollow area is approximately 3 square miles, lying between Zayante and Newell Creeks and the San Lorenzo River, located east and southeast of Ben Lomond. The District wells' primary recharge area is 200 acres or more, depending on water table conditions. Land use in the recharge area includes residential, undeveloped chaparral and parkland, and sand quarrying. Because of the high permeability of the soils and sandstone, the potential for groundwater contamination for spills is significant.

Figure 3.5. Recharge area for the Olympia well field



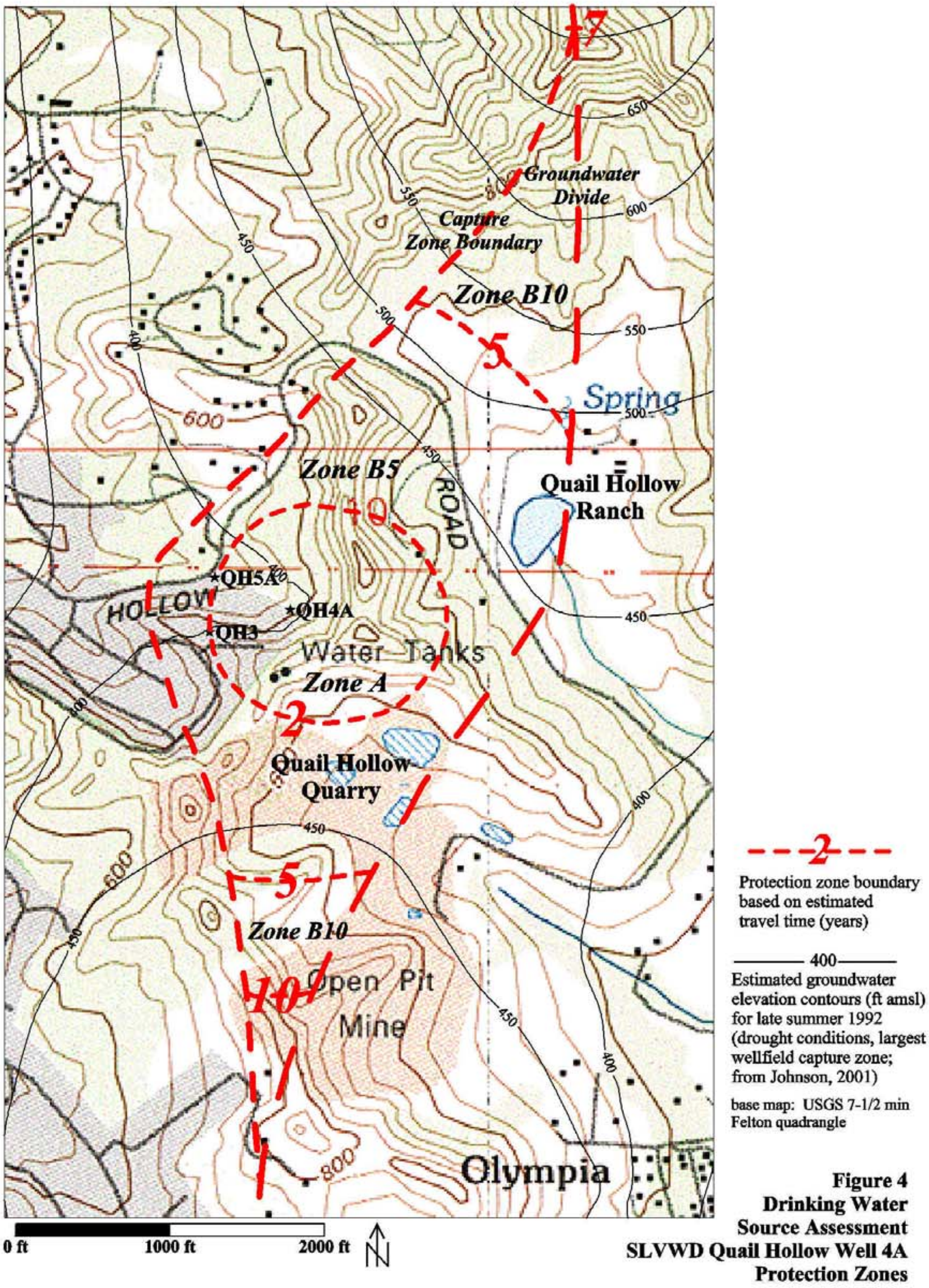
Source: Johnson, 2002.

Figure 3.6. Quail Hollow well 5A recharge area



Source: Johnson, 2001.

Figure 3.7 Quail Hollow well 4A recharge area



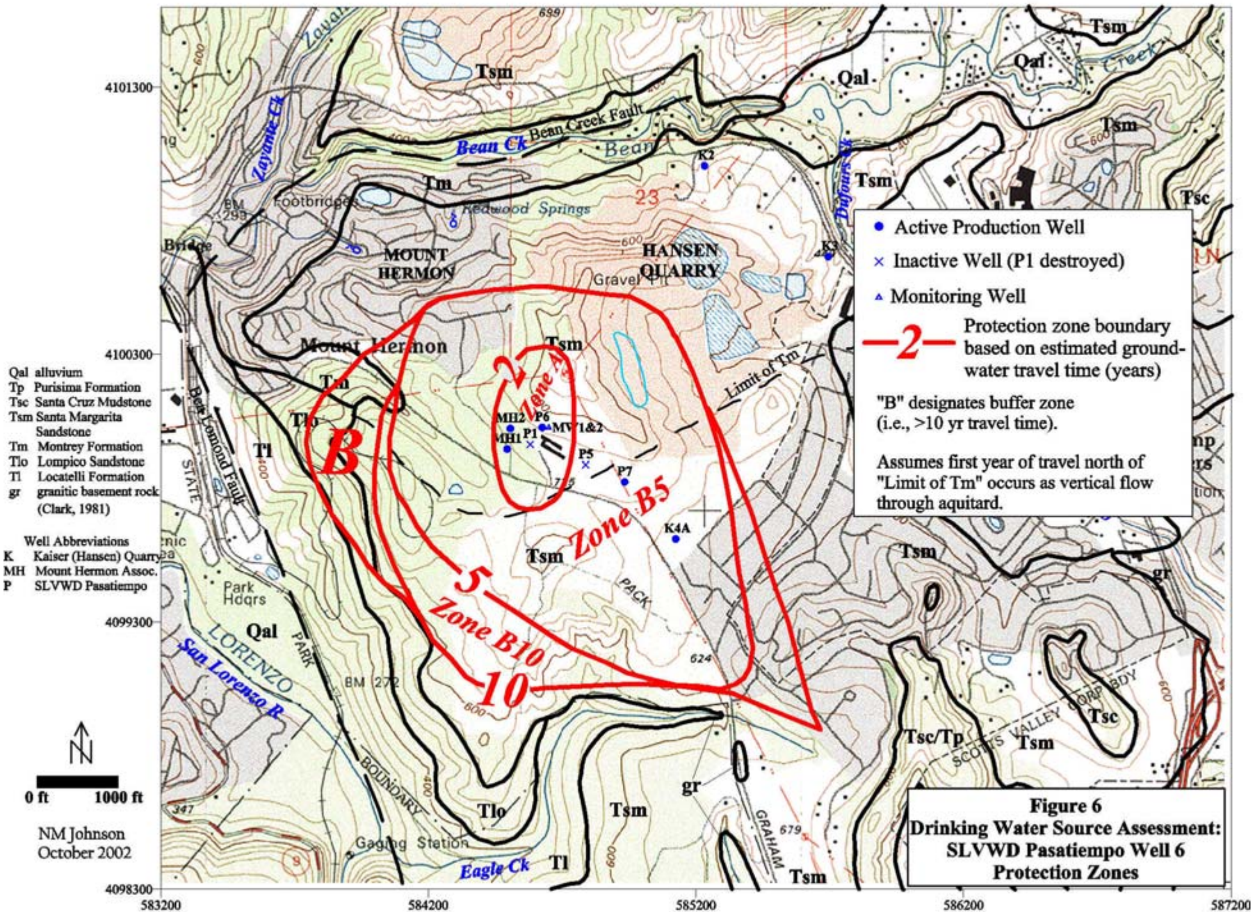
Source: Johnson, 2001.

3.2.5.b The southern service area

The District's southern service area consists of approximately 425 acres overlapping southwestern Scotts Valley. The District has approximately 670 connections in this area for which it produces an average of approximately 400 acre-feet per year. The District currently supplies this area with its two active Pasatiempo wells, 6 and 7. These wells are located near the Santa Cruz County Probation Center.

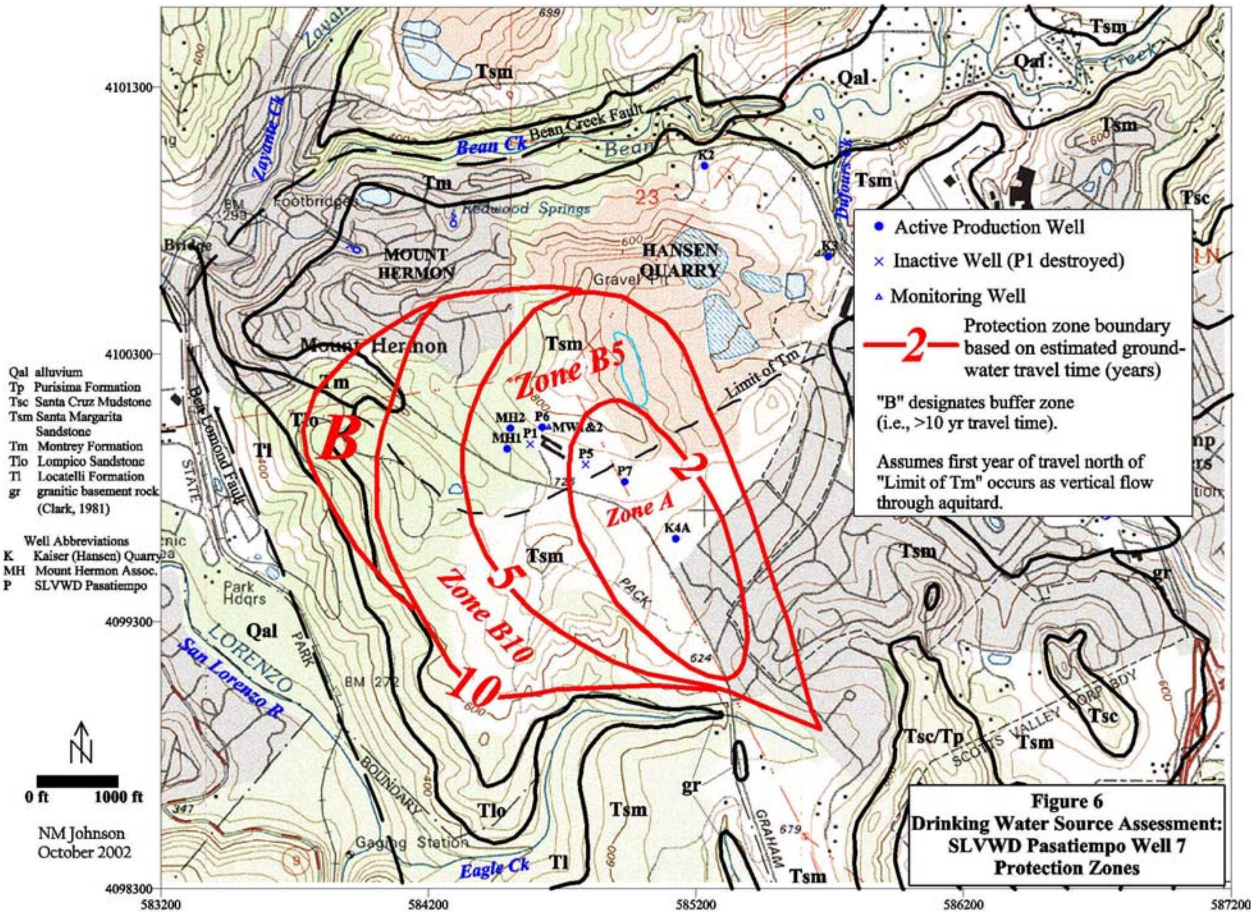
The District's Pasatiempo wells 6 and 7 are encompassed by a recharge area of slightly greater than 500 acres, as shown in Figures 3-8 and 3-9. Supply wells for Mount Hermon Association and Hansen Quarry also lie within this recharge area. Land use in the recharge area includes the mostly undeveloped probation center property, Henry Cowell State Park and Roaring Camp recreational areas, sand quarrying, portions of the unincorporated Mount Hermon residential area, and a residential area both within and outside the southwestern city limits of Scotts Valley.

Figure 3.8. Recharge area for Pasatiempo well 6.



Source: Johnson, 2002.

Figure 3.9. Recharge area for Pasatiempo well 7.



Source: Johnson, 2002.

3.2.5.c Mañana Woods

The Mañana Woods system provides water service to approximately 113 homes in the unincorporated Mañana Woods area southwest of Mt. Hermon Road, Scotts Valley, and three adjacent homes within the Scotts Valley city limit. The service area's only water source is a well located on Kings Village Drive approximately ½ mile from Mañana Woods. The water is treated at the site and pumped via mains to storage tanks within the service area.

In 2006, the SLVWD annexed the Mañana Woods area and the Mañana Woods Mutual Water Company. The annexation followed many years of the mutual water company dealing with hydrocarbons in its well water, litigation with oil companies, and a March 2005 agreement between the mutual water company, the SLVWD, and the oil companies to pursue this annexation. Petroleum hydrocarbon and gasoline additives including BTEX, 1, 2-DCA and MTBE were detected in ground water beneath and downgradient from four gasoline service stations located at the intersection of Mount Hermon Road and Scotts Valley Drive. The site, consisting of four service stations, has been a Regional Board lead groundwater investigation and cleanup case since 1989 (CCRWQCB, 2003).

In 2004, the oil companies treated the well and installed a new water treatment plant that effectively removes target hydrocarbon contaminants to a 'non-detection' level.

The District now operates and manages of all aspects of water service, and has installed meters.

3.3 Soils, geology, and hillslope geomorphology

This section discusses the soils, geology, and hillslope geomorphology of the San Lorenzo River watershed. The watershed is characterized by steep, rugged topography, with relatively high annual rainfall and episodic storm events. These factors combine to give the watershed a high natural background erosion rate (County of Santa Cruz, 2001).

3.3.1 Soils

Soil is the unconsolidated material found on the surface of the earth consisting of minerals, organic material, water, air, and organisms (mostly microscopic). Soil is capable of supporting plant growth, and is normally required for same. Individual soil particles vary greatly in size. The smallest ones (<0.002 mm) are called clay particles and the largest ones are called sand particles (.05 – 2.0 mm). In-between in size are silt particles. The relative proportion of sand, silt, and clay in a soil determines the “texture” of the soil, i.e., sandy, clayey, etc. A soil with a somewhat similar volume of sand, silt, and clay in it is referred to as “loam”, or as having a loamy texture.

Soil is, arguably, the most important natural resource. Soil facilitates plant growth which provides food, wood for shelter, clothing, and other materials essential for human life. Soil supports wildlife populations by promoting vegetation that provides wildlife habitat. Soils store organic and inorganic chemicals, and provides habitat for microbes which decompose or degrade dead organic material and human waste. Soil acts to filter and purify water as occurs when water percolates through a healthy forest soil. Soil also stores some of the water from rainfall and slowly releases it into streams of springs during the dry season, thereby reducing flooding and supplementing water levels for fish. Soil microbes and soil organic matter can lock-up or break down many toxic chemicals, and make them unavailable for uptake. The organic matter in soil can provide long-term carbon sequestration that will reduce global warming. Lastly, soil serves as the structural material that supports buildings, roadways, and other structures necessary for modern society.

Sand particles can be up to 1000 times larger than clay particles. Consequently, the relative composition of sand, silt, and clay in a soil greatly determines soil physical properties such as drainage, water storage, aeration, and nutrient-holding capacity. A soil that is not dominated by either sand or clay particles, as for example a loamy soil, usually has the best physical properties. Some soils also contain a plentiful quantity of rock fragments and pebbles. Pebbles are small pieces of rock larger than a sand particle but less than 75mm in diameter. If the soil has more than 15 % pebbles by volume, the soil textural name includes the adjective, “gravelly,” as in, for example, “gravelly loam.”

Five factors interact over long periods of time to form soils. These are climate, geology (i.e., parent material), vegetation, soil organisms, and topography. It is important to note that geology is only one of the soil-forming factors. In Santa Cruz County the same geologic formation may be associated with several different soil series. Also, the same soil series may occur on several different geologic formations.

Soils form from both the decay of organic material and the weathering of underlying rock or parent material. As soils form they increase in depth and the action of rainwater seeping through the soil moves clay particles and certain chemical compounds downward, resulting in the formation of layers in the soil. These layers are called soil "horizons". It is the sequence, depth, and composition of these soil horizons that allow soil scientists to distinguish one type of soil from another.

One can think of soil as if it were a slice of layer cake. The icing on top represents the litter layer, also referred to as the *organic layer*. It is composed of needles, leaves, twigs, small branches, cones, etc. The organic layer does not contain sand, silt, or clay particles, so it is technically not soil, but it is acted on by soil invertebrates that slice, dice, and degrade it until it is small enough to be incorporated into the soil. The organic layer also provides numerous benefits to the forest, such as controlling erosion, maximizing the infiltration of rainwater into the ground, and allowing the formation of a humus-rich topsoil, which is high in its ability to hold nutrients and water for plant growth.

The first baked layer of the cake would be equivalent to the topsoil layer or “A” horizon. The greatest amount of soil nutrients, organic matter, and beneficial soil microbes are found in the “A” horizon. Consequently, the “A” horizon is the most fertile layer of the soil and roots from trees and other plants tend to concentrate in this layer. Below the “A” horizon is the “B” horizon which is often composed of finer textured soil particles. The lowest horizon is a layer of rock or other geologic deposit, and is referred to as the “C” horizon. Each of these horizons is routinely divided into further divisions, or sub-horizons. The sequence of soil horizons from the surface to bedrock or a depth of 6 feet is called the *soil profile*. It is the thickness, sequence, and composition of soil horizons in the soil profile that define a specific *soil series*. Soil series are named for the geographic location where that specific profile was first seen, and the texture of the “A” horizon. For example, the Ben Lomond Sandy Loam soil is a soil first described near Ben Lomond having a sandy loam texture in the “A” horizon. A sub-agency of the U.S. Department of Agriculture called the Natural Resources Conservation Service (formerly called the Soil Conservation Service) identifies, names, and maps the different types of soils and provides guidance in soil management.

3.3.1.a Soil diversity in the San Lorenzo River watershed

The distribution of soils in the watershed is complex because of the large number of soil series that are present in a relatively small area, and because the soil series often occur in small areas that are closely inter-mixed with other series throughout the watershed (U.S. Soil Conservation Service, 1980; Estrada and Singer, 1978; Estrada, 1976). The Natural Resources Conservation Service identified 24 different soil series in the San Lorenzo River watershed and produced a soil survey map showing the presence of approximately 54 different soil mapping units[1]. This map can be viewed on the internet at www.ca.nrcs.usda.gov/mlra02/stcruz.html. These soils range from deep, fertile soils (such as Ben Lomond Sandy Loam, Nisene Loam) to thin, rocky and infertile soils (such as Maymen Stony Loam, Bonny Doon Loam). Some soils are excessively well-drained and droughty (such as Zayante Coarse Sand) and some are poorly drained with a seasonal high water table (such as Watsonville Loam).

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[1] A soil mapping unit consists of several soil series mapped together in a specific slope category and named after the most common series present. Since soil survey maps delineate soil mapping units and not individual soil series, one must physically examine the soil profile in the field to determine which of the series found in the soil mapping unit is the one present at any given location.

Most soils in the San Lorenzo River watershed have developed under forest, woodland, or chaparral. About 75 percent of the watershed is covered by redwood-Douglas-fir forest or mixed evergreen forest. Some of the most productive soils for the growth of forest trees are Ben Lomond Sandy Loam, Felton Sandy Loam, Aptos Loam, Nisene Loam, and Lompico Loam. These soils typically have a one to several inches thick litter layer of leaves, twigs, cones, and needles on the surface. The organic matter in the litter layer is decomposed by soil organisms and incorporated in the underlying "A" horizon, giving it a dark color, relatively high porosity, and a good soil structure. The transition zone between the duff layer and the underlying soil is especially rich in plant nutrients and is extensively exploited by fine roots and beneficial soil fungi, called *mycorrhizae*, which form a symbiotic relationship with plant roots.

Some individual tree species within forest or woodland have profound effects on the soil that develops underneath their canopy. These effects are not considered in published soil surveys. Redwood litter is known to promote water infiltration in underlying soils. Bay (*Umbellularia californica*) litter has been observed to have the opposite effect. Soils formed under bay trees have been observed to have a reduced infiltration rate, a lower porosity, and a less favorable soil structure (Singer, 2004). Bay leaves release toxic chemicals that suppress the germination or growth of herbaceous plants and are toxic to insects (Corelli, 2005). Their slow rate of decompositions suggests that they are also toxic to many soil micro-organisms. Consequently, stands of bay trees on steep slopes have little or no litter layer and are extremely susceptible to surface erosion and dry ravel (Singer, pers. obs.).

Chaparral covers about 12 percent of the watershed, and is primarily found on ridgetops and the upper part of south-facing slopes. The soil most commonly associated with chaparral is Maymen stony loam. This soil averages only 14 inches deep and contains many stones and rock fragments throughout its profile. It has formed in material derived from sandstone, shale, or granitic rocks.

Only a few soils in the watershed have conditions that are not favorable for plant growth or for other human uses. Those watershed soils that are shallow, infertile, droughty, or have drainage problems are listed in Table 3-3 below. Soils that are shallow or have slow subsurface percolation rates are generally unsuitable for use as septic tank leach fields.

Table 3-3. Problem soil series in the San Lorenzo River watershed

Soil Condition	**Soils That Are Too Sandy**	**Soils That Are Too Shallow (< 15" deep)**	**Soils With Too Slow of a Subsurface Percolation Rate (< 0.2"/hr)**
Soil Name	Zayante Coarse Sand	Bonny Doon Loam Maymen Stony Loam	Cropley Silty Clay Danville Loam Diablo Clay Lompico Variant Loam Los Osos Loam Tierra Sandy Loam Watsonville Loam
Landform Type	Inland marine sand deposits, developed atop Santa Margarita Sandstone	Upland areas	Upland areas, marine terraces, and old alluvial fans. Cropley and Diablo soils are of very limited extent with Cropley found on younger alluvium.
Problems for Human Use	* Infertile * Droughty * Highly erosive * Unsuited for septic leachfields (perc. rate is rapid)	* Droughty * Unsuited for septic leachfields (inadequate soil depth)	* Seasonal high-water table * High rainfall runoff * Unsuited for septic leachfields (perc. rate is too slow)

Source: Singer, 2008

The most common soil series that occur in the watershed are not listed in Table 3-3, and they include Aptos Loam, Ben Lomond Sandy Loam, Catelli Sandy Loam, Lompico Loam, Elder Sandy Loam, Elkhorn Sandy Loam, Lompico Loam, Madonna Loam, Nisene Loam, and Sur Stony Sandy Loam. Less common watershed soils not listed in Table 3-3 are Baywood Loamy Sand, Pfeiffer Gravelly Sandy Loam, Santa Lucia Shaly Clay Loam, and Soquel Loam.

Neither high salinity nor excessive levels of toxic trace metals are known to occur in the San Lorenzo River Watershed soils with the exception of cadmium.

3.3.1.b High-cadmium soils

Some soils and river sediments have extremely high levels of cadmium. Cadmium is a naturally-occurring trace element that can be toxic to fish, wildlife, and humans, contributing to diseases of the kidney, liver, and skeletal system (CIWMB, 1998). Domesticated animals are also subject to cadmium poisoning, and horses may be especially sensitive (Piscator, 1985). The typical concentration of cadmium in U.S. soils is low, ranging from 0.1 to 1.0 parts per million (ppm) (Page et al., 1987). Many plants are relatively unaffected by cadmium, and some species will concentrate it in high levels in their plant tissue. Food or forage plants grown on soils with high cadmium levels can accumulate it to the extent that they are unsafe for repeated and regular consumption. Leafy vegetable crops (lettuce, Swiss chard, and spinach) are the most efficient concentrators of cadmium (Page et al., 1987).

It is important to note that the District routinely monitors its ground and surface water sources for cadmium, as required by the California Department of Public Health (CDPH). To date, no detectable levels of cadmium have been found (Busa, 2008).

High cadmium levels in food can put humans or animals at risk of cadmium-poisoning if those foods are eaten on a regular basis over a number of years. The U.S. Food and Drug Administration has limited cadmium levels in artificial food colors, which are ingested in only small quantities, to 15 ppm (U.S. ATSDR, 1999). Lettuce and Swiss chard from local areas within the San Lorenzo River watershed have had cadmium concentrations above 30 ppm and one reported value of 55 ppm (Golling, 1983). The source of the plant-absorbed cadmium is soil formed on bedrock or sediment from the geologic strata collectively known as the Monterey formation. Soils associated with the Monterey formation in California are known to have the highest known natural concentrations of cadmium, up to 22 ppm (Page et al., 1987). Some soils that developed from the Monterey Formation in the San Lorenzo River watershed have cadmium values of 5.0 to 6.5 ppm. (Golling, 1983). These soils have not been linked to any one particular soil series, as several different soils may form on the Monterey formation or its sediments and levels of cadmium within the Monterey formation are variable.

Despite the high cadmium levels found locally in leafy vegetables, there have been no publicized local reports of human cadmium poisoning. This may be because the absorption of cadmium in the intestines is only poorly understood. Concurrent ingestion of certain other substances, including zinc, iron, and calcium may block or reduce the absorption of cadmium (Reeves et al., 2005).

A more serious concern may be potential cadmium poisoning of wildlife. Since cadmium levels in organisms increase as one moves up the food chain through the process known as bio-magnification, top-level predators may end up with a debilitating body burden of cadmium. Animals that browse extensively on cadmium accumulator plants, like willows, might also be subject to cadmium poisoning (Larison et al., 2000). Since no studies have been conducted on the effects of cadmium on animals in the San Lorenzo River watershed, no definitive conclusions can be reached. However, it would be prudent for land managers to be cautious about introducing cadmium into the food chain, as they might do inadvertently by placing fill material excavated from roadcuts or construction sites in the Monterey Formation or sediments dredged from the river or local reservoirs onto the ground surface where they can be colonized by willows or other cadmium accumulators.

Some soil management techniques exist that can be used to reduce cadmium levels in crops grown on high-cadmium soils. Maintaining high levels of soil organic matter and keeping the soil pH level above 7.0 will decrease cadmium uptake by plants (Golling, 1983). Alternatively, cadmium-accumulator plants, such as some species of willow, can, when coppiced, be used to reduce cadmium levels in the soil through repeated harvesting and safe disposal of the plant biomass before leaf fall (Dickinson, 2005).

3.3.2 Geologic areas and soil types of the San Lorenzo River watershed

The three distinct geologic areas of the watershed were formed by movement along local fault zones, as shown in Figure 3.10. These geologic areas are characterized by different soil types. Erosion rates vary in different areas of the watershed, depending on soil types, as shown in Table 3.4.

A brief description of the geologic areas and their soil types follows.

3.3.2.a Area 1: Ben Lomond Mountain geologic unit.

This area lies west of the Ben Lomond Fault and south of the Zayante Fault, Ben Lomond Mountain. This geologic unit includes the steep eastern slope of Ben Lomond Mountain, which supplies all of the District’s surface water. Ben Lomond Mountain was formed by movement along the Ben Lomond Fault. The uplifted hard, crystalline rock formed Ben Lomond Mountain, the southwestern edge of the watershed. Principle subwatersheds of the San Lorenzo River draining Ben Lomond Mountain include Fall, Bull, Alba, Malosky, Clear, Sweetwater, Peavine, Jamison, and lower Boulder Creek with its tributaries.

Soil types: The uplifted mass of basement bedrock is predominated by granites of various degrees of weathering, schists and marble (locally known as limestone). A thin soil layer covers the very steep slopes of the drainages supporting dense coniferous and mixed evergreen forest. In areas of the Pacific Northwest, decomposed granite is the parent material of highest concern for erosion (Spence et al., 1996). Here, decomposed granite is the least prone to erosion, relative to other substrates within the San Lorenzo River watershed.

Streams in this area generally have good levels of boulders and cobbles, are free of silt, and clear very quickly after storms. There is generally adequate summer low flow to support diverse aquatic habitat, as well as to supply water purveyors. The lower portions of these watersheds are composed of Tertiary sandstone and mudstone. Figure 3.11 shows a composite stratigraphy of these formations. These lower portions are more susceptible to landsliding and erosion, especially when disturbed. The lower gradient portions of these watersheds still support steelhead and historically supported coho salmon.

Table 3.4. Characteristics and erosional variables of geologic units in the San Lorenzo River watershed.

Name	Geology	General Character	Remarks
Quaternary Alluvium	Coarse – to fine-grained river and marine terrace deposits.	Poorly sorted and loosely consolidated sands and mudstones.	These deposits include all of the marine terrace, river terrace and floodplain accumulations. They are locally discontinuous, not heavily vegetated, moderately stable deposits that show very little landsliding or creep.
Purisima Formation	Medium to very fine-grained sandstone and a fairly common dark-gray silty mudstone (Cummings, Touring, and Brabb, 1962, p. 197)	Massive and poorly bedded or locally cross-bedded.	The fine-grained nature of this formation makes it a potentially large contributor of fine sediment. However, heavy vegetation and generally shallow slope make this one of the more stable substrates. Moderate to low amount of rockfall and landsliding.
Santa Cruz Mudstone	Slightly siliceous organic mudstone (Clark, 1966, p. 133)	Medium to thick=bedded; lacks a distinct fissility.	When severely disturbed this formation acts as a source of fine sediment. In general, it is heavily vegetated and occurs on steep slopes. This formation acts as a protective cover for the underlying Santa Margarita Sandstone. Erosion and quarrying of the underlying formation has produced over-steepened slopes. A moderate amount of landsliding occurs on this unit.
Santa Margarita Sandstone	Moderately sorted, arkosic sandstone. Poorly consolidated and medium-grained with occasional fossil shell hash beds.	Thick-bedded to massive. Steep, thick cross-beds.	This formation is highly susceptible to erosion. Disturbance produces a rapid and severe erosional response. Exposures are subject to both wind and fluvial erosion and act as significant source of medium-grained material. Soils that develop on the sandstone have a thin, encrusting surface layer that cements the sands and prevents removal. Disruption of this layer, either by vehicle traffic or foot traffic, enhances erosion severely.
Monterey Shale	Mudstone. High content of organic mater and discontinuous laminae of clastic material (Clark, 1966, p. 97	Medium- to thick-bedded, irregularly laminated and decomposes into porcelaneous debris.	Resistant formation that forms heavily vegetated, steep slopes whose erosional response is minimal.
Lompico Sandstone	Medium- to fine-grained sandstone. Light gray to yellowish gray; weathers buff (Clark, 1966, p. 80)	Moderately- to well-sorted, thick bedded to massive loosely consolidated sands.	This unit is highly prone to slumping and debris slides. Poorly vegetated in some areas. Shows incipient gullying on numerous, steeper slopes. Occasionally forms steep cliffs. Exposures along Zayante Fault are severely deformed and show a rapid erosional response to disturbance.
Lambert Shale	Organic mudstone with local, thin interbeds of fine sands.	Thin- to medium-bedded; decomposes into friable blocks and fine, easily transported particles.	Steep exposures in road cuts and stream banks show numerous small slumps. May be a source of fine sediment. Shows a moderate response to disturbance. Volumetrically insignificant.

(Continued on next page)

Table 3.4 Characteristics and erosional variables of geologic units in the San Lorenzo River watershed (continued).

Vaqueros Sandstone	Moderately sorted, very fine to medium-grained sandstones with numerous interbeds of mudstone (Brabb, 1960, p. 58)	Laminated to very thick-bedded; complexly fractured; decomposes into friable, easily transportable blocks and fine particles.	This formation is one of the principal contributors of sediment in the Watershed. The heterogeneous nature of the rock types produces variable erosional responses. Some areas are underlain by mudstones and siltstones and are highly prone to sliding. Some localities underlain by interbedded siltstone and sandstone show large block glides on dip slopes. Other localities are underlain by loosely consolidated sands that respond to disturbance in much the same manner as the Santa Margarita Sandstones. The overall response to disturbance is high.
Zayante Sandstone	Heterogeneous sequence of interbedded pebbly sandstone, conglomerate, and sandy siltstone (Clark, 1966, p. 45)	Thick- to very thick-bedded; decomposes into friable, coarse particles.	Potentially significant source of coarse material. Severely disturbed in the Zayante Creek and Lompico Creek drainages. Forms debris slides and slumps. However, overall response is moderate to good.
Mindego Formation	Interstratified volcanic rocks with mudstones, shales, sandstones, conglomerates and carbonates.	Thin- to thick-bedded sedimentary rocks with interbedded massive submarine basaltic flows. Complexly fractured.	Exposures of this formation are limited in their extent. In general, this unit supports steep slopes, and moderate to sparse vegetation. Road cuts show rockfall and debris sliding. This formation weathers to produce fine material that is easily transported.
San Lorenzo Formation (Rices Mudstone and Two Bar Shale members)	Interbedded mudstones, siltstones and shales.	Massive to laminated, friable, decomposes into easily transported fine material. Produces clay soils.	Highly unstable unit. Erosional response to all types of disturbance is rapid and severe. Occurs on moderately vegetated, shallow slopes and is highly susceptible to landsliding and soil creep. Unimproved roads are prone to severe gulling and slumps along cut banks. This formation is one of the principal contributors of fine sediment in the Watershed.
Butano Sandstone	Interbedded sandstones and siltstones.	Medium- to thick-bedded massive sands interbedded with siltstones and mudstones. Decomposes into friable, easily transported blocks.	This unit is generally associated with steep, unstable slopes. Interbedded massive sands and siltstones make hazardous dip slopes. Forms large talus slopes where extensively exposed. Soils are poorly developed and prone to debris sliding. Unimproved roads show marked instability.
Locatelli Formation	Interbedded medium sandstones and siltstones.	Massive, thick sands interbedded with thinly laminated siltstones and shales.	In the area of Jamison Creek, this unit produces moderately vegetated, very steep slopes of high stability. The thick sandstone units produce a strong substrate.
Cretaceous granitic rocks	Intrusive complex ranging from granite to gabbro.	Mostly medium-grained quartz dirite. Deeply weathered in some localities, producing thick, coarse-grained soils.	Produces very steep, heavily vegetated slopes of high stability. In areas of intense weathering, disturbed slopes show extensive gullying. In general, this unit responds to disturbance well.
Metasedimentary rocks	Interstratified marbles and biotite schists.	Schistose rocks with varying amounts of quartz, plagioclase, cordierite, biotie and sillimaite.	This unit produces varying slopes and vegetative cover with moderate to high stability. The overlying soils are fairly well developed and stable. The erosional responses to disturbance is moderate to good.

Source: Mount, 1977.

3.3.2.b Area 2: East of the Ben Lomond Fault and south of the Zayante Fault.

As shown in Figure 3.10, the principle watersheds in Area 2 include Love Creek, Newell Creek below the reservoir; lower Lompico Creek, Zayante and Bean Creeks; Carbonera Creek, Branciforte Creek; the Quail Hollow area; Mount Hermon, Scotts Valley, Graham Hill and Henry Cowell areas.

Soil types: This area is predominated by sandstones and shales forming highly erosive soils that are sand or clay rich. These atypical soils have given rise to very rare and unusual associations of trees and plants such as sandhills communities. Many species found within these sand ecological communities are completely disjunct from their usual areas, and many species are endemic or locally rare. Due to weak cementation, erosion rates are naturally high in this area, especially where sandy soils occur in steep headwater areas or near channels. The Santa Margarita and Lompico aquifers are recharged through the sandy soils. These aquifers not only provide valuable summer base flows to streams of the eastern watershed including the mainstem San Lorenzo River, but also provide the water supply for most of the watershed. Levels of recharge also directly affect groundwater quality. Recharge rates have been drastically reduced due to high densities of impermeable surfaces related to development. The sandy areas have the relatively lowest topographic gradient, high density of land use disturbances, including equestrian facilities, trails, surface mining, residential, commercial, and industrial uses. The sandy soils which were capable of absorbing nearly all of the rainfall under natural conditions now form steep-walled gullies and gulches due to increased runoff from paved and covered surfaces and due to soil disturbance. Roads and homes are the predominant sources of sediment. Large landslides and many small ones, often at the stream margin, chronically feed sediment into stream systems. High levels of erosion chronically feed streams with sediment, filling pools and embedding valuable habitat within all reaches down stream. The erodibility of the mudstone units in the Monterey and Santa Cruz Mudstone Formations within this area can vary considerably.

3.3.2.c Area 3: North of the Zayante Fault

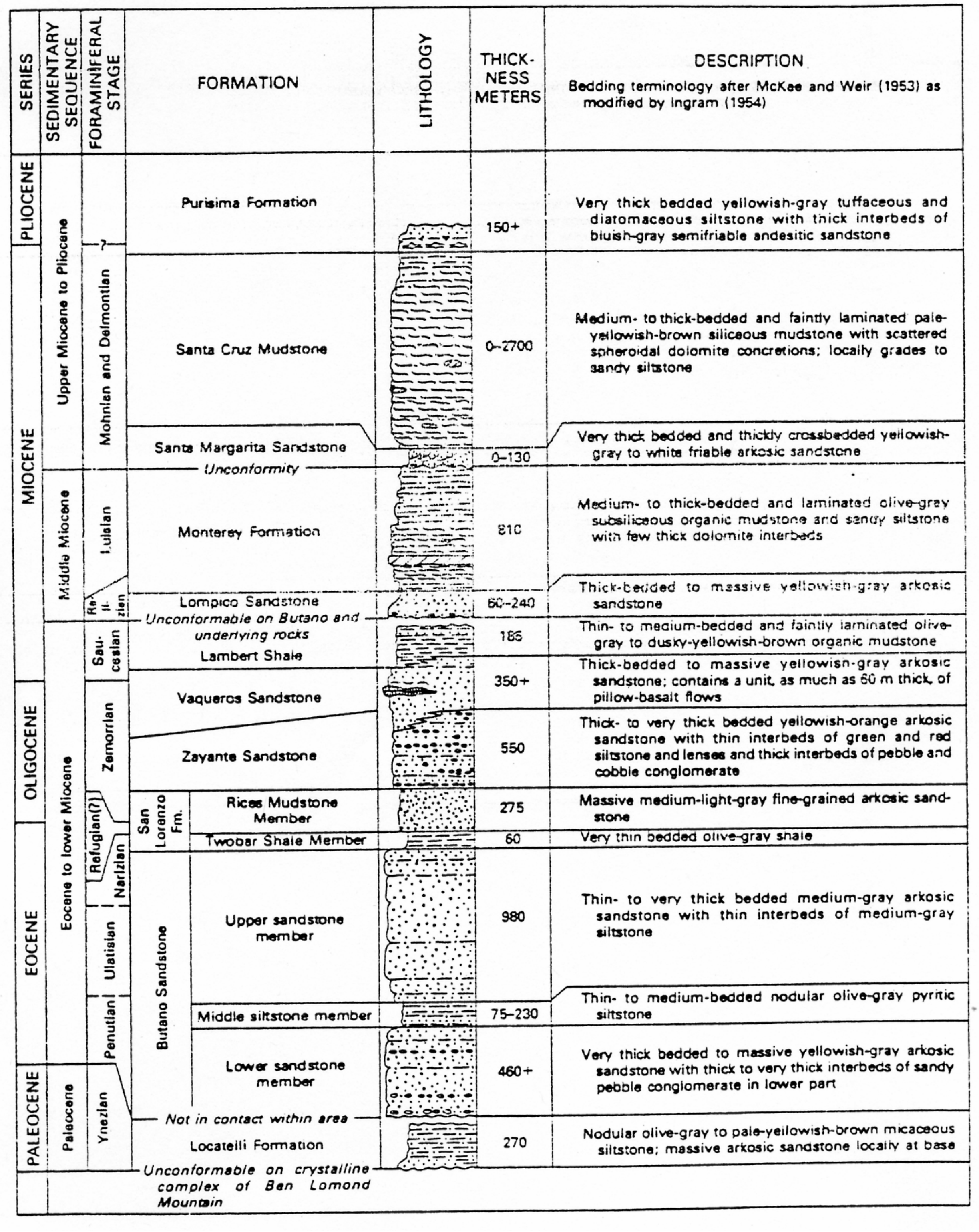
As shown in Figure 3.10, the principle watersheds in Area 3 include the upper San Lorenzo River (above Boulder Creek); Kings, Two Bar, and Bear Creeks, tributaries to the San Lorenzo River; plus the northern portions of the Boulder, Zayante, Lompico, Newell, and Bean Creeks. This area extends from the Zayante Fault to the western and eastern “skyline” of the Santa Cruz Mountains, which form the northern boundary of the watershed.

Soil types: This area’s steeply inclined, dipping and folded strata are comprised of Tertiary Period marine deposits of interbedded sandstones, shales, and mudstone. Soil from these formations is a complex mosaic of coarse-grained loams, ranging from less than a foot deep to deep, organic, rich, sandy loam on valley terraces. This mosaic of soils gives rise to patchy diverse vegetation types and a varying erosiveness. Slopes tend to be steep and prone to moderate to severe erosion, especially where disturbed. The Butano Fault runs across this northern area but does not divide the upper half distinctly in geologic terms. Steep slopes associated with the Butano Fault are especially prone to erosion from roadcuts and land disturbance. Disturbance erosion in this area continually provides easily moved sediment to the watershed. Many of these streams drain steep gradient areas and deliver high sediment yields to downstream reaches. Dry-season flows are generally lowest in this geologic terrain, with streams often drying to isolated pools during summers of dry years. Periods of low summer flows exacerbate impacts from sedimentation on aquatic habitat and domestic water.

Figure 3.10 Geologic areas and major fault zones of the San Lorenzo River watershed.

(11 x 17 color foldout)

Figure 3.11. Composite stratigraphic section of tertiary rocks of the central Santa Cruz Mountains northeast of San Gregorio fault.

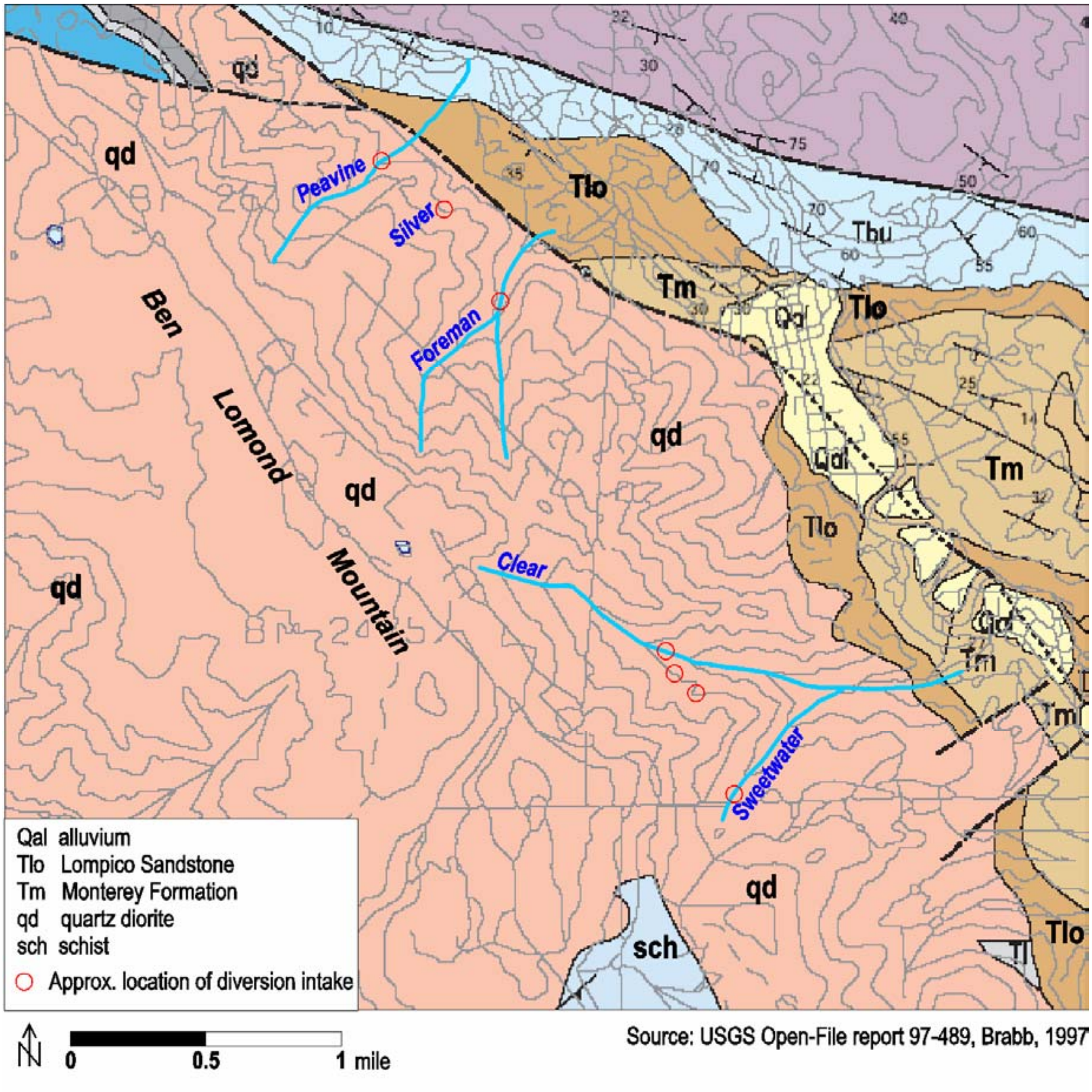


SERIES	SEDIMENTARY SEQUENCE	FORAMINIFERAL STAGE	FORMATION	THICKNESS METERS	DESCRIPTION Bedding terminology after McKee and Weir (1953) as modified by Ingram (1954)
PLIOCENE	Upper Miocene to Pliocene	?	Purisima Formation	150+	Very thick bedded yellowish-gray tuffaceous and diatomaceous siltstone with thick interbeds of bluish-gray semifriable andesitic sandstone
MIOCENE		Mohnian and Delmontian	Santa Cruz Mudstone	0–2700	Medium- to thick-bedded and faintly laminated pale-yellowish-brown siliceous mudstone with scattered spheroidal dolomite concretions; locally grades to sandy siltstone
			Santa Margarita Sandstone	0–130	Very thick bedded and thickly crossbedded yellowish-gray to white friable arkosic sandstone
			Unconformity		
	Middle Miocene	Luisian	Monterey Formation	810	Medium- to thick-bedded and laminated olive-gray subsiliceous organic mudstone and sandy siltstone with few thick dolomite interbeds
		Relizian	Lompico Sandstone	60–240	Thick-bedded to massive yellowish-gray arkosic sandstone
			Unconformable on Butano and underlying rocks		
	Eocene to lower Miocene	Saucesian	Lambert Shale	185	Thin- to medium-bedded and faintly laminated olive-gray to dusky-yellowish-brown organic mudstone
OLIGOCENE		Zemorrian	Vaqueros Sandstone	350+	Thick-bedded to massive yellowish-gray arkosic sandstone; contains a unit as much as 60 m thick of pillow-basalt flows
			Zayante Sandstone	550	Thick- to very thick bedded yellowish-orange arkosic sandstone with thin interbeds of green and red siltstone and lenses and thick interbeds of pebble and cobble conglomerate
		Refugian(?)	San Lorenzo Fm. — Rices Mudstone Member	275	Massive medium-light-gray fine-grained arkosic sandstone
EOCENE			San Lorenzo Fm. — Twobar Shale Member	60	Very thin bedded olive-gray shale
		Narizian Ulatisian	Butano Sandstone — Upper sandstone member	980	Thin- to very thick bedded medium-gray arkosic sandstone with thin interbeds of medium-gray siltstone
		Penutian	Butano Sandstone — Middle siltstone member	75–230	Thin- to medium-bedded nodular olive-gray pyritic siltstone
			Butano Sandstone — Lower sandstone member	460+	Very thick bedded to massive yellowish-gray arkosic sandstone with thick to very thick interbeds of sandy pebble conglomerate in lower part
			Not in contact within area		
PALEOCENE	Paleocene	Ynezian	Locatelli Formation	270	Nodular olive-gray to pale-yellowish-brown micaceous siltstone; massive arkosic sandstone locally at base
			Unconformable on crystalline complex of Ben Lomond Mountain		

Source: Clark, J. C. 1981.

Figure 3.12 shows the geology of the District's stream diversion watersheds on Ben Lomond Mountain.

Figure 3.12 Geology of the District's stream diversion watersheds



Source: USGS Open-File report 97-489, Brabb, 1997

3.3.3 Hillslope geomorphology

Geomorphic processes involve the process of erosion, as soil becomes detached and is transported by water, wind, or gravity. Erosion can be attributed to the underlying geology, seismic or geologic activity, steepness of slopes, climate, vegetation, and land use.

3.3.3.a Soil erosion

Soil erosion is a three-step process consisting of the detachment of a soil particle, its movement down slope, and its deposition in a channel, floodplain, or flatter portion of the slope. The ease of detachment is largely controlled by the following four physical factors: (1) the length and steepness of slope, (2) the amount of vegetation or litter layer cover, (3) soil conditions (texture, degree of compaction or soil aggregation), and (4) rainfall intensity.

Because of the steep slopes, high rainfall intensity, and prevalence of land use activities that disrupt soil cover on watershed lands, the rate of soil erosion in the San Lorenzo River watershed is high.

There are three types of surface erosion – sheet erosion, rill erosion, and gully erosion.

Sheet erosion is the detachment and movement of soil particles due to raindrop impact and sheet flow of rain runoff. The result is the loss of a thin layer of soil that is virtually undetectable by eye. Over time the results of sheet erosion become clearly visible in the form of tree roots seemingly growing on top of the ground surface.

Rill erosion is the erosion of a series of narrow grooves cut into the surface. Sheet erosion usually progresses to rill erosion, which usually occurs on longer slopes or road surfaces. Both sheet and rill erosion are common on dirt roads and construction sites with bare soil and can result in significant soil losses. A soil loss equivalent to the thickness of a nickel over one acre constitutes a soil loss of 15 tons which is roughly equivalent to 15 cubic yards of sediment. Where signs of sheet erosion are visible, or where it has progressed to rill erosion, soil losses are more than 20 tons per acre per year – the equivalent of dropping two or more dump truck loads of soil into the stream.

Gully erosion is erosion that results from gully formation and subsequent growth in gully length, depth, and width. A gully is defined as a new channel, at least one foot square in cross-section that has been eroded by storm runoff. Rill erosion on long slopes will progress into gully formation. Gullies can most frequently be found in roadside ditches, below culvert outlets, or on roadbeds below obstructed culverts.

Sheet, rill, and gully erosion are the most prevalent form of erosion on unpaved roads and driveways, which in turn, are a major source of sediment in the San Lorenzo River Watershed (County of Santa Cruz, 2001).

Because of their sand texture, sparse vegetative cover, and lack of organic matter, Zayante Coarse Sand soils are the most erosive of all soils in the watershed when they are disturbed. In contrast, in their undisturbed state they have a very low erosion rate, probably due to their high infiltration rate which leaves little surface runoff to detach and transport soil particles. When water is concentrated in culverts, roof downspouts, or ditches and released onto Zayante soils, those same soils experience rapid and severe gully erosion.

The least erosive soils in the watershed would be all of those soils that occur within an undisturbed redwood/Douglas-fir forest on level or gently-sloping land.

3.3.3.b Erosion potential

Erosion potential is related to specific properties of soils or rock formations, the steepness of slopes, the volume and intensity of rainfall, and the impacts of human activities. The principal soil properties that facilitate erosion from precipitation or flowing water are detachability and transportability. Soil particles that are easily detached from the soil mass and easily transported by flowing water are most susceptible to erosion. Both detachability and transportability are related to soil or rock texture, particle size, and the degree of cementation between individual grains. For example, clay particles tend to adhere to each other and thus, are not readily detachable. Pebble-to-boulder size clasts (rock fragments) may be too large and heavy to be transported by flowing water, thus armoring the soil against further erosion. In contrast, uncemented ("friable") sand is highly erodible (Swanson Hydrology & Geomorphology, 2001).

Swanson Hydrology & Geomorphology (2001) suggests that the area south of the Zayante fault is more susceptible to surface erosion, while the area north of the Zayante fault is more prone to deep and large scale landslides. However, some sandstone formations north of the Zayante Fault are extremely erodible, once denuded.

Decomposed granite is one of the watershed's most stable geological substrates. Where exposed to weathering or erosion, geologic formations such as mudstones, shales, and less coherent sandstone units may be significant chronic sources of sediment (Hecht & Kittleson, 1998). This occurs more commonly in the steeper, upper watershed areas.

Hecht & Kittleson (1998) recognized four geologic formations in the watershed that are consistent sources of sediment loads to streams, despite stabilization efforts:

- Santa Margarita Sandstone along Bean Creek and neighboring drainages. Disturbance of the Zayante soils and weathered mantle results in severe gullying and long-term instability. The high permeability and low available water capacity and fertility in exposed Santa Margarita sandstone severely limit revegetation efforts, particularly in south-facing slopes.
- Vaqueros Sandstone, where disturbed by road development in upper Bear Creek and Deer Creek, and in the upper Boulder Creek, Zayante Creek, and Kings Creek drainages.
- Sandier parts of the Purisima and Lompico formation in Branciforte and Carbonera Creeks, particularly where residential development, roads, agricultural practices and livestock (primarily horses) concentrate flows or reduce capacity of the soils to hold moisture and attenuate runoff are also sources of landslides and winter debris.
- Mudstones in Kings Creek, Logan Creek, and the upper San Lorenzo River. Where exposed, vegetation is often naturally sparse, soils are thin or non-existent and weathering continuously exposes erosive surfaces. Steep slopes, unsurfaced roads, and roadcuts in these areas are notable sources of persistent turbidity, particularly where year-round road use is necessary for residential access.

Coats et al. (1982) found the two geologic formations that contributed the most sediment to the Zayante stream system from landsliding during the January 3-5, 1982 storm were the Vaqueros Sand Stone and the Butano Sand Stone. Moderate contributors were (in descending order) Lambert Shale, Santa Margarita Sand Stone, Monterey Shale, and Lompico Sandstone; with the Santa Margarita Sandstone and Monterey Shale having the highest representation in the survey areas. They also found that the relative contribution of sediment to the stream system from different geologic formations varied between sub-watersheds and depended largely upon steepness of slope, proximity to stream and disturbance (Coats et al., 1982).

Coats et al. (1982) found Vaquero, Butano, Zayante sandstone, and Monterey shale more resistant to streambank erosional processes than the Santa Margarita sandstone due to the greater degree of consolidation and cementation of the individual grains in the Vaquero, Butano and Zayante sandstones. The Monterey shale bedrock is even more resistant than the sandstones. Coats et al. (1982) further described landsliding in the watershed during the 1982 storm:

> The landslide mapping revealed that the most intense sliding occurred not in the headwaters of Zayante or Lockhart Creeks, where the area of steep slopes is greatest, but rather in areas of steep slopes along the middle portions of the creeks. Differences in bedrock geology cannot explain this observation, since both the same formations occur near the headwaters of Zayante creek but were hardest hit in the mid-basin area. At least three factors may be responsible for the higher landslide frequency in mid-basin areas. First, the slopes in the upper portion of the basin may be better adjusted to intense precipitation events. Second, land use has been more intense in mid-basin areas. Third, the inner gorge slopes in the mid-basin areas may have been vulnerable to undercutting by high peak discharges. Unfortunately, we do not have either a long-term or an event record for headwater areas at Zayante Creek basin, but we know that precipitation was very intense in mid-basin areas. Streambank cutting was a major contributing factor to landslides in the SMss, but overall the volume attributable to stream-induced landslides was not great….We conclude that the observed pattern of landsliding was due more to the interaction of intense precipitation, saturated soil and colluvium, hillslope gradient and land use than to the interaction of peak discharge with inner gorge slopes.

3.3.3.c Channel conditions

Sediment is delivered to streams both chronically and episodically. Natural ecosystems have adapted a resiliency to episodic sedimentation. However, chronic human activities increase the magnitude of these episodic events, often to levels beyond the natural system's ability to transport sediment. Human disturbance also causes chronic sedimentation, which creates the most significant impact to natural watershed processes and health. While it is difficult to control episodic sedimentation, erosion control efforts can reduce chronic sedimentation, and such efforts are key in reducing cumulative watershed impacts.

The characteristics and patterns of runoff within a watershed strongly influence the locality and magnitude of sediment deposition. Areas of the San Lorenzo River watershed naturally have episodic storm events with peak rain and streamflow events that rise and drop very fast. This leads to natural peaks of sediment transport followed by rapid deposition. Suburbanization, roads, impermeable surfaces or the denuding of areas within a watershed cause higher peak flows, which briefly increase the streams ability to transport materials.

3.3.3.d Sediment transport

Transport within stream systems is dependent upon particle size, water velocity, turbulence, channel gradient, and channel morphology. As stream velocity increases, so does its ability to transport material. Narrower channels with faster stream velocities have greater ability to transport material. Wider channels with slower stream velocities are likely to be areas of deposition.

According to Butler (1981), natural erosion rates in the watershed at that time fluctuated between 750 to 1,250-tons/square mile/year depending upon variations in geology, soils, steepness of slope, rainfall and drainage patterns, vegetation, and land use. After substantial rains, the soil becomes saturated resulting in high runoff and loss of structural integrity of soils. During these times erosion, especially from mass wasting, and slope failures is most prominent.

During the relatively wet year of 1973, a total of 438,204 tons (331,970 cubic yards) of sediment were carried down the river past the Big Trees gage in Felton. This indicated an average sediment production for that year of 4,134 tons per square mile from the watershed. During the same year the highly erodible and disturbed upper Zayante Creek sub-basin lost 7,884 tons of soil per square mile (County of Santa Cruz, 1979).

Swanson Hydrology & Geomorphology (2001) describes three “thresholds” of sediment transport within a watershed:

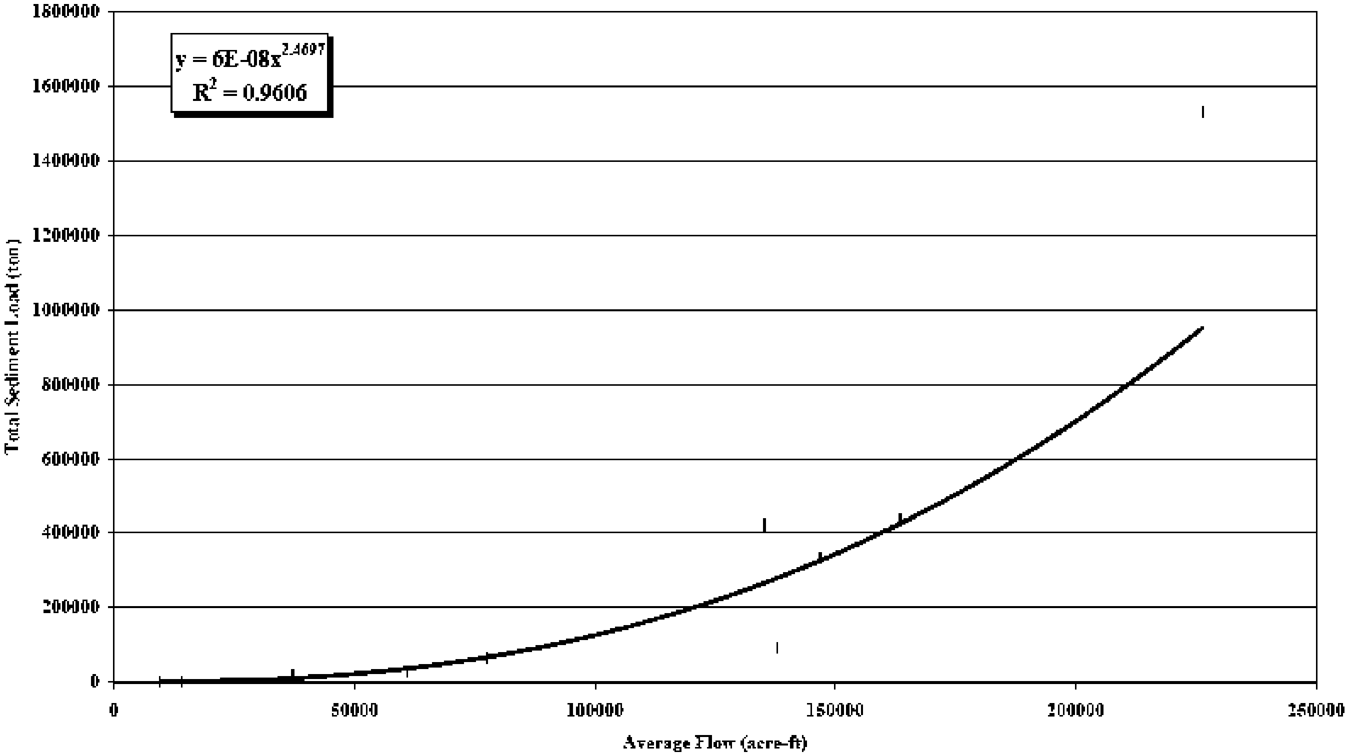
> The first threshold of sediment supply and delivery is due to small and common rainfall events where sediment is mobilized from the surfaces of hillslopes in areas of weak soils and from the bed and banks of high order stream channels. With increasing rainfall, the second threshold is reached and sediments in steep tributary streams are mobilized, thereby increasing sediment delivery to high order streams. The final threshold occurs when intense and/or long duration rainfall over saturates soils and triggers landslides from hillslopes, delivering large volumes of sediment to the streams during flood stage.

While fine sediments can be transported slowly most of the year even at low flows, most of the transport of bed material seems to occur during episodic storm events characteristic of the watershed. Nolan et al. (1984) found that 50% of suspended sediments are transported during discharges that only occur approximately two days a year. Nolan et al. (1984) also calculated that 90% of fine sediment is carried by flows that occur on the average once every 15 years. Hecht & Kittleson (1998) found that much of the transport on the San Lorenzo River occurs at flows of between 500 and 5,000 cubic feet per second (cfs).

Coats et al. (1982) calculated that transport of larger substrate (material larger than 8 mm) is not significant until flows of 500 cfs; flows of this level are reached about 0.51 days a year. It is these larger, winter flows that rearrange habitat and release embedded sediment to be transported downstream. Nolan et al. (1984) stated that the geomorphology of most intermediate and larger channels appear to reflect effects of moderate events as much as catastrophic events; however, the geomorphology of smaller, steeper channels strongly reflect the effects of extreme events.

Swanson Hydrology & Geomorphology plotted annual suspended sediment yield against annual streamflow volume for the San Lorenzo River, using data from the field gage at Big Trees station in Felton. Figure 3.13 shows the rating curve, which was used to extrapolate sediment yields over the stream flow record from 1939-1998, to estimate an average sediment yield. Figure 3.14 shows the synthetic suspended sediment yield for the San Lorenzo River.

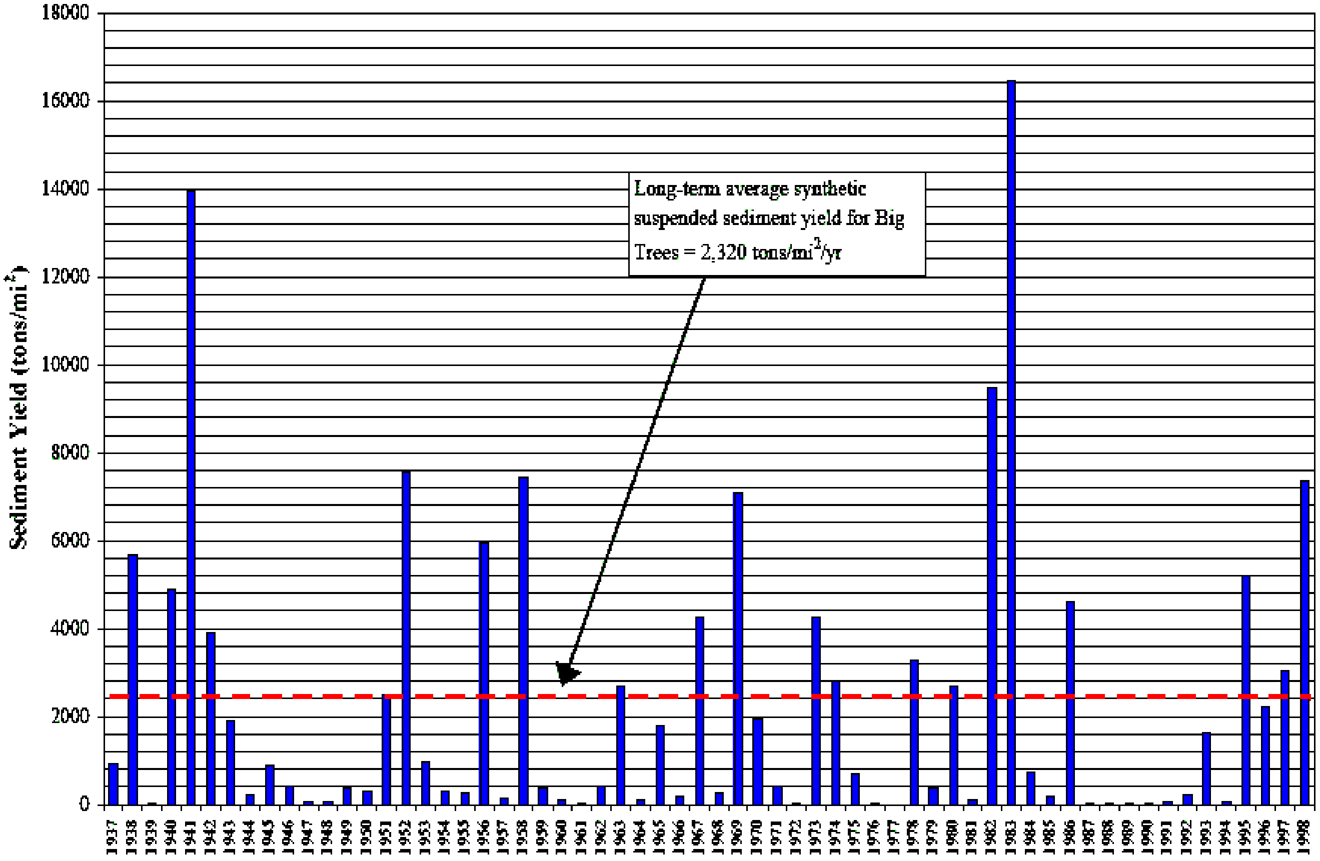
Figure 3.13 Sediment yield rating curve for the San Lorenzo River at Big Trees*



*USGS Station #11160500

Source: Swanson Hydrology and Geomorphology, 2001.

Figure 3.14. Synthetic suspended sediment yield for the San Lorenzo River at Big Trees*



Long-term average synthetic suspended sediment yield for Big Trees = 2,320 tons/mi^2/yr

The dashed line represents the long-term average synthetic suspended sediment yield.
*USGS Station 11160500
Source: Swanson Hydrology and Geomorphology, Zayante sediment study, 2001.

Impervious surfaces such as roofs and driveways greatly increase runoff. Landowner responsibilities to reduce runoff and erosion problems are not well defined. Landowners may attempt emergency fixes without regard to downslope conditions. Undersized, plugged, poorly installed, or inadequately maintained culverts lead to drainage problems. Failed culverts exacerbate erosion and sediment transport within the watershed.

3.3.3.e Bed sedimentation

Maintaining adequate streamflow is necessary to maintain adequate sediment transport within the streams of the watershed. When the hydraulic force of a stream is insufficient to move instream material within the water column (suspended load), or roll it along the bottom (bed load), the material is deposited or remains in the stream until the next major storm. A certain level of streamflow is required to keep fine materials suspended; below this level, sand and silt settle out into the streambed, filling pools, riffles, inter-boulder and inter-gravel spaces.

The dynamics of the channel bottom also affect transport and deposition. Objects within the channel break up the flow of the stream, cause turbulence and areas of increased velocity and change flow directions. Turbulent areas can pick up material and bounce it along the bottom. Boulders, logs or rootwads in the stream become scour objects. Water speeds up as it moves around scour objects, scouring material off the bottom near the object. This material can be deposited a few feet downstream or transported long distances.

Excess fine sediments fill the inter-boulder and inter-gravel spaces and change channel dynamics, greatly affecting streamflow dynamics. As the stream becomes embedded with sediment, the channel becomes smoother, turbulence from roughness decreases, transport of material decreases, and so deposition increases. The channel will continue to aggrade (fill with sediment) until streamflow increases or a scour object enters the stream. Aggraded reaches can store large quantities of sediment with residence times of up to thousands of years (Swanson Hydrology & Geomorphology, 2001). The negative impacts of sedimentation on fisheries habitat is discussed in Chapter 4.

Large instream wood, log clusters, check dams, and reservoirs all act as sediment entrapment basins. By creating an area of slower moving, non-turbulent water the stream no longer can suspend the sediment and the material deposits behind the dam until the “theoretical base level” created by the dam is reached (Mount, 1977).

Instream wood increases the storage capacity of the stream, modulates excess sediment transport, and reduces embeddedness elsewhere in the stream. Stable instream wood forms a stair step channel, which dissipates stream velocities and forms dynamic channel morphology for diverse and abundant habitat characteristics.

3.3.3.f Sedimentation trends

According to Hecht & Kittleson (1998), the only areas where existing data allows long-term historical analysis are Zayante and Bean Creeks and the Lower San Lorenzo River. Hecht & Kittleson initiated research and monitoring throughout the watershed, recommending that it be repeated every 3-5 years, and after every large storm event.

State Department of Fish and Game stream surveys conducted in 1966 and 1972 noted that within the bed composition of the main stem of the San Lorenzo River, silt increased from 8 percent to 65 percent; while spawning gravel decreased from 20 percent to 2 percent (County of Santa Cruz, 2001).

Hecht & Kittleson (1998) concluded that stream conditions had not substantially improved between the 1979 County of Santa Cruz Watershed Plan and their 1996 surveys. They found that, “sediment sources and the causes of erosion have remained fundamentally unchanged since the inception of the first watershed plan.”

Hecht & Kittleson (1998) surveyed bed sedimentation in the San Lorenzo River watershed, drawing the following conclusions:

- There appears to be a general fining of bed materials at all sites except the San Lorenzo River at the Felton Diversion. While the limited number of samples at each study site may preclude a definitive trend analysis, contemporary conditions do not show improvement in reduction of sediment supply or improvements in gravel availability and/or embeddedness of gravel size material.

- Proportionately less bed material in Zayante and Bean Creeks appears to be generated now north of the Zayante fault. Quartzites and volcanics, which originate almost exclusively north of the fault, are only about half as abundant as in 1978-81. These two rock types are both very durable and are also easily identified, so we believe this finding to be especially informative. Proportionately more sediment is originating from areas downstream of the Zayante fault, most of which are sandy.
- Proportionally, more sediment is generated in middle and lower Bean Creek subwatershed than in earlier evaluations, based on gravel lithologies.
- There is a sharp decrease in relative bed material sizes at the station on Bean Creek below Lockhart Gulch. It appears that Lockhart Gulch is overwhelming the monitoring site with sand. Development-related disturbance and road slipouts in Lockhart Gulch are likely sources. Slides and associated gullies on Bean Creek Road, particularly a set of slides 0.5 miles north of Camp Evers, also are significant sources of fines to this reach.
- In streams where residents have undertaken individual streambank stabilization efforts, concrete rubble, cinder blocks, asphalt, baserock and other road-related materials may make up 15 percent or more of the streambed surface. It appears that the presence of these types of materials originated from previous uncoordinated stream bank protection projects. In sections of lower Branciforte, Carbonera, and Bean Creeks, these materials and sand make up the majority of the bed surface. The addition of these materials may have de-stabilizing geomorphic consequences by forming bars and braids in sandy reaches with less-coherent sandy banks and a disturbed riparian buffer zone.
- There is a marked increase in introduced rock types (roadbed, asphalt, and concrete) in Zayante Creek at Graham Hill Road. This was particularly notable in the gravel size classes. About 11 percent of the bed surface is composed of materials entering the stream from the road surface. Nearly all of these materials are associated with roads and point to the importance of roads as sediment sources.
- Future sampling should include establishment of several study sites on the mainstem San Lorenzo. Besides ongoing fish habitat evaluations done by Don Alley & Associates, the historical data are limited. Priority for future bed sampling should include sites above the Zayante Creek confluence, below the old USGS gage on the San Lorenzo (possibly to Paradise Park), and reaches above and below Boulder Creek, Bear Creek and Kings Creek, and on lower Carbonera and Branciforte Creeks. Boulder Creek and Fall Creek sites would also allow for valuable information on bed conditions in the crystalline-bedrock channels that drain Ben Lomond Mountain.
- Existing fisheries enhancement projects that have been implemented at former geomorphic study sites can and should be monitored to assess these structure's effects on local bed conditions. There exists a unique opportunity to use historic baseline conditions data to evaluate the different habitat enhancement designs that have been put in place in the Zayante Creek watershed.
- Bed monitoring is effective in describing changes and trends in streambed conditions if repeated regularly by informed investigators. The two key issues in this type of hands-on field study of bed conditions is that it is done during low flow periods (thereby making it safer for volunteers), and that it can develop trend analyses which can supplement other

fisheries studies in the system. The sites which can still be used should be re-measured at intervals of 3 to 5 years (avoiding times when the bed is episodically sedimented), and no longer then 5 to 10 years, to evaluate the effectiveness of ongoing efforts to improve habitat conditions and recreational values, as well as to protect the quality of community water supply and the habitats of key, sensitive, and/or listed species.

3.3.3.g Upland sediment sources

In 2004, Alley et al. completed a comprehensive geomorphic survey of the San Lorenzo River and its tributaries. Alley et al. (2004) measured extremely high embeddedness in the Upper River, Kings Creek, Bear Creek, and the Rincon area, consistent with past findings made by Alley. From these surveys, Alley et al. (2004) concluded that sediment loads are coming from upland sources such as Kings and Bear creeks and from the more developed subwatersheds of Bean and Carbonera creeks.

3.3.3.h Bank erosion

Excess streambed sedimentation leads to increased bank erosion.

While some streambank erosion is natural, humans increase its rate by altering or removing riparian habitat, which serves as a buffer for acute storm events and chronic bank erosion. Altering runoff and drainage characteristics of upland areas also decreases streambank stability.

An intact riparian forest helps to minimize bank erosion. Breaks in riparian canopy are often associated with bank instability. Once the disturbance is ceased or remedied riparian vegetation will generally re-establish itself naturally. Efforts to stabilize eroding banks without restoring riparian vegetation often fail (Hecht & Kittleson, 1998).

Butler (1981) described bank erosion in cubic yards per 1000 ft reach of stream, and reported bank erosion from a low of 5 cu yd/1000 feet of streambank to extreme rates of over 70 cu yd/1000 ft of bank. Butler (1981) then determined that with about 150 stream miles, the San Lorenzo averages approximately 15,000-20,000 cubic yards of sediment from streambank erosion each year. According to estimates in the San Lorenzo River TMDL (CCRWQCB, 2002), about 60,143 tons/yr of sediment is contributed from channel and bank erosion, equal to about 14.3% of the total sediment load, as shown in Table 3.5.

Table 3.5 estimates sediment yields of each subwatershed of the San Lorenzo River, as well as sediment source categories. This table was included as part of the San Lorenzo River TMDL (CCRWQCB, 2002). The data was extrapolated from sediment studies in the Soquel Demonstration State Forest, and likely underestimates sediment yields from the San Lorenzo River. A previous study of the San Lorenzo River (County of Santa Cruz, 1979) showed considerably higher sediment yields.

Based on the input data available for the analysis, Swanson Hydrology & Geomorphology (2001) calculated that the estimated average sediment yield contributed by bank erosion in Lower Bean, Upper Bean, and Lockhart Gulch alone is 240 tons/mi/yr. Comparing these numbers to load amounts at the watershed scale suggests that bank erosion contributes a significant proportion of the total sediment load to stream channels (Swanson Hydrology & Geomorphology, 2001).

Table 3.5 Estimated sediment yield in the San Lorenzo River watershed, by subwatershed and source category

SubWSID	Sub-watershed	Area (sq mi)	Upland THP roads (tons/yr)	Streamside on steep slopes THP roads (tons/yr)	Upland public/private roads (tons/yr)	Streamside on steep slopes public/private roads (tons/yr)	THP lands (tons/yr)	Other urban and rural lands (tons/yr)	Mass wasting (tons/yr)	Stream channel/ bank erosion (tons/yr)	Total sediment yield (tons/yr)	% of Total	Sediment yield (tons/sq mi/yr)
30412010	Upper San Lorenzo River	11.52	5915	2683	2260	951	134	5491	32085	4712	54321	12.93	4703
30412011	Kings Creek	12.12	10667	4842	1921	1317	319	4648	17419	5172	46315	11.04	3818
30412020	Boulder Creek	11.47	7708	3496	2003	1176	232	4839	10580	5312	35346	8.43	3082
30412021	Ben Lomond	10.32	4143	1879	3147	1509	106	5005	23499	4964	44252	10.55	4288
30412022	Middle San Lorenzo River	15.87	2284	1036	3291	12942	71	8284	12215	8190	36665	8.74	2310
30412023	**Shingle Mill Creek**	0.71	0	0	275	150	0	391	0	358	1174	0.28	1654
30412030	Bear Creek	16.23	9230	4186	2566	1638	246	7368	12975	6422	44631	10.64	2750
30412031	Newell Creek	9.72	1539	698	590	79	49	1018	1503	935	6411	1.53	660
30412040	Zayante Creek	14.02	6924	3140	3376	1432	207	6393	28110	5254	54836	13.08	3911
30412041	Bean Creek	10.41	1753	795	2804	1499	49	5416	13937	6134	32387	7.72	3111
30412042	**Lompico Creek**	2.77	883	401	896	582	23	1378	7156	1236	12555	2.99	4532
30412050	**Carbonera Creek**	7.08	878	398	2583	295	33	3687	4464	3728	16066	3.83	2269
30412051	Branciforte Creek	9.95	1676	760	2051	1744	39	5223	10668	5088	27269	6.50	2741
30412052	Pasatiempo Creek	0.8	0	0	348	0	0	442	2872	0	872	0.21	1096
30412053	Santa Cruz	4.23	0	0	1302	54	0	2327	31	2638	6352	1.51	1502
Total sediment load for **San Lorenzo River** (tons/yr)		137.23	53610	24314	29415	13720	1508	61910	174749	60143	419369	100.00	3056
% of Total			12.78	5.80	7.01	3.27	0.36	14.76	41.67	14.34	100.00		
Sed. yield (tons/mi^2/yr)			391	177	214	100	11	451	1273	438	3056		

Note: Waterbodies listed as impaired by sediment on the 1998 303 (d) List are shown in bold type.

Source: CCRWQCB, 2002.

3.4 Natural disturbances in the San Lorenzo River watershed

Natural disturbances, including fire, storms, floods, landslides, and earthquakes have occurred throughout time, changing the landscape of the watershed. Stream networks and ecosystems have evolved with natural disturbances. Healthy ecosystems and stream systems have a built-in resilience to the impacts caused by natural disturbances, and may even depend on natural disturbances to maintain a healthy state.

3.4.1 Storms and floods

Extreme storm events that lead to flooding are cyclic, as are the disturbances they create throughout the watershed. The San Lorenzo River watershed is prone to flooding, due to its steep topography, extreme episodic storm events, and relatively high water table during storm events.

Flood stage storms can dramatically increase sediment and gravel input and transport within streams. In healthy stream networks, the periodic input of smaller material is necessary for aquatic ecological function. For example, gravels necessary for anadromous spawning generally result from storm events.

The storm of 1956-1957 damaged natural features and human structures, and increased chronic sediment delivery to streams. After this storm, the US Army Corps of Engineers (Corps) built the “flood control” levee system on the lower San Lorenzo River and Branciforte Creeks within the City of Santa Cruz. These levees drastically disturbed the natural ecosystem function of the final miles of the watershed. The channel, filled with sediment, increased the flood risk to the City. The Corps and the City, in the past few years have raised the walls of the levee to increase its flood control ability.

Among El Niño events, the 1981-82 winter storm was the largest, and produced the most intense rainfall ever recorded in the area. It delivered more than 19 inches of rain to Lompico in a 24 hour period. The watershed received over 100 inches of rain that winter. In the aftermath of this storm were road failures, streambank erosion, and landslides throughout the watershed, including the massive Love Creek slide. Runoff from already saturated hillslopes caused extreme erosion and sediment from landslides, debris slides and slope failures impacted all the waterways.

Pools and riffles in all reaches of Zayante Creek were essentially obliterated following the January 1982 storm, except where riffles were formed of large boulders, as below the USGS gage on Zayante Creek. One large pool cut into bedrock in the Olympia reach remained, but it was largely filled with sand following the storm. Significant scouring occurred in all reaches during March and April, as the sand and gravel deposited during and shortly after the storm began to move out of the stream (Coats et al., 1982).

Following this storm, the State Water Resources Control Board organized a study (Coats et al., 1982) to quantify certain aspects of a sediment budget and monitor changes in substrate and channel morphology in Zayante Creek and the lower San Lorenzo River.

> General effects of the January storm on channel morphology included scour in small first- and second-order channels and fill in larger, higher order channels. . . The mean

> streambed elevation of the San Lorenzo River rose 0.85 m, and the remaining sites ranged from 0.46 m of scour on Bear Creek to 0.06 m of fill on the San Lorenzo River near Boulder Creek . . . The most numerous and severe channel modifications were found along midbasin locations of Zayante and Bean Creeks (Nolan et al., 1984).

In all instances within the Zayante area, sediment transport was an order of magnitude higher at lower flows after the flood than it was before (Coats et al., 1982). The massive input of sediment to the system slowed the "clearing the waters" and the transport of sediment along the stream system for a long period of time to come.

Floods can drastically alter stream channels and, in some cases, upland habitats. Floods facilitate the input and transport of large wood into the channel, which provide beneficial structure and aquatic habitat. Floods move larger bed material through the channel, release and flush out stored sediment, and reconfigure channels. Sediment supply to streams in landscapes subject to landsliding and debris flows often have long periods of relatively low sediment input with brief periods of extremely high input, characterized by waves of sediment moving down the stream during flood flows (Miller and Benda, 2000).

Floods often damage or remove sections of riparian ecosystem, opening up stream corridors, and creating variation in habitat and water temperatures within the stream. The result is often increased variability and diversity in aquatic habitat conditions. In response, the riparian corridor may re-establish itself, through revegetation and re-armoring of the stream bank.

Most landslides occur during flood stage storms. Extreme sediment input from flooding can lead to overburdening of the stream system, especially in impaired streams, which are lacking in natural mechanisms capable of absorbing such increases.

As El Niño winters become more frequent, intense storm events contribute more erosion and sedimentation throughout the watershed.

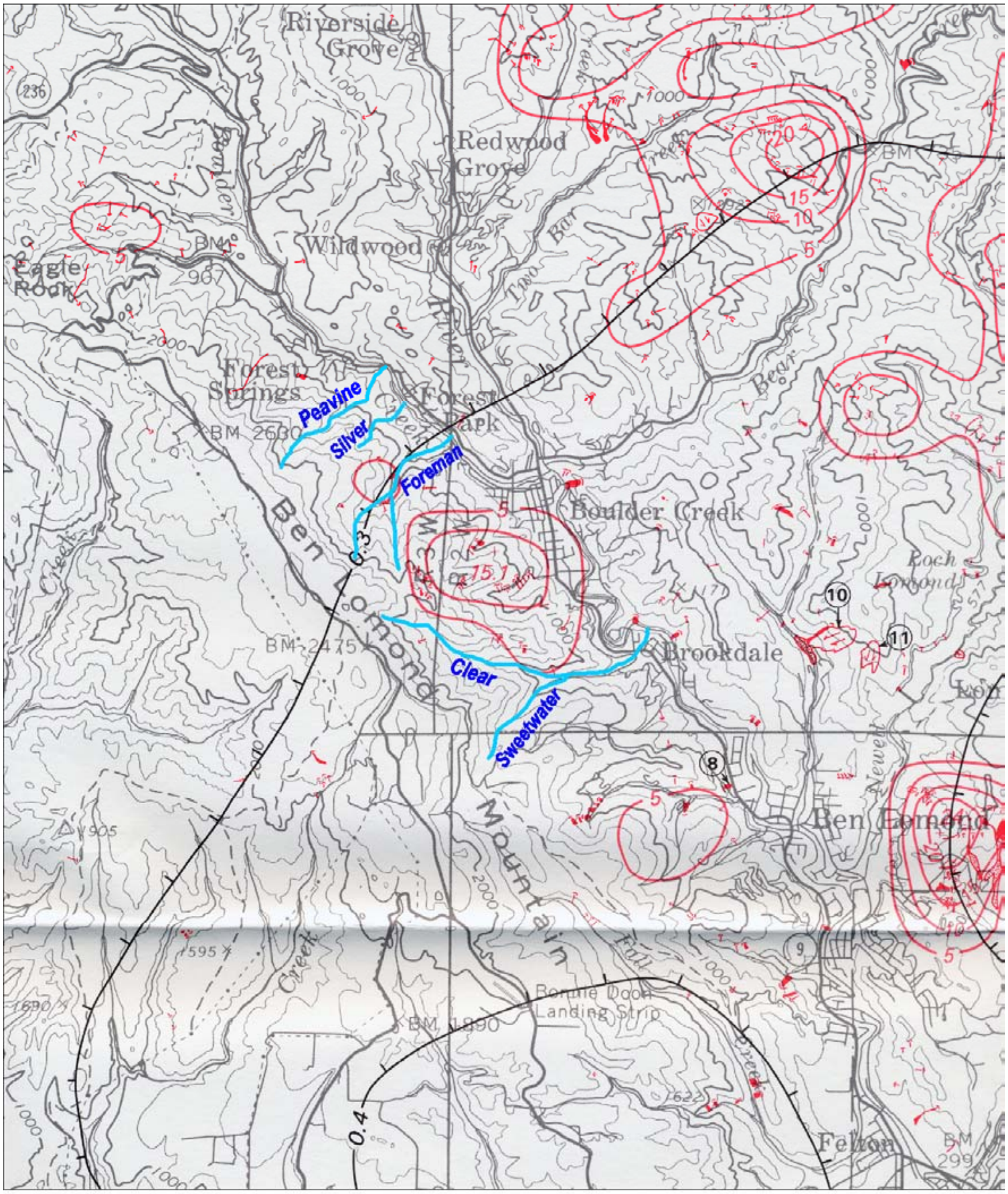
3.4.2 Wind

Wind can erode bare areas and transport sand and other small particles for relatively long distances. Mount (1977) observed that winds blowing across steep quarry faces had transported large amounts of loose sand out of the pit area. In the San Lorenzo River watershed, bare cut faces due to mining within the Santa Margarita Sandstone are especially susceptible to wind erosion. Revegetation efforts are also critical in reducing erosion. Natural unvegetated sand outcrops in the sand hills areas exist in a stable state. For example, Quail Hollow has sand outcrops that are stable due to increased cementation of the sandstone. In addition, liverworts, lichens or other organisms encrust the outside layer, reducing wind and water erosion.

3.4.3 Landslides and mass-wasting

Landslides and mudflows are common in California because of active geologic processes, rock characteristics, earthquakes, and periodic intense storms. Figure 3.15 shows landslides in the area of the District's surface water diversions.

Figure 3.15. Distribution of landslides and debris flows from January 1982 storms.



Red contours represent concentration of debris flows per square kilometer. Black contours represent normalized storm rainfall.

Source: USGS Professional Paper 1434, Ellen and others, 1968, as cited by Johnson, 2002

Landsliding (or mass wasting) is the dominant geomorphic process in the Santa Cruz Mountain landscape. Landslides create a patchy mosaic of geology, soil type and soil stability, which in turn, leads to a patchy mosaic of diverse age and structure of vegetative communities. Landslides can also destroy life and property, increase erosion, sediment transport and sedimentation. For example, a landslide across Conference Drive, destabilized by hydrologic changes to surface and groundwater movement at Kaiser Quarry, is now a major chronic contributor of fine sand to Bean Creek.

In their report on erosion and sedimentation in the Zayante area, Swanson Hydrology & Geomorphology (2001) explained:

> Landsliding results from weak geologic formations, steep topography caused by tectonic uplift, and occurrence of intense periods of rainfall and seismic forces. Landslides often terminate at and impinge upon stream channels, sometimes feeding a seemingly endless supply of sandy material directly into the channels (e.g. Mount Hermon Landslide at Bean Creek). In the worst cases, chronic sediment loading from landslides can eliminate pools, riffles and coarse substrate for hundreds of feet below the point of delivery.

Different types of landslides deliver sediment to streams at different rates. Rapidly moving *debris flow* slides can instantly deliver much of a landslide mass to a stream. Debris flow slides typically begin after intense rainfall elevates soil saturation to a level that liquefies the mass, triggering abrupt and rapid movement (Benda and Dunne, 1997). Debris flows were ubiquitous, and in some cases deadly, within inner gorge slopes in the Santa Cruz Mountains following the January 2-4, 1982 storm.

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

3.4.4 Earthquakes

Earthquakes can significantly change the flows of springs, impact water quality, and cause release of constituents from reservoir-bottom sediments. Earthquakes can also damage underground storage tanks, wastewater treatment facilities, and drinking water treatment and distribution facilities. The 1989 Loma Prieta Earthquake had major impacts on upland erosion and stream function.

3.4.5 Fire

Fire is an important natural disturbance that contributes to a patchy framework of forest age and structure, and increases the overall health and resilience of the forest through time. Forests that are predominately redwood *(Sequoia sempervirens)* are able to resist the effects of all but the most intense wildfires (Agee, 1993). Critical fire weather is concentrated in the months of July through October. Drier inland areas are more prone to fire than moister coastal forests. Forests in areas of high wind are prone to windthrow, which creates a significant fuel load. As the watershed became increasingly developed, fire suppression became an accepted management goal. Fire suppression allowed the build-up of fuel material, increasing the risk of a catastrophic fire. A catastrophic wild fire would create large tracts of bare soil, leading to extensive erosion and sedimentation. Refer to Chapter 5: Fire, which addresses the role of fire and fire suppression, in terms of potential impacts to water quality.

3.5 Human-induced disturbances in the San Lorenzo River watershed

Human disturbance has altered hydrologic processes by increasing the magnitude and frequency of peak discharges and reducing summer base flows (Klein, 1979; Booth, 1991; cited in Spence et al., 1996). Urban and rural development is a major source of erosion and sedimentation. Many current and historic human induced impacts in the San Lorenzo River watershed cause or exacerbate erosion and sedimentation. According to the Draft San Lorenzo River Watershed Management Plan (County of Santa Cruz, 2001):

> Overall, the most persistent, chronic source of sediment to area streams appears to be (1) roadcuts on public and private roads, (2) year-round use of dirt roads, primarily for residential access, and (3) timber harvest road networks. Periodic roadcut failures, grading and leveling of road surfaces continuously expose erodible material both on the road surface and along the road shoulder. This loose, unconsolidated material may be extremely mobile in relatively insignificant rainfall events. Roadcuts along most steep roads are chronic sediment sources. Small cut/fills for residential driveways exacerbate sedimentation problems… Residential land clearing, grading without effective erosion control, and ad-hoc drainage management, active timber harvests and disruption of riparian zones continue to contribute sediment, most noticeably from newer or recurring areas of disturbance.

Hecht & Kittleson (1998) also noted significant human-induced impacts:

> Many erosion sites, mudslides, and landslides result from ad hoc and uncoordinated control for drainage onto, across, and off of private lands and public rights of way. Landowner responsibilities and obligations for management of storm runoff are not well understood and chosen strategies are often emergency “fixes” that neglect to consider downslope conditions. Runoff from roofs, impervious driveways and private roads can greatly increase the volume, velocity and erosive force of offsite runoff. In addition, undersized, plugged, poorly installed, or inadequately maintained culverts and drainage structures can lead to changes in drainage patterns that exacerbate gullying, sheet erosion, or sliding of saturated slopes.

Table 3.6 describes erosion sources identified in a 2001 sediment study of the Zayante area, within the San Lorenzo River watershed (Swanson Hydrology & Geomorphology, 2001).

Table 3.7 lists sediment source estimates in the San Lorenzo River watershed.

Table 3.6 Description of erosion sources in the San Lorenzo River watershed

Sediment source category	Source extent	Erosion description/ types/sources
Timber harvest plan (THP) roads (streamside on steep slopes) THP roads (upland)	Includes road cuts, shoulders, surfaces, and ditches on permanent and seasonal roads and skid trails	Predominately surface erosion from road-related activities, including erosion from drainage modifications caused by roads. Considered to be 100% human caused, this category was divided into streamside roads on steep slopes (within 200 ft. of a waterway) and upland roads, because of differences in delivery ratios.
Public and private roads (streamside on steep slopes) Public and private roads (upland)	Includes road cuts, shoulders, surfaces, and ditches on paved and dirt roads	Predominately surface erosion from road-related activities, including erosion from drainage modifications caused by roads. This category is assumed to be 100% human caused. This category was further divided into streamside on steep slopes (roads within 200 ft. of a waterway and on slopes less than 15%) and upland roads, because of differences in delivery ratios.
Active and recent THP parcels	Includes all forested land with THPs generated since 1987	Includes all surface erosion including sheet erosion, rills, and gullies. This category has both a human and natural component.
Other urban and rural lands	Includes all forested and unforested lands outside of recent THP plots	Includes surface erosion from sheet erosion, rills, and gullies, as well as mass wasting (i.e.; landslides, debris flows). The mass wasting component was pulled out of the final numbers and put into a separate mass wasting category. This category has both a human and natural component.
Mass wasting	Includes all lands within the study area	Includes erosion from landslides and debris flows, road and disturbance-related mass wasting. This category has both a human and natural component though available data is insufficient to determine proportions.
Channel/bank erosion	Includes all stream corridors within the study area	Includes main channel, banks, and floodplain areas of the stream. Does not include landslide toes or erosion form culvert outfalls. This category has a predominately natural component, though rates can be accelerated from human activities.

Source: Swanson Hydrology & Geomorphology, 2001; Zayante Area Sediment Source Study, as cited in CCRWQCB, 2002.

Table 3.7 Sediment source estimates in the San Lorenzo River watershed

Sediment source category	Erosion rate	Delivery ratio	Sedimentation rate	
Timber harvest plan roads (streamside on steep slopes)	413 tons/mi/yr	1.00	413	tons/mi/yr
Timber harvest plan roads (upland)	413 tons/mi/yr	0.42	173	tons/mi/yr
Public and private roads (streamside on steep slopes)	120 tons/mi/yr	1.00	120	tons/mi/yr
Public and private roads (upland , <=15% slope w/in 200ft. of stream; >15% slope outside 200ft. of stream)	120 tons/mi/yr	0.42	50	tons/mi/yr
Public and private roads (upland, <=15% slope outside 200ft. of stream)	120/tons/mi/yr	0.10	12	tons/mi/yr
Active and recent timber harvest plan parcels	206 tons/mi^2/yr	0.42	87	tons/mi^2/yr
Other urban and rural lands	1,310 tons/mi^2/yr	0.42	550	tons/ mi^2/yr
Mass wasting	3,570 tons/mi/yr	0.42	1500	tons/mi/yr
Channel/bank erosion- alluvium and Santa Margarita Sandstone geologic units	400 tons/mi/yr	1.00	400	tons/mi/yr
Channel/bank erosion – other geologic units	200 tons/mi/yr	1.00	200	tons/mi/yr

Source: Swanson Hydrology & Geomorphology, 2001; cited in CCRWQCB, 2002.

Table 3.8 was derived from Table 3.5 and shows estimates of sediment yields from different sources.

Table 3.8 Sediment source categories and estimated contributions

Sediment Source Category	Estimated Contribution (tons/yr)	Percent of Total
Mass Wasting	174,749	41.7
Timber Harvest Roads	77,924	18.6
Rural/Urban Lands	61,910	14.8
Channel/Bank Erosion	60,143	14.3
Public/Private Roads	43,135	10.3
Timber Harvest Lands	1,508	0.4

Source: CCRWQCB, 2002.

3.5.1 Mass Wasting / Landslides

Due to the watershed’s steep slopes, unstable geology and high rainfall, mass wasting occurs at a naturally high rate. The high concentration of human activities and development can reduce the stability of slopes and exacerbate the contribution of sediment from this natural source. Many mass wasting incidents can be linked to human disturbance.

In 1981 Butler described localized, severe erosion problems that are significant and chronic sources of sediment. He estimated that these “major problems” contributed 8-10% of the total annual sediment load to watershed streams. Specific examples were the Mt. Hermon slide, old quarries, and the abandoned Happyland subdivision.

Twenty years later, according to a 2002 CCRWQCB staff report, mass wasting (the downslope transport of rock, soil, or sediment under the influence of gravity) is the largest single source of sediment load to streams, contributing approximately 42% of the total load (Table 3.8). These results indicate a four-fold increase in the contribution of sediment from landslides in the past twenty years, when compared to the Butler report (1981).

The two studies did not use identical methods, and the later study included the massive 1982 Love Creek slide, as well as the Bean Creek slides.

Swanson Hydrology & Geomorphology (2001) estimated that the Love Creek Slide contributes a total of 46 tons/yr of sediment off the slide toe, and the Mt. Hermon Slide contributes a total of 1,030 tons/yr of sand to Bean Creek. When Bean Creek Road sediment delivery is added, a total of 1,470 tons/yr of sand is estimated to be delivered to Bean Creek (Swanson Hydrology & Geomorphology, 2001).

3.5.2 Roads

Roads have been reported as the primary sediment source in the San Lorenzo River watershed (Butler, 1981; Coats et al., 1982; Hecht & Kittleson, 1998; County of Santa Cruz, 2001; Swanson Hydrology & Geomorphology, 2001). A detailed study of 48 northern California watersheds found that the average effect of roads was to increase sediment yields by 37% (Anderson, et al., 1976 as cited in Mount, 1977). Roads also increase the risk of chemical pollutants entering waterways and water supplies.

All forms of roads including abandoned logging roads, dirt roads, private roads, public roads and highways form a network affecting a great portion of the watershed. Roads increase runoff and focus flows, creating a high erosive capacity.

The pervasive road network in the San Lorenzo River watershed is very effective in transporting sediment to streams. According to the CCRWQCB staff report on the San Lorenzo River TMDL (CCRWQCB, 2002), roads contribute approximately 29% of the sediment that enters the streams of the watershed. Of this amount, approximately 19% comes from timber harvest roads and skid trails (the second largest single contributor of sediment to streams), and approximately 10% comes from public and private roads (Table 3.8).

With some detective work to trace the source of these materials, Hecht & Kittleson (1998) discovered:

> The portion of the bed composed of baserock used in road construction and maintenance has increased slightly in the two watersheds where most measurements have been made. Nearly all of the baserock is composed of a distinctive rock type produced only at one quarry (Felton Quarry), which did not become the primary source of such materials until the early 1970s. Hence, it is clear that current roads and practices are largely responsible; first-time failures of older roads constructed more than 30 years ago are not a significant factor because older types of baserock were not encountered.

According to Hecht & Kittleson (1998), "The major sources of bed sediments related to roads are (1) unpaved, or unimproved, road surfaces, (2) continuous use of unsurfaced roads throughout the rainy season, (3) road slipouts and roadcut failures, (4) undersized, poorly maintained or improperly installed culverts and drainage structures, (5) change in use from timber harvest access to residential access, and (6) failure to maintain roads between timber harvests." Swanson

Hydrology & Geomorphology (2001) reports that erosion from road surfaces, ditches, shoulders and other human-induced land clearing contribute mostly fine-grained sediment.

3.5.2.a Unpaved roads

The most persistent, chronic source of sediment to streams is the year round use of unpaved roads. From their field inventory, Butler (1981) estimated that unimproved roads contributed approximately 35% of the total annual sediment load to the San Lorenzo River, compared to 15% of the total annual sediment load contributed by paved roads. Routine grading and leveling of dirt road surfaces creates loose material along the road and on the shoulder that can be easily transported during rains. Clearing of ditches and berms also creates loose soil. Clearing vegetation from road shoulders exposes soil to erosive forces.

3.5.2.b Continuous use of roads through the rainy season

The continued use of dirt roads through the winter months greatly increases erosion and sediment transport throughout the watershed. With rainfall softening the road surface, ruts form. Puddles that form in these ruts further erode and deepen the ruts. Ruts then become targets for road maintenance, which involves more clearing and grading, perpetuating the disturbance cycle. Winter use without proper maintenance can lead to the compromising and breaching of erosion control structures such as water bars, which, in turn, leads to concentrated runoff. If unchecked, concentrated runoff results in rills, gullies and accelerated erosion damage.

3.5.2.c Road slipouts and roadcut failures

Small, paved mountain roads also cause erosion damage and contribute to sedimentation throughout the watershed. Paved roads increase runoff and concentrate flows, which increase erosive forces downslope. Paved roads generally have exposed cut banks and shoulders, and inboard ditches. As a result, the impermeable paved surface leads to an increased volume of runoff. As it leaves the road surface, it can overwhelm roadside ditches, culverts and natural channels. Any accumulated sediment is mobilized and transported downstream.

Roads can exacerbate geologic instability, landslides, mudflows or debris flows. Often roads cross a preexisting failure with no engineering and improper drainage. When a road fails it may be rebuilt without regard to the geologic instability. Often it is “too expensive” or “too difficult,” or “too ecologically damaging” to reroute the road. This cycle appears more often on timber harvest roads, public roads and highways than on residential roads. Routing new roads around these instabilities, or to span them, should be incorporated early in the design or grading review (Hecht & Kittleson, 1998). Hecht & Kittleson (1998) found that many private and county maintained roads cross old landslides and debris flows or cones.

Roads located along streams in the riparian zone are frequently subject to failure by slippage and/or undercutting as streams migrate into the fill prism below the roadbed (Hecht & Kittleson, 1998; County of Santa Cruz, 2001). Most streams within the watershed have a road running parallel to its course within the steep, “inner gorge” part of the canyon close to bank full water level.

3.5.2.d Undersized or faulty culverts and drains

Culverts can cause severe erosion. Culverts that spill water out without dissipation focus increased surface runoff onto one area. Severe erosion can result. Often these eroded areas lead directly into stream channels. Improperly placed or undersized culverts also lead to erosion problems and are pervasive in the watershed (Hecht & Kittleson, 1998; Swanson Hydrology & Geomorphology, 2001). If a culvert entrance becomes clogged, runoff accumulates and often will spill out on top of fill, causing erosion.

3.5.2.e Change in use from timber harvest to residential and recreational use

Many of the residences or communities of the San Lorenzo Valley share or were developed on old logging roads. Logging roads are generally designed to be simple and cost effective to transport machinery and logs within a property. This design is not optimal for long-term, year round residential use. Residential landowners generally lack the funds or equipment necessary for proper maintenance of logging roads, adding to the problem.

Legacy logging roads and skid trails also attract off-road vehicle and motorcycle enthusiasts. Off-road recreational use of logging lands creates a high degree of disturbance. Off-road recreation of all types has increased in the past 20 years as hiking; mountain biking and horse back riding has gained popularity. Once the area becomes popular for recreational off-road use, enforcement becomes difficult. Putting timber harvest roads and skids "to bed" and effectively gating entrances can help to curtail this abuse.

3.5.2.f Failure to maintain logging roads

For current logging, actively used haul roads and skids usually contribute the majority of a timber harvest site's sediment yield (Hecht & Kittleson, 1998). The CCRWQCB (2002) estimated that approximately 18.6% of the sediment load for the San Lorenzo River comes from timber harvest roads and skid trails. Failed drainage or erosion control measures associated with forest roads or skids may also affect other downslope areas.

Abandoned or legacy logging roads and skid trails continue to act as sources of chronic erosion, long after the last timber harvest operation. Much of the watershed, including private property, public land, and watershed conservation land, has legacy logging roads and skid trails. The amount of compaction, soil removal, and previous erosion often makes natural revegetation slow and difficult. Mount (1977) calculated that abandoned and poorly graded dirt roads contribute more sediment to the river system than all other land uses combined. The decommissioning of legacy roads and skid trails by land owners would greatly diminish the amount of sedimentation in the watershed and improve ecosystem function in the watershed.

3.5.2.g Poor road construction practices

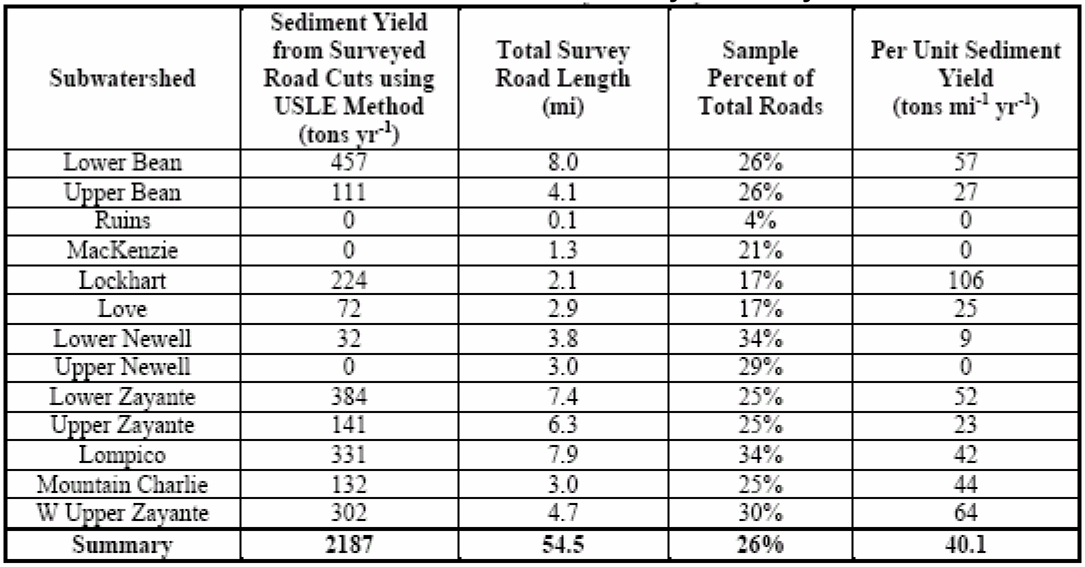
Both paved and unpaved roads in steep areas of the watershed must rely on cuts and fills, which cause geologic instability and erosion. Cuts and fills de-stabilize slopes, alter drainage patterns, promote erosion of roadway surfaces and induce landslides. Roadcuts found along most of the steep roads are notable chronic sediment sources (Hecht & Kittleson, 1998). Much of the watershed is steep and there are often high densities of steep roads. Especially notable are upper watershed roads and communities.

> Roads in steep side drainages, particularly long access roads to homes, retreats, and camps appear to contribute significant sediment to larger tributaries just downstream, particularly when sediment yield is viewed on a road mileage per capita perspective. This is due to the persistent use of unpaved roads in all seasons. Use of baserock on the road surface or

paving the roads reduces rutting, and may decrease fine sediment loads (Hecht & Kittleson, 1998).

Swanson Hydrology & Geomorphology (2001) measured the length of road cuts within the network of roads in the Zayante area to quantify erosion from roads, as shown in Table 3.9. Swanson Hydrology & Geomorphology (2001) found that, “When averaged over the entire area of road cuts, the net surface erosion rate is estimated to be 0.25 inches per year.”

Table 3.9. Sediment erosion from road cuts in the Zayante study area



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

Source: Swanson Hydrology & Geomorphology (2001)

3.5.3 Logging

A majority of the watershed was clear-cut in the late 1800s extending into the mid 1900s. Turn of the century logging removed the stable state old growth redwood forest and created large-scale cumulative watershed impacts. It was common practice to burn the slash to ease the transport of logs out of the cut area. This opened large tracts of the steep watershed to increased runoff, erosion and sedimentation. Historical accounts document higher streamflows due to increased runoff. Logging has continued throughout the watershed at a smaller scale.

3.5.3.a Legacy impacts

In his study of historical logging of North Fork Caspar Creek (a coastal California redwood watershed very similar to the San Lorenzo River watershed), Napolitano (1998) found that the most profound effects of logging persisted from the legacy of 19th century logging. These effects include a relatively simple channel isolated by incision from its former floodplain and the low volume and small size of woody debris. Similar circumstances can be observed in the San Lorenzo River watershed. Zeimer et al. (1991) found that the cumulative impacts of increased sedimentation due to logging may take 100 years or more to allow streams to return to preharvest conditions.

Butler (1981) estimated that logging operations contributed 8-10% of annual sedimentation to the San Lorenzo River. The CCRWQCB (2002) estimated that current timber harvest operations contribute approximately 19% of the total sediment load in watershed streams (Table 3.8), mostly from roads. The actual harvest areas do not have as much soil disturbance, and shrubs and trees naturally revegetate to stabilize the site over time. Even well managed timber harvest areas produce sediment, especially the first winter following construction or harvest (Hecht & Kittleson, 1998).

3.5.3.b Cumulative impacts

According to the Council on Environmental Quality's (CEQ) interpretation of the National Environmental Policy Act, a “cumulative impact” is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency or person undertakes such other actions (CEQ, 1971). The CEQ definition is useful in identifying an approach to land management and impact mitigation, and over time, has been accepted by most researchers and jurists (Reid, 1993).

The magnitude of the impact to a stream channel depends upon the extent and magnitude of the disturbance relative to the size of the contributing watershed. Because these impacts are cumulative, it is difficult to isolate cause-and-effect relationships between disturbance events and channel impacts (Swanson Hydrology & Geomorphology, City of Santa Cruz, 2001). Research conducted over the past 30 years in the Casper Creek watershed in Mendocino County suggests that logging has a considerable impact on channels through increases in peak storm flow, summer baseflows, and suspended and bedload transport rates (Lewis, 1998; Cafferata and Spittler, 1998; Napolitano, 1998 as cited in Swanson Hydrology & Geomorphology, City of Santa Cruz, 2001). Increased peak stormflows result in increased channel down-cutting and channel erosion, which in turn, contribute to increases in suspended sediment loads. Logging can also incur changes in hillslope hydrology from soil disturbance and modifications of drainage pathways. Reduced canopy after logging means that more rainfall hits the soil directly, which results in increased erosion and gullying (Cafferata and Spittler, 1998).

From their modeling of different management regimes affecting erosion and sedimentation Ziemer et al., (1991) found that dispersing timber harvest units did not significantly reduce cumulative effects. Ziemer et al., (1991) hypothesized that current cumulative impact assessments may over-estimate the benefits of dispersion in reducing sedimentation impacts, because effects accumulate over much longer periods than previously considered.

As Reid (1998) concluded, “if enough excess sediment has already been added to a channel system to cause a significant impact, then any further addition of sediment also constitutes a significant cumulative impact.” In their modeling of the cumulative effects of logging over hundreds of years, Ziemer et al. (1991) found that the frequency of small changes in stream channel bed elevation dramatically increased, due to logging. Changes in bed elevation due to sediment negatively affect spawning habitat, juvenile fish habitat, invertebrate habitat, productivity and overall water quality.

In discussing cumulative watershed effects, Reid (1998) stated:

> Results of the South Fork Caspar Creek study suggest that 65-percent selective logging, tractor yarding, and associated road management more than doubled the sediment yield from the catchment, while peak flows showed a statistically significant increase only for small storms near the beginning of the storm season.

Pre-Forest Practice Rules methods for roading, yarding and logging were used in the study area of the South Fork Caspar Creek study (Reid, 1998). Sedimentation returned to background levels within 8 years, while minor hydrologic impacts persisted for at least 12 years (Reid, 1998).

The frequency of logging operations increases the vulnerability of the landscape. On a regional scale, areas with an average rotation of 60 years will have 25% of the landscape vulnerable to landslides at any time, versus 15% vulnerability with a 100-year rotation, or 5% vulnerability with a 300-year rotation (Spence et al., 1996).

While there has been considerable improvement in logging practices since the 1970s, current logging practices still result in significant sediment increases to streams. Recent timber harvests conforming to modern state Forest Practice Rules showed an 89% increase in background suspended sediment and bedloads, while logging operations in the 1970s showed a 212% increase (Lewis, 1998 as cited in Swanson Hydrology & Geomorphology, City of Santa Cruz, 2001).

According to a study of streambed conditions and erosion control efforts prepared for Santa Cruz County (Hecht & Kittleson, 1998) locally observed problems from timber harvesting within the watershed included:

- At-grade crossings in residential, open-space or timber harvest areas are chronic sediment sources.
- Harvest landings may eventually be converted to home sites without measures to anticipate and reduce erosion, both at the home site and along access roads.
- Timber harvests can result in road networks, which may result in ongoing erosion as neighboring or subsequent homeowners modify the road net to provide privacy and as they perform ad hoc repairs of post-logging instabilities.
- We suspect that the construction of multi-purpose road nets (for timber harvest and post-harvest uses) may result in road systems that may be longer or denser than might be built for each use alone. If true, there may be opportunities to reduce erosion through improved design or re-bedding of roads at the time when the post-harvest uses commence (Hecht & Kittleson, 1998).

3.5.4 Rural and urban development

Urbanization significantly alters hydrologic processes by increasing the magnitude and frequency of peak discharges and reducing summer base flows (Klein 1979; Booth 1991 both as cited in Spence et al., 1996). Development is also a major source of erosion and sedimentation.

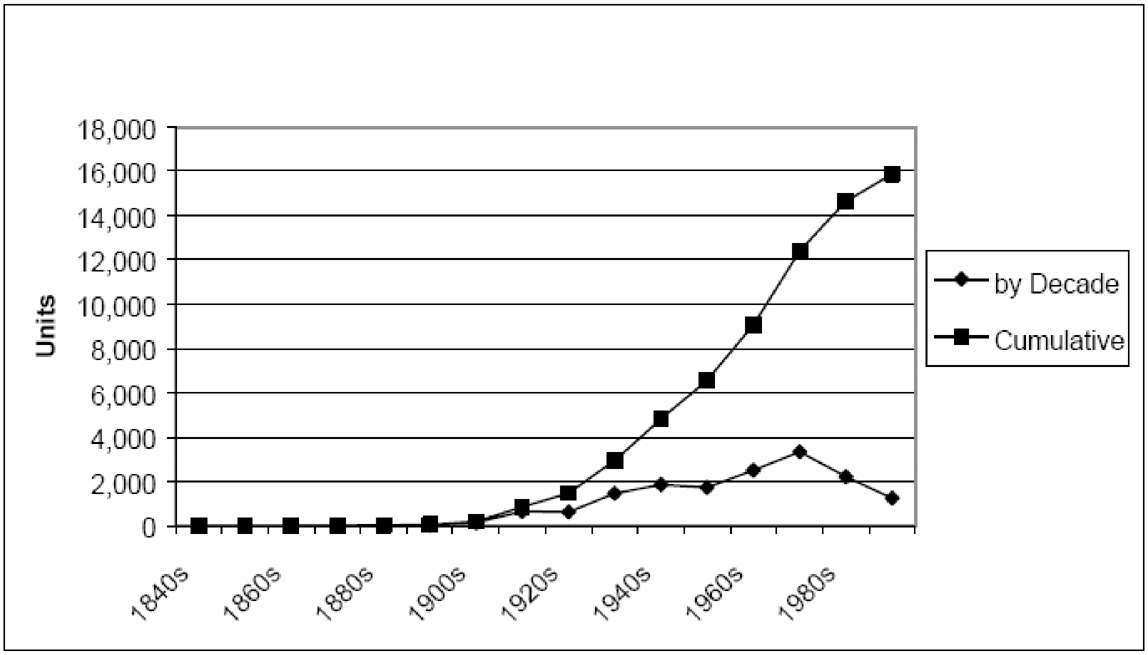
Residential land clearing, grading without effective erosion control, ad-hoc drainage management, and disruption of riparian zones continue to contribute sediment to watershed streams. The CCRWQCB (2002) estimated that human disturbances, related to rural and urban land use, accounts for 14.8% of the total sediment load in watershed streams (Table 3.8).

Prior to 1980, development of new homes and roads was very high, including the conversion of summer homes to permanent residences, as shown in Figure 3.16. Butler (1981) estimated at that time new construction accounted for 25% of sediment reaching the San Lorenzo River and that new construction and associated new road development together accounted for 45-50%. A peak of sediment production occurs during and immediately following new construction, estimated to be 10-100 times that of normal erosion, and after ten years most soil disturbance due to construction or grading activities is minimal or stabilized (Butler 1981).

In the years following this surge, new development continued to a lesser degree but in more remote, steeper locations requiring longer roads traversing less stable, steeper terrain, and in headwater areas. Densities in steeper, less suitable areas increased including erosive sandstones and mudstones. The current level of impact from existing homes and roads adds to the of long-term cumulative watershed impacts. While building new roads increases erosion, improper design and poor maintenance of existing roads has been stated as the primary cause of erosion and sedimentation within the watershed (Coats et al. 1982; Hecht & Kittleson, 1998; County of Santa Cruz 2001; Swanson Hydrology, 2001).

Hecht & Kittleson (1998) reported that higher percentages of existing sites seem to be effectively managed; nonetheless, with more residents there is more activity and contributions from such areas.

Figure 3.16 Development by decade and cumulatively for the San Lorenzo River watershed



Source: CCRWQCB, 2002.

Sandy soil contributes disproportionately high levels of habitat-impairing fine sediments to watershed streams. The Scotts Valley, Quail Hollow, Zayante and Bean Creek watersheds have extensive rural and urban land disturbance. These are key areas of concern for human induced impacts. Information compiled in many studies has shown that erosion in sandy Santa Margarita soils can persist for many years following the initial disturbance:

> Approximately five to ten years after a residential development of about 50 homes was completed in the Lower Newell Creek Watershed, erosion and sediment delivery to streams from roadcuts and the drainage system was still very high (Swanson Hydrology, 2001).

The County of Santa Cruz (2000) and the CCRWQCB (2002) have both expressed the priority of addressing management of impacts within these and other sandy areas of the watershed.

3.5.5 Agriculture

When vineyards are located on steep slopes and have inadequate erosion control measures, they are a source of erosion and increased runoff. At least one commercial and many residential vineyards have been cited by the County Resource Planners as causes of bed sedimentation, impairing fisheries and stream habitat (Camp, Dresser, & McKee, 1996).

3.5.6 Livestock and equestrian uses

Horse and livestock facilities on slopes and encroaching into the riparian zones may locally be notable contributors of sediment. Where riparian vegetation has been lost and use is constant, livestock facilities and stream crossing trails are chronic sources of fine sediment. (Hecht & Kittleson, 1998).

Horses, their facilities and trails can be found throughout the San Lorenzo watershed, including dense concentrations of horses in sandy soil areas. Many residences have one or two horses. Larger commercial facilities can be found in three or four locations. As ground within the corrals becomes denuded, and the soil becomes compacted by horses, runoff and erosion increase. The top layer of soil becomes loosened for transport by wind or water erosion. Corrals are often near or even encompass swales or natural drainages, which can quickly transport soil into creeks, often resulting in sediment deposits.

Equestrian trail use is widespread throughout the watershed. Many trails cross streams or rivers, leading to the direct input of sediment, as well as invasive species, nitrate and pathogens to surface waters.

3.5.7 Mining

Mining has been recognized as a potential contributor to sediment in the watershed since the 1950s (California Department of Water Resources, 1958). Coats et al. (1982) described sand quarry contribution to sedimentation during the 1982 storms.

Sand quarries near Zayante Creek and Bean Creek (in the Santa Margarita Sandstone) provided a major but unquantifiable quantity of sediment in the January 4, 1982 storm. Failure of a sand embankment at a small tributary on Zayante Creek dumped perhaps several hundred cubic meters of sand into the creek, covering the road and destroying a small house in the process. Another quarry on Mackenzie Creek contributed large amounts of sand as a result of surface transport.

Quarries are regulated by the Surface Mining and Reclamation Act (SMARA) and by the Santa Cruz County Mining Ordinance (16.54.030). The purpose of the county ordinance is to:

> Prevent or minimize adverse environmental effects and require that mined lands are reclaimed to a usable condition which is readily adaptable for alternative land uses and implement the policies of the State of California Public Resources Code Section 2710, et seq., commonly known as the Surface Mining and Reclamation Act of 1975, as required by Section 2774(a) thereof.

The county ordinance states:

> Significant surface and groundwater resources including springs and aquifers shall not be adversely affected as a result of the proposed mining operation.

The ordinance requires that the application package be submitted to the water purveyor within the drainage area (Camp, Dresser, & McKee, 1996). Each quarry within the watershed has an erosion control and revegetation plan. The County of Santa Cruz and the state inspect quarries to monitor compliance.

3.6 Human-induced disturbances on District watershed lands

The primary human-induced disturbance on District watershed lands is roads, which are used primarily to access and maintain District infrastructure such as wells, water uptakes, the water treatment plant and the five-mile pipeline. In addition, roads are needed for fire and emergency access. Whenever such roads have been cut or trenched, the District uses best management practices to minimize disturbance and erosion. Unpaved roads are out-sloped to facilitate drainage off the road surface. Large rolling dips are used on in-sloped roads for drainage. District staff is trained in erosion control practices. The District routinely maintains its road system each year before the start of the rainy season. Large rolling dips, water bars, or other drainage features are checked and repaired. The use of heavy equipment is minimized to reduce compaction and disturbance. Hand crews maintain drainage and erosion control features as much as possible.

?

The District has not yet surveyed, mapped, and assessed the existing road system on its watershed land holdings. The District has not yet mapped sites of toxics or hazardous wastes, dangerous cliffs, erosion prone soils, mine shafts, pipeline and overhead power line corridors, etc. that might limit management actions and access

Other erosion problems on District land include landslides and slope failures, which were especially pronounced following the 1982 and 1998 storms. Figure 3.15 shows the location of these debris slides. The District assessed the damage to watershed lands and facilities, and followed FEMA procedures to secure grants and funding to repair damage. The District has codified procedures in its Emergency Response Plan.

Some dumping, especially of old quarrying and mining refuse and equipment, has occurred on District lands, especially at the Olympia watershed property, and on the Fall Creek property.

Staff has observed some recent homeless encampments on both the Fall Creek and the Olympia watershed properties.

Trespass from off-road vehicles and equestrians are an on-going problem on District lands, especially at the Olympia watershed property. An increasingly dense network of trails is being used by both horses and ORVs. For more discussion of this problem, refer to “Chapter 6: Cultural, recreational, and educational resources.”

Invasive exotic species are also an increasing problem on District watershed property. For more discussion of this problem, refer to “Chapter 4: Biotic resources.”

3.7 District water quality

The US Congress passed the Clean Water Act in 1972 to protect and restore the beneficial uses of fresh water bodies throughout the nation. The law is administered by the states; in California, by the state and regional water quality control boards.

The San Lorenzo River has been considered impaired under the Clean Water Act by sediment since 1998, and has since been listed as impaired for nitrates and pathogens. *Impaired* means that the pollutants are significantly affecting the beneficial uses of the waterway, such as drinking water quality, fisheries and recreational uses.

To address these problems, the sediment Total Maximum Daily Load (TMDL) for the San Lorenzo River was adopted by the Central Coast Regional Water Quality Control Board in 2002 and approved by the Office of Administrative Law in 2003. The nitrate TMDL was also approved in 2003. The pathogen TMDL is scheduled for consideration in 2008.

3.7.1 Source water protection and drinking water treatment

As a provider of community drinking water, the District's water quality is regulated under the federal Safe Drinking Water Act (SDWA), which is administered by the state Department of Health Services (DHS) and state Environmental Protection Agency (EPA). The 1996 amendments to the SDWA focused on a new approach to drinking water protection, away from total reliance on water treatment, and toward a more preventive approach. The new laws required every community drinking water provider in the nation to complete a source water assessment (SWA) for both surface water and ground water supplies. Each SWA identifies the source of the supply, either a water uptake or a wellhead, identifies potential sources of contamination to the water source, and assesses the vulnerability of the water source to the contamination source. SWAs were completed in 2002 in California. The new approach to drinking water protection is known as the multiple barrier approach, recognizing that both source water protection and water treatment are necessary for the vast majority of water purveyors. The recent emphasis on protecting watersheds and recharge areas is based on the fact that water that is cleaner to start with is less expensive to treat. Now that SWAs have been completed, the next step in the EPA's Source Water Protection Program is the preparation of Source Water Protection Plans. This step, however, is voluntary.

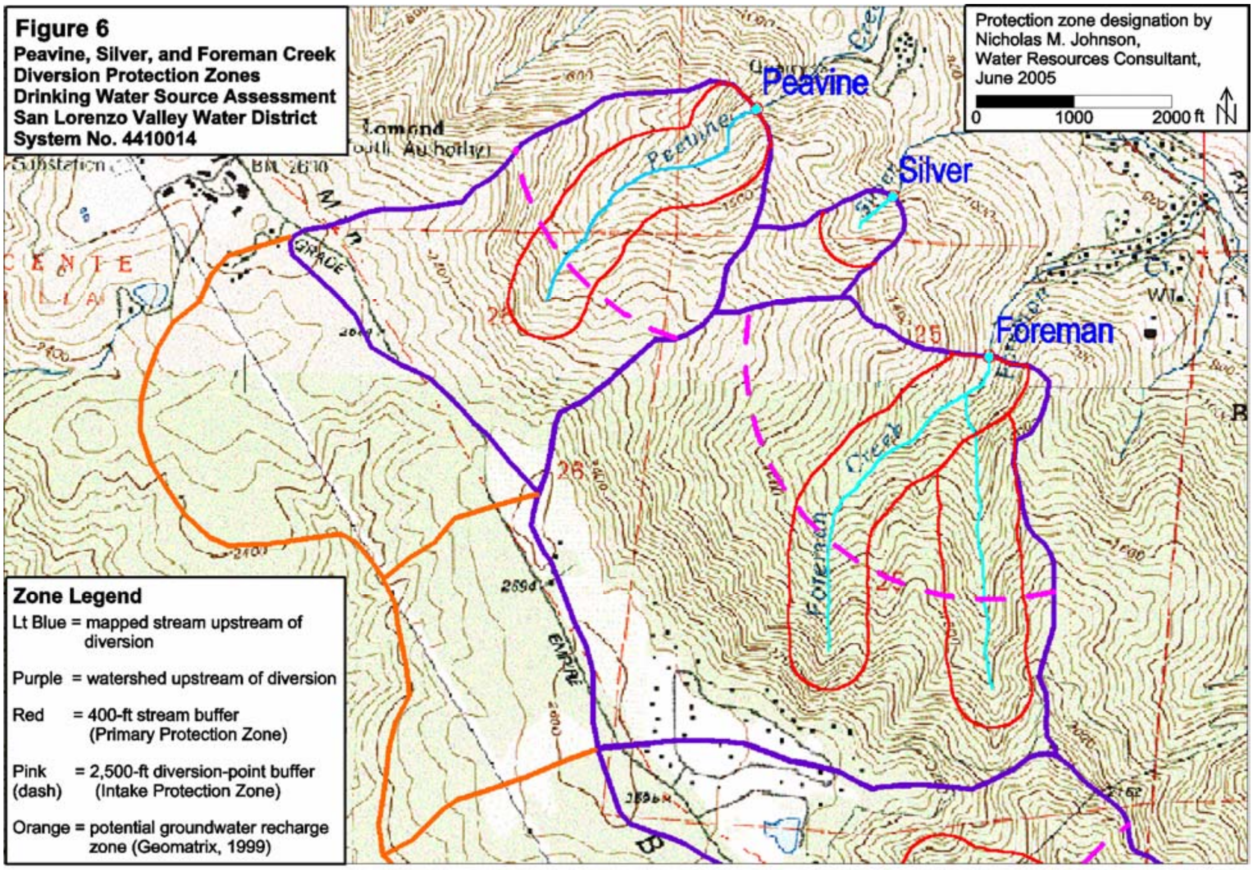
3.7.1.a District source water protection zones

The size of source water protection zones is defined by the DHS. The source water protection zones for District ground water sources are the same as the recharge areas depicted in Figures 3-5 through 3-9.

The source water protection zones for District surface water sources are shown in Figures 3.17 and 3.18. Figure 3.17 shows the stream protection zones and water intake protection zones for the Peavine, Silver, and Foreman creek intakes, as indicated by a District consultant (Johnson, 2005), following DHS guidelines for preparing the DWSAP.

The District does not practice commercial logging on its watershed lands and there are no septic systems located within the source water protection zones shown in Figures 3.17 and 3.18. However, because of the high erosion potential and existence of septic systems in these watersheds, the District's surface water intakes are considered vulnerable to these land uses (Johnson, 2005).

Figure 3.17. Source water protection zones for Peavine, Silver, and Foreman creek intakes.

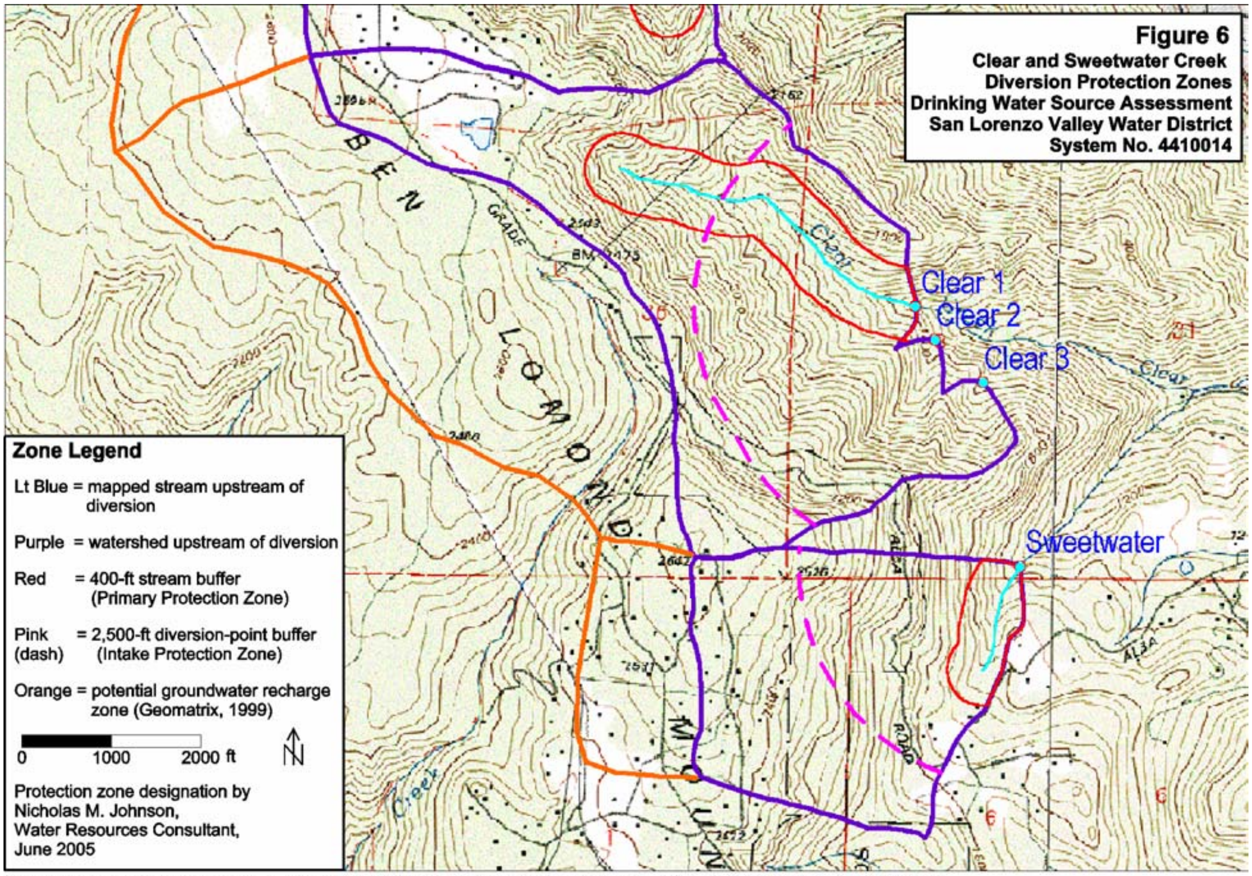


Peavine Ck: Source No. 015, PS Code E44/014-PEAVINE; Foreman (and Silver) Ck:, Source No. 004, PS Code E44/014-RAWFORE

Source: Johnson, 2005

Figure 3.18 shows the stream protection zones and water intake protection zones for the Clear and Sweetwater creek intakes, as delineated by a District consultant (Johnson, 2005), following DHS guidelines for preparing the DWSAP.

Figure 3.18. Source water protection zones for Clear and Sweetwater creek intakes.



Clear Ck: Source No. 003, PS Code E44/014-RAWCLER; Sweetwater Ck: Source No. 021, PS Code E44/014-RAWSWEE

Source: Johnson, 2005

3.7.1.b Maximum contaminant levels

The EPA and the DHS have developed Maximum Contaminant Levels (MCL) for over 100 organic and inorganic compounds. Contaminants in drinking water can be divided into two different categories: those that cause acute illness and those that pose chronic health concerns. Pathogenic microorganisms will cause acute health risks. Excessive concentrations of compounds inherent to source waters, carried into source waters, or created as byproducts of the water treatment process can pose long-term or chronic health risks.

The Total Coliform Rule (TCR) ensures that proper treatment and management of water treatment facilities is in place to ensure microbiological water quality. If water supply sources are found to contain high levels of total coliform, DHS may increase the minimum disinfection requirements for that plant. Other newly adopted regulations include primary MCL for MTBE, Best Available Technology for Fluoride, DHS Unregulated Chemicals Requiring Monitoring, DHS Operator Certification, Federal Interim Enhanced Surface Water Treatment Rule, Federal Arsenic MCL, Federal Disinfection and Disinfection Byproducts Rule, and Minor Revisions Federal Lead/Copper Rule (Berry, 2001).

3.7.2 Surface water quality

The EPA's Surface Water Treatment Rule (SWTR) establishes primary treatment regulations for drinking water supplied from surface water sources. Treatment generally requires both filtration and disinfection. Watershed protection is necessary to meet water quality standards under both the federal Clean Water Act, and the federal Safe Drinking Water Act. Contaminants of primary concern in the watershed include turbidity and sediment, nitrates, pathogens, and toxic compounds.

3.7.2.a Sediment and turbidity

Sediment and turbidity are the primary water treatment concerns for the District's surface water. There are two different categories of sediment sources within a watershed: *point sources* and *non-point sources*. Point sources have a specific location and are easily documented as sediment sources. Non-point sources of sediment have dispersed locations, are less easily documented, though they can contribute significant levels of sediment. Examples of non-point sources of sediment include natural surface erosion and background landslide sources; surface erosion from cleared areas including timber harvest, urban and agricultural areas; erosion from exposed soils along roads including surfaces, ditches, road cuts, shoulders, fill and side cast spoils; surface and landslide erosion stemming from defective road drainage networks; and land use that accelerates channel erosion of banks or streambeds (Swanson Hydrology & Geomorpology, 2001). Section 3.4 provides a more complete discussion of the sources of sediment.

For drinking water purposes, turbidity is often used as a measure of sediment. Turbidity is a measure of the cloudiness of water, and is caused by dissolved or suspended materials such as fine sediment, or residue from organic material, which can act as a carrier for pathogenic organisms, such as Giardia cysts. Turbidity is difficult and expensive to remove from drinking water and can potentially damage water treatment facilities.

Turbidity typically increases dramatically after a storm. In the San Lorenzo River watershed, streams usually clear 1-4 days after a storm. Turbidity is measured in terms of nephelometric turbidity units (NTUs). The Source Water Treatment Rule requires all water purveyors to continuously monitor raw water turbidity as it enters the treatment plant. Water exceeding 20 NTUs is considered untreatable, so most water purveyors in the watershed routinely experience periods during high runoff when they must shut off raw water inputs to their treatment plants. During this time, purveyors must rely on either stored water or other sources.

During a wet year, the District's Lyon treatment plant averages approximately 60 hours of down time due to high turbidity, typically occurring in the period of January – May. This is less than 2% of the average runtime of the plant for the same period, which averages approximately 3,564 hours. During the same period in an average or dry year, the plant averages approximately 40 hours of down time due to turbidity (Busa, 2008).

3.7.2.b Nitrates

Nitrates furnish nutrients that facilitate biological productivity in surface waters. Elevated nitrate levels may adversely affect drinking water and other beneficial uses by stimulating growth of microscopic algae and other organisms, which can impart taste, odor, increase organic load and summer turbidity.

Nitrates also lead to high concentrations of organic carbon. Organic carbon reacts with chemicals used in the disinfection process at water treatment plants. This interaction produces chemical by-products known as such as trihalomethanes (THMs), which pose long-term health threats (Camp, Dresser, & McKee, 1996).

The low flow summer period has the highest potential for biostimulation and other impacts to beneficial uses, so summer nitrate levels are of the highest concern (County of Santa Cruz, 1995). During the summer months, nitrate is also removed naturally from the river system at a rate of about 7% per mile, in both wet and dry years (County of Santa Cruz, 1995). This naturally occurring denitrification process occurs partially within the organic bottom sediments, and partially through uptake by riparian and aquatic vegetation (County of Santa Cruz, 1995). Without this natural denitrification process, nitrate loads in the streams would be expected to be five to ten times greater (County of Santa Cruz, 1995).

Algal influence on nitrates

In other watersheds, nitrogen levels have been observed to directly increase algae levels and to cause detrimental algal blooms. Studies have found that current elevated nitrate levels within the San Lorenzo River system do not seem to be the primary influence of algae growth in streams (County of Santa Cruz, 1995). Results from laboratory studies using *Cladophora spp* collected from the San Lorenzo River have shown no significant effect on algae growth from addition of nitrate and/or phosphate (County of Santa Cruz, 1995).

Algae levels in the San Lorenzo River are apparently at low enough levels in the San Lorenzo River so as not to be detrimental to fish, and may have been beneficial to anadromous fisheries (Gilchrest and Associates, 1984 as cited in County of Santa Cruz, 1995). The County of Santa Cruz (1995) reported that nitrate levels had no noticeable adverse effects on fishery resources, and little impact to recreation.

The County Nitrate Management Plan found that several species of nitrogen fixing algae are common to reaches of the San Lorenzo River; i.e., atmospheric sources of nitrogen are a source of water nitrates, due to these species.

Sources of nitrates

Nitrate enters surface waters primarily by seeping into the streams from septic system leach fields, community sewage disposal systems, runoff from confined animal facilities, and from urban runoff. According to watershed nitrate budgets calculated by the County of Santa Cruz (1995), 84% of the nitrate load in the middle San Lorenzo River is from non-natural sources.

> The daily summer nitrogen load from non-natural sources in the River at Big Trees is comparable to the load that would be generated by 500 houses discharging untreated sewage directly to the River (County of Santa Cruz, 1995).

The County of Santa Cruz (1995) has estimated that septic systems contribute an estimated 57% of the summer nitrate load in the San Lorenzo River. Nitrate levels increased dramatically in the 1970s as a direct result of development and poor septic system management, but increases since the 1990s have been low to insignificant due to management practices, control measures and enforcement (Santa Cruz, 1995 & 2000). Still, nitrate levels are approximately four times greater today than levels in the 1960s. However, the Regional Board updated the nitrate objective when they adopted the TMDL for the San Lorenzo River. Currently, nitrate levels in the River are only about 1.5 times the present objective (Ricker, 2008).

In typical soils of the watershed, approximately 25% of the nitrogen from septic systems is removed by through natural denitrification in the upper soil layers, whereas in sandy soils only about 15% is removed and approximately 75-80% percolates as nitrate to ground water (Ramlit, 1982 as cited in County of Santa Cruz, 1995). In their studies, the County of Santa Cruz (1995) found that 10-25% of the nitrogen from septic systems in the sandy areas underlain by Santa Margarita Sandstone reached the streams as nitrate. The County of Santa Cruz also determined that a septic system in sandy soils contributes 10-15 times more nitrate to the river than a septic system in less permeable soils (County of Santa Cruz, 1995). Approximately 67% of the nitrate load in the river comes from the area of the watershed comprised of the highly permeable Santa Margarita sandstone (County of Santa Cruz, 1995). Therefore, management practices to reduce nitrogen inputs in the watershed will be the most effective in sandy areas.

The County of Santa Cruz and the Regional Board have taken actions to reduce nitrate levels in the watershed (Camp, Dresser, & McKee, 1996). The County of Santa Cruz (1995) found a 20% reduction in nitrate discharge from a shallow trench compared to a deep trench in septic systems in sandy soils. The San Lorenzo River Watershed Sanitary Survey (Berry, 2001) states that nitrate levels in the San Lorenzo River were decreasing slightly from previous levels. Nitrogen control measures and management practices are described in the San Lorenzo Draft Nitrate Management Plan Phase II Final Report (County of Santa Cruz, 1995), the Draft San Lorenzo River Watershed Management Plan Update, (County of Santa Cruz, 2001), in the San Lorenzo Valley and North Coast Watersheds Sanitary Survey (Camp Dresser & McKee, 1996), in the San Lorenzo River Nitrogen Control Measure project (White and Hecht, 1994), addressing the Quail Hollow Ranch Regional Park Stables, and in numerous Santa Cruz County Resource Conservation District (SCCRCD) documents.

The Boulder Creek Country Club sewage treatment facility has been upgraded for denitrification and tertiary treatment for possible use of reclaimed water on the golf course (County of Santa Cruz, 2000). If all other sources of nitrogen are controlled within this area, it is estimated that the San Lorenzo River between Boulder Creek and Ben Lomond could experience nitrate reductions as high as 75% (Berry, 2001).

The County Draft San Lorenzo Nitrate Management Plan (1995) states that livestock and stables contribute 6% of the present summer nitrate levels in the lower River at Felton. In sandy areas, a single horse without nitrate management practices contributes nitrate to streams comparable to rates from a single household in the same area (County of Santa Cruz, 1995). Horses in sandy soils contribute a higher percentage of the nitrogen load due to the highly permeable soils rapidly transporting the untreated waste. There are also high densities of horses in sandy soil areas. For example, horses contribute 41% of the estimated nitrate load in lower Zayante Creek (County of Santa Cruz, 1995). Horses and their contribution to nitrate within the watershed are one of the sources of highest potential reduction due to management practices. The County, the SCCRCD, Camp, Dresser & McKee and Balance Hydrologics have produced documents that contain simple and cost effective recommendations to reduce nitrogen loading from equestrian facilities and trails to ground and surface waters.

Areas where animal wastes are concentrated and left untreated on the surface elevate nitrogen and pathogen levels. This happens through runoff and percolation, especially with the "first flush" of stormwater. According to some studies, horses and horse facilities are one of the principle causes of elevated nitrogen and pathogens within the watershed (Camp, Dresser, & McKee; White & Hecht, 1994; County of Santa Cruz, 2001). Other confined animals such as dogs, cats and chickens also increase nitrate and pathogen pollution.

3.7.2.c Pathogens

Bacteria, virus, giardia, cryptosporidium, and other pathogens can make water unsafe for swimming, as well as require more expensive treatment for drinking water. Most testing for pathogens involves testing for indicator bacteria that would suggest the presence of pathogens from sewage, fecal contamination, or other contamination (County of Santa Cruz, 2001).

While indicator bacteria themselves do not necessarily cause illness, their presence causes warning signs to be posted at beaches, and significantly impacts recreational opportunities.

Sources of pathogens and indicator bacteria are non-point source urban runoff, failing septic systems, sewer system leaks, pet waste, livestock, feral pigs, encampments, and waterfowl. In natural settings, pathogens percolate into the soil where microbial organisms naturally decompose them.

The Watershed Sanitary Survey for the San Lorenzo and North Coast Watersheds (Camp, Dresser & McKee, 1996) found low to moderate levels of coliform bacteria in the tributaries of the San Lorenzo River, such as those that supply surface water to the District. These low levels result from the lack of development and the large areas of intact open space upstream of the water uptakes.

Domestic and commercial wastewaters potentially contain a number of pathogenic microorganisms that can cause diseases such as hepatitis, typhoid, cholera, dysentery, salmonella, giardiasis, and cryptosporidiosis (Camp, Dresser & McKee, 1996). Incompletely treated effluent may reach groundwater supplies or streams from an improperly functioning septic system. However, a properly functioning septic system will remove these pathogens within a short distance by microbial action in the soil.

The Department of Health Services (DHS) requires disinfection to treat pathogenic organisms, at all surface water treatment plants. If water supply sources are found to contain high levels of total coliform, DHS may increase the minimum disinfection requirements for that plant.

Sources of pathogens

The highest levels of indicator bacteria are consistently observed in more dense urban areas such as Scotts Valley and Santa Cruz, indicating that urban runoff and leaks in sewer systems, rather than septic tanks, are the main cause. As the river flows out of suburban areas and through State Parks or other low-density areas, bacteria levels drop substantially as stream flow picks up speed, and natural ecological processes take effect. After passing through the gorge, the river flows through the channelized and heavily developed area of downtown Santa Cruz. Here the river is subject to all the key contributors of pathogens: urban runoff, sewer leaks (within permeable alluvial soils), trash, pet wastes, homeless encampments, water fowl and general non-point human pollution. The river mouth continues to have high bacteria levels and is permanently posted as unsafe for swimming.

Urban runoff can be a source of fecal and total coliform bacteria in stream water. In an urban setting, non-permeable surfaces collect by-products of human activity, pet and animal wastes, and organic debris, holding them at the surface, until they are washed into streams by rain. Moderate to high coliform bacteria levels are frequently measured in the more urban lower San Lorenzo River (Camp, Dresser & McKee, 1996).

A vast majority of residents in the watershed are on private, individual septic systems. An estimated 14,000+ individual onsite septic systems exist in the 138 square miles San Lorenzo River watershed (County of Santa Cruz, 2000). Community sewer systems with treatment serve about 300 homes in the Boulder Creek Country Club, 30 homes in Rolling Woods, 54 homes at Bear Creek Estates, and the Mount Hermon Association (County of Santa Cruz, 2000). The Bear Creek Wastewater System is operated by the San Lorenzo Valley Water District. Both the Boulder Creek and the Rolling Woods wastewater systems are under the jurisdiction of the County Public Works Department (County of Santa Cruz, 2001). The Boulder Creek Country Club facilities have recently been upgraded and improved. All of these community systems including local schools are regulated by the Regional Water Quality Control Board (RWQCB).

The frequency of posting swimming areas in the watershed has also decreased significantly since the 1970s and 1980s due to the upgrading and improved maintenance of septic systems within the watershed. With improved management and monitoring summer bacteria levels have substantially improved, and the river generally meets all standards for safe swimming at all areas upstream of Santa Cruz (County of Santa Cruz, 2001).

The San Lorenzo and North Coast Watershed Sanitary Survey (Camp, Dresser & McKee, 1996) summarized the effects that the large numbers of septic systems have on coliform levels within the watershed:

> The absence of fecal coliforms in shallow groundwater underlying developed areas indicates that incidents of bacterial contamination of surface waters do not result from cumulative contamination of groundwater, but result from failures and discharges to the ground surface from individual systems. Rapid detection of failing septic systems under the Wastewater Management Program has anecdotally reduced the frequency of high microbial concentrations in the San Lorenzo River. The County found that human waste is not the primary source of fecal coliform in the San Lorenzo River based on fecal coliform to fecal streptococcus ratios. After many years of study, the County and Regional Board have concluded that the majority of existing septic systems do not consistently contribute significantly to the bacteria concentrations measured in the surface waters.

An evaluation of the County fecal coliform bacteria data, conducted by the County Health Services Agency, found no significant increase in bacteria in the swimming areas of the San Lorenzo River system.

Greywater systems are common throughout the San Lorenzo Valley and are often utilized to alleviate stress to septic systems with inadequate leaching capacity. Greywater systems collect and dispose of wastewaters originating from washing machines, showers and sinks. Although greywater contains fewer pathogens, solids and nutrients than toilet wastes it can still be a hazard to health and water quality.

According to the Santa Cruz County Environmental Health Services, bacterial concentrations in greywater from shower or bath water can reach 400,000 fecal coliforms and 3 million total coliforms/100 milliliter (ml). Washing machine wastewater can range from 2,000 to 10 million fecal coliforms/100ml. In addition, there are roughly 200 enteric virus/liter of undisinfected greywater from showers and baths and 3,000 viruses/liter from washing machines. County policy requires connection of all greywater to an adequately sized septic system but probably allows installation of at least 25 to 50 greywater sumps each year under appropriate conditions (Camp, Dresser & McKee, 1996).

A marked decrease in septic system failures has occurred since the time when the San Lorenzo Valley was being converted from summer homes to permanent residences. The Santa Cruz County Health Services Agency reported that, "Since 1986, the wintertime septic failure rate has declined from 5-14% to 1-3% depending on the area" (County of Santa Cruz, 2001).

Another source of pathogens is from equestrian trails, paddock areas, and manure stockpiles, which can contribute elevated levels of fecal coliform, Cryptosporidium, and other organisms (County, 2001). Other sources of pathogens are pets, livestock, waterfowl, decaying garbage, homeless encampments, sewage leaks, and general nonpoint urban pollution (County of Santa Cruz, 2000 & 2001). The potential for erosion from horseback riding and the introduction of fecal matter from horses may be significant, especially at stream crossings. However, the effect of horseback riding cannot be quantified separately from other sources which contribute microbial contaminants and turbidity/sediment (Camp, Dresser & McKee, 1996).

Homeless encampments near creeks may dispose of human waste directly into the streams. Even if latrines are dug, the encampments are often within the floodplain. Encampments effect riparian vegetation and concentrate trash. Homeless encampments directly elevate levels of sediment, pathogens, nitrate and particulate contaminants in streams.

3.7.2.d Toxic compounds

Toxic compounds include synthetic organic chemicals (SOCs); volatile organic compounds (VOCs), which include fuel, oil, gasoline, and MTBE; heavy metals, including lead, zinc and cadmium, pesticides, PCBs, oil and grease. The presence of toxic compounds in the San Lorenzo River has primarily resulted from discharge of VOCs from leaking underground storage tanks.

Drinking water aquifers in Scotts Valley and some other localized parts of the watershed have been contaminated by these toxic compounds, which has required discontinuance of wells and/or expensive treatment (County of Santa Cruz, 2001).

Past studies in the San Lorenzo River watershed have indicated low to nondetectable levels of heavy metals, pesticides, PCB's, oil and grease in the San Lorenzo River. There have been no documented impacts on organisms or beneficial uses of the River resulting from toxic constituents in urban runoff. Very low levels of only a small number of trace organic compounds (pesticides and PCB's) were found, at only 2-7% of the level considered hazardous (County of Santa Cruz, 2001).

Elevated levels of lead, zinc, and cadmium have been found, but none of the compounds were found at levels that are known to cause a threat to human or biotic health. Zinc and cadmium are of geologic origin, while lead is a likely result of historic accumulations from vehicle emissions (County of Santa Cruz, 2001).

The EPA has established maximum contaminant levels for volatile organic compounds (VOCs), which include fuel, oil, gasoline, and MTBE, and for inorganic compounds, pesticides, and herbicides.

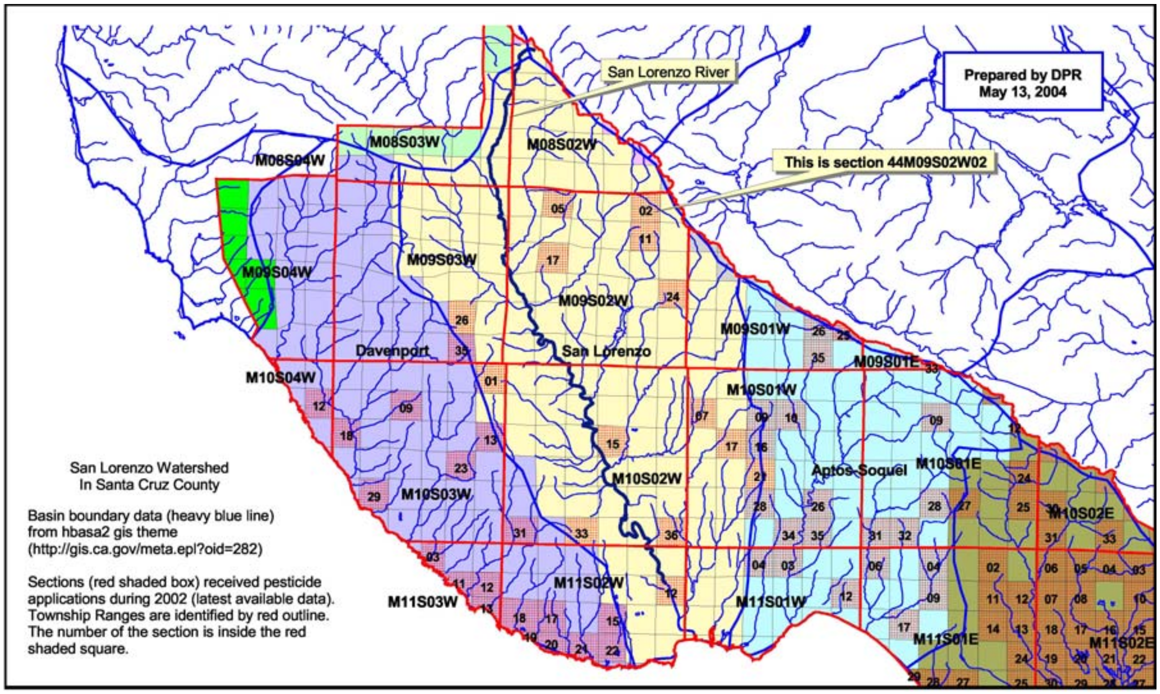
The government agencies that regulate pesticide and herbicide use are the County Agricultural Commission, the California Department of Pesticide Regulation (DPR), and the United States Environmental Protection Agency (EPA).

The San Lorenzo and North Coast Watersheds Sanitary Survey (Camp, Dresser & McKee, 1996) defines pesticides and herbicides and lists their uses as:

> Chemical compounds specifically formulated for their lethal effects on animal and plant life; used in (1) agriculture, (2) rights-of-way along roadsides, (3) landscaped areas such as parks and golf courses, (4) for structural pest control, and (5) by individuals.

All pesticides are considered as undesirable in a drinking water source. The majority of the agricultural and structural pest control applications are in areas of the county outside of the San Lorenzo watershed, as shown in Figure 3.19. The other two reported uses, rights-of-way along roadsides (CalTrans), and within parks, are reported to be used sparingly and are not a significant contaminant source of concern within the watershed (Camp, Dresser & McKee, 1996). Private use of herbicides and pesticides is not reported. Due to public opposition and sensitivity to chemical use, private pesticide and herbicide use is probably low in the San Lorenzo Valley and therefore not a significant contaminant of concern (Camp, Dresser & McKee, 1996). Vineyards are potential sources of organic chemicals from fertilizers, pesticides and herbicides.

Figure 3.19. Areas with reported annual agricultural pesticide and herbicide use in Santa Cruz County, 2002.



Source: California Department of Pesticide Regulation, 2004.

The San Lorenzo River watershed has few industrial facilities that handle or produce toxic compounds. Most are found in Scotts Valley or Santa Cruz. Any facility that handles, stores, or generates hazardous materials is subject to regulation by the Santa Cruz County Environmental Health Services Hazardous Materials program, as well as the state Department of Health Services, the state Environmental Protection Agency, and the U.S. Environmental Protection Agency. According to the County of Santa Cruz (2001), every facility must have a hazardous material management plan to prevent any release of materials into the environment. They are inspected annually, at a minimum, for compliance.

Incidents of contamination of surface waters within the watershed by toxic compounds have occurred. A Chevron station in Felton had an underground storage tank that leaked toxic compounds into the San Lorenzo River. Initial remediation efforts were not completely successful, but additional remediation measures followed (Camp, Dresser & McKee, 1996). Contamination by gasoline also occurred in Boulder Creek (County of Santa Cruz, 2001).

PG&E power line transformers have been found in creeks of Santa Cruz County, though not within the San Lorenzo River watershed. These transformers contain toxic compounds that could potentially be released into stream habitat. PG&E was quick to respond to at least one of the reported transformers found in Soquel Creek.

Abandoned cars are found throughout the watershed including a significant number in watercourses. Traffic accidents are potential sources of hazardous materials from spilled cargo or from petrol-chemicals leaking from the vehicle. A system exists for clean up and the reporting of traffic accidents and other surface spills to appropriate agencies and water purveyors (Camp, Dresser & McKee, 1996).

3.7.3 Groundwater quality

Groundwater quality is subject to impacts from both natural and human causes in the District's water supply area.

3.7.3.a Natural impacts to groundwater quality

Groundwater can be found in the interspaces of geologic materials such as highly porous sandstone, upper weathered portions of granitic formations, or along cracks and fissures found in shale. Waters originating in the older sedimentary formations north of the Zayante fault contain relatively high concentrations of dissolved solids.

Table 3.10 describes the types of rock composing the District's source aquifers in terms of their naturally occurring water quality limitations.

Waters of the younger sedimentary formations, generally south of the Zayante and east of the Ben Lomond faults, contain water of intermediate quality. This area contains Santa Margarita Sandstone and includes Quail Hollow, Zayante, Mt. Hermon and Scotts Valley. Wells in areas of this highly permeable aquifer have lowered and altered the direction of groundwater flow, diminished streamflow, and caused degradation of water quality (Camp, Dresser & McKee, 1996). Some of the ground water recharge in this area is from leach fields or other sources in contact with wastes, resulting in elevated nitrate levels in this aquifer.

Groundwater produced from the Olympia wells intermittently exceeds recommended drinking water standards for total dissolved solids, sulfate, iron, and manganese. This is caused by naturally occurring poor quality water that is believed to migrate upwards from the underlying Monterey Formation (Johnson, 2002).

Waters from the crystalline rocks west of the Ben Lomond fault have relatively low concentrations of dissolved solids and streams of this area tend to provide high quality water at reasonably constant rates.

Table 3.10 Aquifer rock types and their naturally occurring water quality limitations

Aquifer Rock Type	Naturally Occurring Water Quality Limitations
Granite	Relatively low concentrations of dissolved solids. Low recharge. Potential for rapid contamination through fissure flow.
Vaqueros Sandstone	Regionally high sodium, iron, sulfide and fluoride.
Lompico Sandstone	Susceptible to pollution because of high permeability. Variable water quality due to lack of freshwater flushing in some areas.
Santa Margarita Sandstone	Due to high permeability, susceptible to pollution from contaminated recharge water and adjacent aquifers generating poor quality water. Potential source of high phosphate surface waters.
Monterey Formation	High iron and sulfate. Possibly high cadmium and contamination through fissure flow.
Alluvium and Terrace	Water quality varies greatly with composition and quality of recharge water. Often susceptible to pollution because of high permeability.

Source: Haynes, 1985.

3.7.3.b Human impacts to ground water quality

The County Nitrate Management Plan (1995) reports that, "Invariably the nitrate concentrations in surface water are one-half to one order of magnitude lower than the nitrate levels in nearby contributing shallow and deep groundwater." Well pumping directly affects nitrate levels in the surrounding ground water. Johnson (1988) found that as pumping increased, increasing the cone of depression around the well, nitrate was drawn from a wider area and caused nitrate concentrations to increase (County of Santa Cruz, 1995).

In 1986, nitrate levels in the Quail Hollow aquifer rose dramatically and rapidly towards the maximum drinking water standard. At that time, the District used the Quail Hollow aquifer for approximately 25% of its water supply. It was determined that the rapid spike in nitrate levels was due to heavy rains flushing nitrate, stored in the unsaturated zone, from the overlying development. Nitrate levels have since dropped to and remained at low levels, and have not hindered the District's ability to supply clean water.

The recharge area for the District's Olympia well fields is rural and undeveloped, and much of the aquifer lies beneath less permeable mudstone. Where the aquifer is exposed to surface, it has a high percolation capacity, increasing its vulnerability to human impacts.

Several factors contribute to the vulnerability of the Quail Hollow wells. The first is high percolation capacity of the Santa Margarita Sandstone and associated Zayante soils. The second is the absence of a confining zone above the aquifer. The third is the existence of about 40 residential septic tank systems in the estimated wellfield capture zone. The fourth is three unused production wells with the capture zone. Because of high permeability of the soils and sandstone, percolation from quarry detention ponds and the Quail Hollow Ranch pond originates from undeveloped watershed areas, and thus does not pose a significant threat to groundwater quality (Johnson, 2002).

Scotts Valley groundwater is unusually high in nitrate, which is probably from the result of past sewage treatment in Scotts Valley, which involved disposal within the Bean Creek watershed. The Hansen Quarry site is thought to be a primary contributor of the nitrates. For the last decade Scotts Valley has been exporting treated sewage in a pipeline to the Santa Cruz City outfall into the ocean. This makes management and reduction difficult. This "nitrate plume" migrates through the groundwater and contributes about one half of Bean Creek's nitrate load (County of Santa Cruz, 1995). The Scotts Valley nitrate plume has contributed up to 9 percent of the nitrate load in the San Lorenzo River (Camp, Dresser & McKee, 1996)

Septic tanks and horses

The protection zone around the wells contains no development, but the overall capture zones for the wells contain many residences with septic tanks. These residences along with horse stables, riding trails, and active quarrying near the fringe of the protective buffer zone are potential contaminating sources to the aquifer. However, there is no evidence of any water quality influence from septic tanks or horses.

Quarries

An old quarry immediately west of the Olympia wells serves as a stormwater retention basin that recharges the aquifer, and receives stormwater from a relatively pristine, undeveloped area. Potential fuel spills could be associated with active quarrying.

Toxic compounds

When in ground water, toxic chemicals can be difficult to impossible to remove, and may require expensive and elaborate clean up operations.

Gasoline and toxic chemicals leaking from underground storage tanks and illegal dumping of wastes has contaminated ground water aquifers in Scotts Valley used for drinking water. As a result, drinking water wells have been discontinued or have required extensive and expensive treatment. Methyl Tertiary-Butyl Ether (MTBE) was detected in wells in the Manaña Woods and in the Camp Evers area of Scotts Valley. This area is underlain by Santa Margarita Sandstone and may hydrologically connect to Carbonera, Bean and/or Zayante Creeks. The Santa Cruz Water Department has not detected MTBE above limits in any monitoring of its source waters (Berry, 2001).

Past operations at the old Watkins-Johnson Facility in Scotts Valley near Bean Creek contaminated ground water with methylene chloride, chloroform, and trichloroethylene (TCE) (Camp, Dresser & McKee, 1996). These contaminants also reached Bean Creek through the ground water. The EPA has overseen a very extensive remediation project since 1990 (County of Santa Cruz, 2001). Water is extracted, treated and then (considered contaminant free) is used, recharged or pumped into Bean Creek (Camp, Dresser & McKee, 1996; County of Santa Cruz, 2001).

The septic tank of Valeteria Dry Cleaners input tetrachlorethylene (PCE) into the San Lorenzo River via a spring (Camp, Dresser & McKee, 1996). The old septic tank was removed; a new one installed in a new area and clean up efforts ensued (Camp, Dresser & McKee, 1996). The City of Santa Cruz Water Department has not detected any contamination from this site above the detection limit in its water testing (Berry, 2001).

The closed landfill and Ben Lomond Transfer Station appear to have a low level plume with a few volatile organic compounds in the ground water; however, the plume does not appear to be migrating into the creek (Camp, Dresser & McKee, 1996).

3.7.4 The connection between surface water, ground water, and water quality

Surface water quality in the San Lorenzo River and its tributaries fluctuates with rainfall and streamflow. During the wet season, groundwater and surface runoff are high. Wastewater from septic systems and urban runoff transports turbidity, domestic animal waste, nitrates, pathogens and toxic compounds into streams. The County of Santa Cruz (1995) found that with higher levels of rainfall, soil moisture and/or elevated groundwater, there is a greater potential for flushing and delivery of nitrate to surface waters. During dry periods, the stream system of the watershed is fed by ground water. When groundwater enters a stream, it may carry dissolved constituents from geologic formations, discharges from septic systems, and/or other constituents that have percolated into the groundwater from other land use influences.

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