3 Climate and Hydrology

This section characterizes the climate and hydrology of San Lorenzo Valley as needed to understand and establish the following:

- The average and variable yield of SLVWD's diversion watersheds
- Climatic factors controlling the amount and variability of groundwater recharge
- A representative climatic cycle for evaluating conjunctive use

The following subsections evaluate the study area's rainfall, evapotranspiration, streamflow, and potential climatic cycles and trends.

3.1 Rainfall

SLVWD's stream and groundwater resources are solely derived from precipitation within the study area. This report refers to rainfall and precipitation synonymously, although on occasion some precipitation does occur as snow at higher elevations. Table 3-1 summarizes information for selected rainfall stations in the region and Figure 3-1 shows their location.

Tables 3-2, 3-3, and 3-4 provide monthly rainfall records for three stations in the study area with 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. Table 3-5 provides annual rainfall totals for the Santa Cruz and Lockheed stations extending back to the 1800s. Based on a double mass curve analysis, the early Santa Cruz record appears to be slightly drier as a result of one or more changes in station location prior to 1950 (Geomatrix, 1999). Annual rainfall at Santa Cruz, Ben Lomond, and Lockheed averages approximately 30, 50, and 55+ inches per year (in/yr), respectively.

Table 3-6 is the monthly rainfall record maintained by SLVWD since 1981 at its office, 13060 Highway 9, Boulder Creek. As shown by this table's inset plot, rainfall measured at the SLVWD office correlates reasonably well with the Ben Lomond 4 annual record. Average rainfall at both stations is about 50 in/yr.

3.1.1 Areal Distribution

Figure 3-1 is a map showing estimated contours of equal average annual rainfall (i.e., an isohyetal map) constructed from rainfall stations throughout the Santa Cruz Mountains region (Geomatrix, 1999). Mean annual rainfall ranges from less than 30 inches near the coast to more than 60 inches along the crest of Ben Lomond Mountain.

This spatial variability of mean annual rainfall results from the relation between typical storm patterns and the regional topography. Figure 3-2 presents satellite images of two types of Pacific storms, (a) cold cyclonic storms that descend from the Gulf of Alaska and (b) relatively warm advective storms driven by a strong westerly jet stream with entrained tropical moisture (i.e., a "pineapple express"). Although cyclonic storms generally approach from the northwest, their counter-clockwise frontal winds first arrive from the west or southwest. Thus, winds are typically from the west-southwest when either type of storm approaches California's central coast. When aimed directly at the study area, there is a strong orographic effect because of the perpendicular orientation of the Santa Cruz Mountains relative to the storm's strongest and wettest winds. Storm clouds cool as they lift up these slopes, resulting in steadily increasing rainfall, and sometimes snow at the highest elevations.

Figure 3-3 is a radar image illustrating the distribution of storm rainfall in relation to the Santa Cruz Mountains. The mountains have two parallel axes, (1) the range's main crest inland along the Santa Cruz County line and (2) an axis nearer to the coast comprised of Ben Lomond Mountain and Butano Ridge. Heavy rainfall begins near the coastal ridge crests and carries over into immediately adjacent portions of San Lorenzo Valley. Rainfall decreases across the valley's eastern slopes until storms encounter the higher inland mountain crest. This topography effectively harvests much of a storm's moisture within San Lorenzo Valley and causes a strong rain-shadow effect east into Santa Clara Valley. Figure 3-4 is a schematic profile illustrating this phenomenon.

SLVWD monitors rainfall at five stations in addition to the one at its main office (Table 3-7). These are located as follows: north of Boulder Creek at 1700 Highway 9; Lyon Water Treatment Plant (WTP); Quail Hollow tank; Olympia well 2; Pasatiempo well 6. Records for these stations are brief and/or discontinuous. However, the distribution of rainfall at these stations, along with those described above, for October 2006 through February 2007 is consistent with the pattern shown in Figure 3-1.

Other active rainfall stations in the area include one operated by the California Department of Forestry (CDF) on the crest of Ben Lomond Mountain (since 2001; Table 3-8) and one operated by SVWD at its El Pueblo yard (since 1945, Table 3-9). Annual precipitation at the CDF station is similar to that at Lockheed. Rainfall averages about 43 in/yr at the SVWD station.

Based on the isohyetal map presented in Figure 3-1, the mean annual rainfall of SLVWD's diversion watersheds is estimated to range from 58 to 60 in/yr (Geomatrix, 1999).

3.1.2 Seasonal Variation and Extremes

Figure 3-5 is a bar chart of the mean monthly distribution of annual rainfall at the Santa Cruz, Ben Lomond 4, and Lockheed stations. On average, more than 90 percent of annual rainfall occurs during the half-year period from November through April.

Figure 3-6 is a plot of the frequency of cumulative rainfall at the NOAA Ben Lomond 4 station since 1973 for periods lasting 1 to 30 days. Approximately 80 percent of all days and 50 percent of all weeks have rainfall totaling less than 0.01inches. This is reflective of the distinct dry season and recurrence of droughts.

Since 1973, the greatest one-day rainfall at Ben Lomond was 11.5 inches on January 4, 1982, equal to more than one-fifth of mean annual (Table 3-3); the greatest 30-day rainfall was nearly 33 inches during January and February, 1998. SLVWD measured rainfall greater than 30 inches at its office station during March 1983, January 1995, and February 1998 (Table 3-6). The Lockheed station received a monthly maximum of 41 inches of rain in January 1969 (Table 3-4) and had season totals of more than 100 inches five times during the past 117 years, with a maximum of 124 inches during WY 1890 (Table 3-5).

Minimum seasonal rainfall of about 35 percent of average occurred at both the Santa Cruz and Lockheed stations in WY 1924.

3.1.3 Historical Variation

Table 3-5 and the bar charts in Figure 3-7 present the annual rainfall records for the Santa Cruz, Ben Lomond 4, and Lockheed stations. Annual rainfall in the study area has ranged between about 35 and 220 percent of average during the available periods of record. Water-years of distinctly above or below average rainfall often occur consecutively and/or in clusters. As shown in Table 3-5, wet and dry years can be grouped into periods averaging about 7 years long and ranging in length from 2 to 20 years. Most periods begin with more than one year of above or below average rainfall and have a period average that is either less than 80 percent or more than 125 percent of mean annual rainfall. However, the criteria for retrospectively selecting these periods are not definitive and other groupings may be reasonable.

The two most recent significant droughts were WYs 1975-77 and 1987-94, which had about 60 and 75 percent of average rainfall, respectively. In the case of the more recent drought, WY 1993 is an example of a single wet year that does not mark the end of a drought. Prior to these two droughts, a prolonged 19-year drought occurred during WYs 1917-35 with 80 percent or less of average rainfall. A prolonged period of below average rainfall also occurred prior to 1890, although its relative magnitude is uncertain given suspected changes to the Santa Cruz station.

Recently, WYs 1995-2006 have comprised a prolonged, 12-year period of near average to above average rainfall. Other significant wet periods were WYs 1978-86, 1967-74, 1936-43, and 1890-1895.

Figure 3-8 presents the results of a moving-average analysis that highlights the driest and wettest 1 to 20 year periods for the Santa Cruz, Ben Lomond 4, and Lockheed stations. This analysis provides an alternative, objective approach for identifying such periods and supports the selection of dry and wet periods in Table 3-5.

Trend lines fit to the bar charts of annual rainfall in Figure 3-7 indicate slight long-term increases of 0.1 and 0.2 percent per year for the Lockheed and Santa Cruz stations, respectively. In the case of Santa Cruz, the relatively dry earlier record may be due artificially to station changes. For data since 1950 only, a slight upward trend remains in the Santa Cruz record while the Lockheed record exhibits no trend. Annual rainfall at the Ben Lomond 4 station has been trending upward 0.4 percent per year since 1973, although this record is too short to validate this observation.

The plots of water-year rainfall cumulative departure from average presented in Figure 3-9 provide an additional approach for evaluating the historical record. By definition, these plots begin and end at zero cumulative departure from average. Droughts are indicated by the plots' downward segments, periods of average rainfall are relatively flat, and wet periods are generally upward. Other than indicating these trends, the actual value of cumulative departure is relevant only in relation to various water-storage capacities (e.g., reservoirs, groundwater). Once such storage is either full or empty, a continuing trend of cumulative departure indicates only that it remains full or empty. The large magnitude and duration of the pre-1890 and 1917-35 droughts relative to more recent droughts is dramatically illustrated by these plots.

3.2 Evapotranspiration

Rainfall becomes either (1) evapotranspiration, (2) streamflow, or (3) pumped groundwater. Evapotranspiration estimates are needed to estimate the sum of the other two components. In Section 3.3.4 the streamflow component is separated further into stormflow and baseflow. Together, stream baseflow, pumped groundwater, and phreatophyte evapotranspiration[2] comprise the fate of groundwater recharge. Phreatophyte evapotranspiration is a relatively small component of the water budget that may be assumed to fall within the range of error of other components.

The following table provides "textbook" estimates of actual evapotranspiration representative of the study area:

[2] Transpiration by plants with roots drawing moisture from at or below the water table.

Setting		Rainfall	Actual ET	Source
		(in/yr)		
Pacific Douglas fir-redwood		30-100	30	Lull, 1964
Western mixed conifer		22-70	22	
California woodland-grass		18-40	18	
Pajaro basin	Forest	32	24	Blaney and Ewing, 1953
		40	28	
		48	32	
	Dry-farm orchard		17	
	Chaparral	32	20	

The California Irrigation Management Information System (CIMIS), administered by the California Department of Water Resources (CDWR), provides estimates of monthly "reference evapotranspiration" (ETo) based on the modified Penman equation. This approach represents the unrestricted water consumption of irrigated pasture grass and takes into account temperature, solar radiation, wind, and humidity.

Figure 3-10 is a map showing the CIMIS reference evapotranspiration zones in the vicinity of Santa Cruz County. The zones within the county and their annual ETo values are: zone 1, coastal plains heavy fog belt (33 in/yr); zone 2, coastal mixed fog area (39 in/yr); and zone 3, coastal valleys and plains (46.3 in/yr). Mostly within zone 3, San Lorenzo Valley receives relatively little fog due to the barrier presented by Ben Lomond Mountain and the lack of prevailing winds up from the river's mouth, resulting in significantly higher ETo than near-coast areas.

Table 3-10 presents five monthly soil-water budgets representative of various portions of the study area. Each case calculates the average annual amount of rainfall lost to evapotranspiration and the remaining portion that becomes stream and groundwater flow. These calculations are based on the following variables and assumptions:

- Average monthly rainfall – The Lockheed station is used to represent the crest and steep eastern slopes of Ben Lomond Mountain; the Ben Lomond station is used to represent the valley floor along the mountain base; values proportional to Ben Lomond are used to represent slightly drier areas across eastern San Lorenzo Valley; and the Santa Cruz station represents the lower valley.
- Average monthly ETo – San Lorenzo Valley is assumed to be zone 3 except: (a) along the crest and steep eastern slopes of Ben Lomond Mountain where an average of zones 2 and 3 is used; and (b) at the lower end of the valley where zone 1 is assumed.
- Soil-water storage capacity – A soil's capacity to store water significantly affects actual evapotranspiration by determining the amount of seasonal rainfall available for dry-season growth. Table 3-11 provides a summary of study-area soils and their estimated water storage capacities (Bowman and Estrada, 1980). Forest sandy loams have capacities up to 10 inches whereas sand-hill soils have capacities as low as 2 inches.
- Crop coefficients relating local ground cover to that assumed by ETo – Such coefficients have been established for many farmed crops and irrigated landscapes but are much less certain for large forested watersheds such as San Lorenzo Valley. The cases presented in Table 3-10 assume a crop coefficient of 1.0, meaning that local conditions are suitably represented by unadjusted values of ETo. Potential errors in this assumption may be partially compensated for by assumed values of soil-water storage capacity.

- Non-irrigated conditions – These examples represent non-irrigated conditions, as occurs throughout most of San Lorenzo Valley (Section 5 evaluates the significance of irrigation and wastewater in local water budgets).

The results of the five example soil-water budgets are tabulated and plotted in Table 3-10 and summarized as follows:

Case (Table 3-10)	Rain-fall	ETo	Soil-Water Capacity	Actual ET	Runoff & Recharge
	(in/yr)		(inches)	(in/yr)	
1. Ben Lomond Mountain	59	43	10	31	28
2. Ben Lomond	49	46	10	29	20
3. Loch Lomond watershed	43	46	10	28	15
4. Quail Hollow, Zayante Soils	47	46	3	21	26
5. Santa Cruz	31	39	9	23	8

These results are consistent with the table of "textbook" values of actual evapotranspiration provided above. Evapotranspiration from San Lorenzo Valley's forests (represented by cases 1 through 3) is relatively constant at about 30 in/yr, regardless of rainfall. Thus, the portion of rainfall that becomes runoff and recharge increases significantly with increasing rates of average rainfall.

Evapotranspiration is only about 20 in/yr in the vicinity of SLVWD wells because of the low water-retention capacity of the area's sandy soils (case 4). Because these soils are also characterized by low runoff, groundwater recharge rates are particularly high.

3.3 Streamflow

San Lorenzo Valley's streamflow hydrology is relevant to SLVWD's stream diversions as well as baseflows discharged from its groundwater aquifers. The streams from which SLVWD diverts are ungaged, although known to flow equal to or more than the recorded rates of diversion. This report uses the terms streamflow and stream discharge synonymously. Streamflow consists of both storm runoff and baseflow.

3.3.1 Gaged Watersheds

As mapped in Figure 3-11 and summarized in Table 3-12, the USGS has gaged more than 30 streams in the Santa Cruz Mountains region for various periods of record. The longest records are for the San Lorenzo River at Big Trees (since WY 1937) and Pescadero Creek in San Mateo County (since WY 1952). Other gaged streams with reasonably long records and some relevance to SLVWD include Boulder, San Vicente, Zayante, and Bean creeks and the San Lorenzo River at Waterman Switch (gage locations shown in Figure 3-1).

Table 3-13 presents the streamflow record for the San Lorenzo River at Big Trees, including estimated annual adjustments of generally 3 to 6 percent for Loch Lomond and City of Santa Cruz diversions since 1961; these adjustments do not account for numerous small diversions throughout the San Lorenzo River watershed, however. No major diversions or dams occur on the other six gaged streams summarized in Table 3-14.

A previous study (Geomatrix, 1999) correlated average annual unit streamflow[3] with estimated average annual watershed rainfall for these gaged streams, normalized to a 60-year period of record. Figure 3-12 is a plot of this correlation. SLVWD's diversion watersheds receive higher rates of rainfall and have much smaller watershed areas than any of the gaged watersheds. However, an extrapolation of the correlation presented in Figure 3-12 indicates that the average unit streamflow of SLVWD's diversion watersheds is at least 25 in/yr.

Also plotted in Figure 3-12 are the rainfall "surplus" estimates from the soil-water budgets presented in Section 3.2. These estimates plot consistently with the gaged-watershed data (except, as expected, in the sandy-soil case), and confirm that gaged streamflow is largely representative of total watershed yield, including baseflow derived from groundwater discharge. The extrapolated yields of SLVWD's diversion watersheds are presented and discussed in Section 4.

No gaging data exists for the sandy soil drainages of SLVWD's groundwater recharge areas. Average annual runoff is estimated to be as little as a few inches where these areas are relatively undeveloped.

3.3.2 Seasonal Variation and Extremes

Figure 3-5 includes a bar chart of average monthly streamflow, expressed as a percent of average annual streamflow, based on the records of seven gaged streams in the study area (Table 3-14). On average, nearly 90 percent of annual streamflow occurs during the half-year period from December through May. As shown in Figure 3-5, the annual streamflow hydrograph lags behind the rainfall hydrograph by a month or more.

Streamflow was only 10 percent or less of average during WY 1977, the lowest year of record, and about 15 percent or less of average in WY 1976, the second driest year of record (Table 3-14). The next four lowest streamflow years were WYs 1961, 1988, 1990, and 1939, all of which were less than 25 percent of average.

Streamflow was nearly 300 percent or more of average during WY 1983, the highest year of record. Other years with streamflow generally above 200 percent of average include WYs 1941, 1952, 1958, 1969, 1982, 1998, and 2006.

3.3.3 Historical Variation

Table 3-14 and the bar charts in Figure 3-13 present the annual streamflow records for selected streams with gaged records relevant to SLVWD. Historically, annual streamflow varies over a much broader range than annual rainfall, ranging between about 5 and 400 percent of average. As shown in Table 3-14, annual streamflow records can be grouped into periods of above and below average streamflow consistent with the rainfall record. An attempt to fit trend lines to the bar charts of annual streamflow in Figure 3-13 does not reveal any significant long-term change in mean annual streamflow during the past 70 years.

During the two most recent droughts, WYs 1975-77 and 1987-94, streamflow was about 35 and 40 percent of average, respectively. The magnitude of these two droughts is evident from the hydrographs of mean daily flow for WYs 1975-95 presented in Figure 3-14. Flows were about 50 to 65 percent of average during the three earlier droughts that occurred during WYs 1944-50, 1953-55, and 1959-66. Streamflow records do not exist for the prolonged 19-year drought that occurred during WYs 1917-35.

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[3] Unit streamflow is the volumetric rate of streamflow divided by the watershed area, e.g., AF/yr per square mile, or, as expressed in this report, inches per year.

Figure 3-15 is a plot correlating annual rainfall and unit streamflow for selected records, each expressed as percent of average. Annual rainfall of 50 to 75 percent of average results in annual streamflows of only about 20 to 50 percent of average, respectively, whereas rainfall of 125 to 175 percent of average results in streamflows roughly 150 to 250 percent of average. As shown, this relationship is consistent with the distribution of gaged-watershed averages (Table 3-12, expressed as a percent of average for all watersheds) and soil-water budget estimates (Table 3-10).

3.3.4 Stream Baseflow

Baseflow is the portion of streamflow that originates from groundwater. During the dry season, streamflow is essentially all baseflow. The contribution of baseflow to total streamflow increases throughout most of the wet season as groundwater pressures rise in response to rainfall recharge and diminished evapotranspiration. As the wet season ends, baseflow begins an exponential decline that continues throughout the dry season.

The proportion of baseflow relative to total flow is difficult to evaluate during periods of stormflow, although several studies have done so using water quality data (e.g., Pinder and Jones, 1969). For this study, a stormflow-baseflow hydrograph separation was performed for the average mean-daily flows of the seven stream records summarized in Table 3-14. Each hydrograph separation uses an exponential backward extension of the dry-season flow recession curve. Baseflow is assumed to increase at a linear rate from the beginning of the wet season until intersecting the extrapolated recession curve in the spring (typically early April) when peak groundwater levels occur. Figure 3-16 presents the results of this analysis.

A baseflow recession curve may be segmented where significant groundwater discharge occurs from more than one aquifer and/or set of aquifer conditions. Three of the seven hydrograph separations presented in Figure 3-16 have two recession curves (those for Pescadero, Zayante, and Bean creeks), in which case the earlier of the two was extrapolated backward.

As summarized in Figure 3-16’s inset table, the hydrograph separations indicate that unit baseflows range from about 5 to 10 in/yr during an average year, comprising 35 to nearly 50 percent of total streamflow. Based on this analysis, typically about 35 to 40 percent of the “rainfall surplus” estimated from soil-water budgets (Table 3-10) becomes groundwater recharge. Most of the recharged groundwater becomes baseflow, although some is pumped from wells and lost to phreatophyte evapotranspiration.

In the case of well-drained soils, such as those in the vicinity of SLVWD's wells, a much larger proportion of rainfall contributes to stream baseflow (~70 percent) because of the high rates of rainfall percolation that result from low runoff and low evapotranspiration.

3.4 Past and Potential Climatic Change

3.4.1 State and Global Climatic Record

Globally since 1900, average near-surface air temperatures and ocean surface temperatures have increased about 0.15°F per decade, and precipitation appears to have increased about 0.2 percent per decade. Across the middle and high latitudes of the northern hemisphere, over-land precipitation and streamflow have increased at a rate of about 0.5 to 1 percent per decade (CDWR, July 2006).

Since the late 1800s in California, mean annual precipitation appears to have slightly decreased in the central and southern portions of the state while increasing in the north. Statewide, the overall trend has been relatively flat with a recent upward trend. The variability of statewide annual average precipitation within a moving 10-year period between 1890 and 2002 has about doubled, increasing from about 0.18 to 0.36 (CDWR, July 2006).

3.4.2 Local Climatic Record

Figure 3-17 presents the records of mean annual daily minimum, maximum, and average temperatures for four NOAA stations in the region: Santa Cruz and Los Gatos (both since 1949), San Gregorio 2SE (since 1955), and Ben Lomond 4 (since 1973). The two longest records exhibit the following similar trends: an increasing mean daily minimum temperature (0.4° to 0.9°F per decade); a decreasing mean daily maximum temperature (0.1° to 0.2°F per decade); and a resulting slight increase in average mean temperature (0.1° to 0.4°F per decade). These trends may be partially due to a "heat island" effect related to urbanization. However, the magnitude of change is consistent with global observations summarized above. Furthermore, the pattern of increased nighttime temperatures has been observed globally and attributed to climatic change (Easterling and others, July 1997). At the rural San Gregorio 2SE station the mean annual daily average and minimum temperatures have increased slightly (about 0.1°F per decade) whereas the mean annual daily maximum has been essentially flat. This station is more within the fog belt than the others. The relatively short Ben Lomond 4 record exhibits no temperature trend.

As shown in Figure 3-7, there has been an apparent increase in mean annual rainfall of 1 to 2 percent of average per decade at the Santa Cruz and Lockheed stations during the past 140 years. This range of increase is similar to the average hemispheric rate of increase cited above. Furthermore, the observed trend of increasing rainfall is consistent with satellite data showing that precipitation has kept pace with increased humidity induced by climatic change (Wentz and others, May 2007). Local streamflow records extend back only half as long and do not exhibit any trend (Figure 3-13).

The rainfall records for the Santa Cruz and Lockheed stations exhibit an increasing trend in variability similar to the statewide trend described above. Figure 3-18 compares the plot of the statewide trend in precipitation variability (CDWR, July 2006) to similar plots for the Santa Cruz and Lockheed stations. The plots are remarkably similar and indicate that the study area is experiencing climatic change consistent with statewide trends.

3.4.3 Climate Predictions

The following climatic conditions are predicted statewide for California:

- A 3 to 10°F temperature increase by 2100, with a greater proportion of this increase occurring in summer than in winter (Cayan and others, March 2006).
- A continuation of mostly winter precipitation, virtually all from North Pacific winter storms. Precipitation may increase in winter while decreasing in spring (Cayan and others, March 2006).
- Either relatively little change in overall precipitation statewide (Cayan and others, March 2006) or a trend toward moderately decreased precipitation as indicated by a majority of model projections (CDWR, July 2006).
- A statewide 27 percent reduction in the average annual availability of water supplies, and a resulting 17 percent reduction in average annual water deliveries, mainly due to changes in the nature, spatial distribution, and timing of precipitation (e.g., decreased snow pack; Medellin and others, March 2006).
- A relatively small increase in evapotranspiration assuming that most of the temperature increase is nocturnal (CDWR, July 2006).
- During the next 50 to 100 years in Santa Cruz County, temperatures will rise 8° to 9°F and rainfall will decrease by nearly half between February and April, and summers will be hotter

with increased water demand, according to researchers from the UCSC Climate Change and Impacts Laboratory (Santa Cruz Sentinel, November 12, 2006).

- Although unlikely, the possibility of sudden climatic change exists as evidenced by extreme droughts apparent in extended records, occurring over large areas and several decades, possibly due to oscillating ocean conditions. Sudden cooling could be brought on by volcanic eruptions or other causes of atmospheric debris (CDWR, July 2006).
- Significant uncertainty remains about the nature and magnitude of potential climatic change in California (CDWR, July 2006).

California's most significant expected impact from climate change, reduced snow pack, will not directly impact coastal areas relying solely on local water supplies, such as Santa Cruz County. However, the central coast appears to be located near the boundary between an increasingly dry south and a possibly wetter north. Furthermore, increased spring and summer temperatures will result in increased water demand.

The increased variability of annual rainfall over 10-year periods (Figure 3-18) suggests a potentially greater frequency of extremely wet and/or dry years. Thus, even if little change in mean annual rainfall occurs, it may become more difficult to effectively capture and/or store the increased proportion of average rainfall that occurs during very wet years. Increased variability also suggests the potential for a reduced occurrence of extended droughts, given that one period of lowest historical variability was the prolonged drought of 1917-35.

3.5 Design Climatic Cycle

The reliability of SLVWD's water supply system is qualified largely by its capacity to sustain adequate production during the annual dry season and through the recurrence of expected multi-year droughts (i.e., the climatic cycle). As such, this study requires a design climatic cycle suitable for evaluating SLVWD's ability to meet expected future water demand through the conjunctive use of its surface water and groundwater sources. Alternative approaches for defining a design climatic cycle include the following:

1. Repetition of the climatic period that occurred from 1970 to the present, during which two significant droughts occurred, WYs 1975-77 and 1987-94. Much of this period has an excellent data record and high degrees of variability.
2. Repetition of a prolonged drought similar to that which occurred during WYs 1917-35. Due to its length, this presents more of a worse case than more recent droughts. However, there are no streamflow or water-production records representative of this period.
3. Formulation of a hypothetical period assumed to represent future conditions under climatic change. However, there is little scientific certainty upon which to base such an assumption.

Because the second and third approaches would require many uncertain assumptions, this study bases its analysis on a repetition of the well-documented climatic conditions since about 1970 and water production history since 1984. Analysis of this period affords a relatively high degree of confidence, which can then be extrapolated to address other potential conditions including the potential effects of climate change.

4 Stream Diversions

This section evaluates SLVWD's stream diversions with regard to watershed conditions, infrastructure, and recorded and potential water production. Figures 1-3 through 1-6 and Figure 4-1 show the location of SLVWD's five current diversion watersheds on Peavine, Silver, Foreman, Clear, and Sweetwater creeks. As summarized in Table 4-1, SLVWD has pre-1914 appropriative water rights for these streams as well as inactive diversions on Harmon, Earl, and Manson creeks. Table 4-2 provides watershed areas and elevations relevant to these diversions.

SLVWD's past and potential use of water from Loch Lomond Reservoir is addressed in Section 6. SLVWD's diversion rights to Fall Creek, which it obtained in its recent acquisition of the Felton system formerly operated by Cal-Am, are not within the scope of this report.

Since 1984, production from SLVWD stream diversions has ranged from about 500 to 1,200 AF/yr (160 to 400 MG/yr), averaging nearly 900 AF/yr (290 MG/yr or 0.8 mgd). These diversions satisfy more than half of SLVWD's Northern Service Area average annual water demand. Table 4-3 presents a summary of the annual diversion record. The monthly diversion record is included in appended Table A-1.

4.1 Diversion Watersheds

SLVWD currently diverts from a total of seven stream intakes with a combined contributing watershed area of approximately 1,400 acres, or 2.2 square miles (Figure 4-1, Table 4-2). This configuration of diversions allows gravity conveyance to centralized water treatment. Prior to 1995, the combined diversion watershed area was about 1,750 acres and included three additional intakes. Conveyance by gravity to the Lyon Water Treatment Plant (WTP; completed in 1994) required the upstream relocation of some points of diversion and the discontinuation of others.

4.1.1 Physiography

SLVWD's diversion watersheds are located west and northwest of the towns of Ben Lomond, Brookdale, and Boulder Creek along the steep northeast-facing slopes of Ben Lomond Mountain (Figure 4-1). Peavine, Silver, and Foreman creeks drain directly to Boulder Creek, which has a watershed area of nearly 12 square miles upstream of its confluence with the San Lorenzo River. Clear Creek and its tributary Sweetwater Creek drain directly to the San Lorenzo River. The river has a watershed area of about 55 square miles above and including Clear Creek, and 106 square miles upstream of the Big Trees USGS gage near Felton.

Elevations decline about 2,000 ft within a distance of only 1.5 miles from the crest of Ben Lomond Mountain to the river and Boulder Creek. The watershed divides of each diverted stream extend up to the crest of Ben Lomond Mountain, with the exception of Silver Creek and the formerly diverted Harmon, Earl, and Manson creeks. Areas of potential watershed recharge lie along the crest of Ben Lomond Mountain, as shown in Figure 4-1 and discussed in Section 4.1.3.

The diversion watersheds are underlain entirely by granitic rock except for a portion of the Sweetwater Creek watershed underlain by schist (Figure 1-5). Ridge-top areas of Ben Lomond Mountain are underlain by a thick mantle of weathered granitic rock. Figure 4-2 shows the distribution of landslides and debris flows in the watershed area following the January 1982 storm. Potential erosion hazards associated with watershed area soils are high to very high (Bowman and Estrada, 1980).

4.1.1.1 Active Diversion Watersheds

The watersheds upstream of SLVWD's seven current diversion intakes have areas ranging from 20 to 480 acres (Table 4-2). Due to the area's remote and heavily forested nature, the watershed