5 Groundwater Sources

This section describes SLVWD's groundwater resources, wells, and recorded and potential groundwater production. Figure 5-1 shows the location of SLVWD's seven active production wells in the Quail Hollow, Olympia, Pasatiempo, and Camp Evers areas. These wells are:

- Quail Hollow wells 4A and 5A (QH-4A & -5A)
- Olympia wells 2 and 3 (Oly-2 & -3)
- Pasatiempo wells 6 and 7 (Paso-6 & -7)
- Mañana Woods well 2 (MWd-2)

The Quail Hollow and Olympia wells supply water to the Northern Service Area in conjunction with SLVWD's stream diversions. The Pasatiempo wells are the sole water supply for the Southern Service Area, and MWd-2 is the sole source of water for the recently annexed Mañana Woods service area.

Table 5-1 summarizes construction, performance, and aquifer information for SLVWD's active and former production wells. Table 5-2 summarizes information for SLVWD monitoring wells. Selected non-SLVWD wells are summarized in Table 5-3.

Since 1984, production from SLVWD wells has ranged from about 600 to 1,200 AF/yr (200 to 400 MG/yr) and averaged about 1,000 AF/yr (325 MG/yr or 0.9 mgd). Groundwater production satisfies nearly half of the average annual water demand of SLVWD's Northern Service Area and all of the Southern Service Area and Mañana Woods demand. Since 2001, groundwater production has averaged about 750 AF/yr (245 MG/yr) in the Northern Service Area and 410 AF/yr (135 MG/yr) in the Southern Service Area. Available data for previous years suggests that production for the Mañana Woods service area has averaged about 70 AF/yr (23 MG/yr; Table 2-2). Production from MWd-2 during SLVWD's first year of operating this system was only 54 AF/yr (18 MG/yr; Table 5-5), reflecting an expected decline in use as a result of metering each connection.

Tables 5-4 through 5-8 summarize the groundwater production record for each SLVWD well and group of wells. SLVWD's complete monthly pumping record is appended in Table A-2. Table 5-9 provides the annual pumping record for selected other groups of wells in the area.

In the remainder of this section, Section 5.1 defines the relevant groundwater subareas; Section 5.2 summarizes the hydrogeologic conditions of each subarea; Section 5.3 describes SLVWD's groundwater infrastructure and operations; Section 5.4 evaluates the historical record of groundwater levels and production; Section 5.5 documents the water quality of SLVWD-produced groundwater; Section 5.6 estimates the groundwater budget; Section 5.7 summarizes various aspects of groundwater management and protection; and Section 5.8 provides an evaluation of SLVWD's groundwater production potential.

5.1 Groundwater Subareas

Figure 5-2 shows the boundaries of the following groundwater subareas defined for the purpose of characterizing SLVWD's groundwater resources:

Subarea	sq. miles
Quail Hollow	3.0
Olympia	2.9
Pasatiempo	1.9
Camp Evers	0.9
Mission Springs	2.3
Scotts Valley	~8

(adjacent areas of exposed Monterey Formation excluded)

These subareas extend 4 miles from the San Lorenzo River east into the Scotts Valley area. The overall area is distinguished by sandhills of exposed Santa Margarita Sandstone. The Quail Hollow area is relatively separate from the clustered Olympia, Pasatiempo, Camp Evers, Mission Springs, and Scotts Valley subareas. From west to east across these subareas, mean annual rainfall trends from a high of 50 in/yr near the base of Ben Lomond Mountain to a low of slightly above 40 in/yr in eastern Scotts Valley. On average, approximately 85 percent of annual rainfall occurs from November through March.

Other than the fairly well-defined Quail Hollow area, the subarea designations are somewhat arbitrary, inasmuch as continuous aquifer zones extend between them.[10] However, they provide a convenient structure for providing information in the remainder of this section. The selected subarea names are also the names of actual sites or locations. In this report, use of these names is in reference to the defined groundwater subareas unless otherwise specified.

5.1.1 Quail Hollow

Quail Hollow is a hillslope area of exposed Santa Margarita Sandstone encompassing about 3.0 square miles (1,940 ac) between the communities of Ben Lomond, Glen Arbor, Felton, Zayante, and Lompico (Figure 5-3). It is bounded on the west by the San Lorenzo River and Love Creek and on the east by Lompico and Zayante creeks; it is crossed by Newell Creek. With regard to roadways, the area is partially bounded by Glen Arbor Road on the west and Zayante and Lompico roads on the east, and crossed east-west by Quail Hollow Road. Nearly the entire Quail Hollow area lies within SLVWD's current serviceable area. The groundwater resources of the Quail Hollow area were evaluated in detail by Johnson (2001).

Quail Hollow groundwater supplies SLVWD, residential, and quarry wells, and discharges to springs and streams that contribute to the local and regional water supply. Relatively major springs discharge to Zayante Creek from the eastern margin of the sandstone outcrop, including Azalea, Olympia Circle, McHenry, and Arcadia springs. Diversions from these springs have supplied mutual water companies and a bottled water company.

The area sandhills rise 300 to 600 ft above the surrounding streams. The crest of the main ridge separating Newell and Zayante creeks ranges in elevation from 800 to 1,200 ft msl and includes several small hilltops capped with mudstone. The area’s sandy, well-drained soils support Ponderosa pine and chaparral vegetation, in contrast to the redwood and Douglas fir forest that covers most of San Lorenzo Valley. Mean annual rainfall is about 45 to 50 in/yr.

The exposed sandstone is overlain by several neighborhoods of single-family homes that are supplied water by either SLVWD or private wells, all of which rely on septic tanks. The area also includes the 200-acre Quail Hollow sand quarry operated by Granite Rock; Quail Hollow Ranch County Park (nearly 280 acres), which includes a spring-fed pond; and the closed Santa Cruz County Ben Lomond Landfill west of Newell Creek (24 acres). The quarry captures and percolates both on-site runoff and used process water supplied from its well.

Active and former SLVWD wells are located within about 2,000 ft of each other near Quail Hollow Road on the hillslopes leading down to the east bank of Newell Creek. The wellhead elevations at active QH-4A and QH-5A range between 500 and 600 ft msl. These two well sites are located on adjacent SLVWD-owned parcels that have a total area of nearly 3 acres.

SLVWD also monitors five non-pumping wells in the Quail Hollow area: its former production well QH-8; the former production well for Quail Hollow Ranch (QHR); and three monitoring wells

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[10] The term groundwater “subarea” is used instead of “subbasin” for this reason.

constructed by SLVWD (MW-A, -B, & -C). The quarry and closed landfill each have their own monitoring-well network.

5.1.2 Olympia

The Olympia groundwater area, as defined for the purpose of this study, lies between the communities of Mount Hermon, Zayante, and Scotts Valley (Figure 5-4). It is a hillslope area of partially exposed Santa Margarita Sandstone that covers 2.9 square miles (1,825 ac) between Zayante Creek to the west and north, Bean Creek to the south, and Lockhart Gulch to the east. The area also is bounded by East Zayante Road on the west, Mount Hermon Road on the south, and Lockhart Gulch Road on the east. This same area was used by Johnson (1989) to evaluate a proposed SLVWD well site.

The Olympia and Mission Springs subareas (Figure 5-4), along with portions of the Camp Evers and Scotts Valley subareas (Figure 5-2), comprise more or less a single groundwater subbasin. SLVWD's Olympia wells are located toward the western edge of this subbasin and are unlikely to significantly influence groundwater conditions in the Mission Springs or other areas. For this reason, the groundwater resources of the Olympia subarea are described separately.

Olympia groundwater supplies SLVWD and residential wells, flows into adjoining groundwater subareas, and discharges to springs and streams that contribute to both local and regional water supplies. The sandstone aquifer extends beneath Lockhart Gulch and Bean Creek into the adjacent Mission Springs and Camp Evers subareas.

The north-south ridge lying between Zayante Creek and Lockhart Gulch reaches elevations of 800 to 1,200 ft msl. This ridge is broadly covered with rock and soils that are less permeable than areas of exposed Santa Margarita Sandstone. Much of the area is zoned for timber. Residential development is clustered mostly along stream corridors. Average annual rainfall is nearly 45 in/yr.

Three closed sand quarries are located along the southeastern margin of the Olympia area where the sandstone is most exposed. The largest and most recently retired of these is the 120-acre Lonestar Olympia quarry at the southeast corner of the sandstone outcrop. The fully reclaimed old Olympia quarry is further north near SLVWD's Olympia wells whereas the abandoned Geyer Road quarry is along the southeast near Bean Creek.

SLVWD's three Olympia wells are located within about 1,000 ft of each other. Active wells Oly-2 and Oly-3 are located on a 61-acre parcel at elevations 525 and 538 ft msl. SLVWD also owns four adjoining parcels with a combined area of _ ac. Oly-1 is located on one of the adjoining parcels and is maintained as a monitoring well. SLVWD's Olympia wells are located at the southeastern edge of its Northern Service Area.

5.1.3 Pasatiempo

The Pasatiempo groundwater area, as defined here, is a plateau and hillslope area of exposed sandstone between the communities of Felton, Mount Hermon, and Camp Evers in southern Scotts Valley (Figure 5-5). This 1,200-acre (1.9 square mile) area encompasses the following: all active and former SLVWD Pasatiempo wells; a large portion of SLVWD's mostly residential Southern Service Area (a portion of which is in the City of Scotts Valley); most of the service area of Mañana Woods Water Company (now part of SLVWD); much of the Mount Hermon community, along with its three production wells; the nearly 300-acre Hanson Quarry, which is undergoing closure; and large tracts of undeveloped land to the west and southwest. The area is bound by Bean Creek to the north, the San Lorenzo River to the west, Eagle Creek to the southwest, and small tributaries to Bean and Carbonera creeks to the east and southeast. The area lies south and west of Mount Hermon Road and is traversed by Graham Hill Road and Lockwood Lane. SLVWD's groundwater resources in the Pasatiempo area were evaluated by Johnson (2002).

In the Pasatiempo area, the Santa Margarita Sandstone is underlain by the Lompico Sandstone at relatively shallow depths and productive zones in older formations at greater depths. These aquifers supply groundwater to SLVWD, Mount Hermon, and quarry wells; subsurface flow into the adjoining Camp Evers subarea; and baseflow to springs and streams that contribute to both local and regional water supplies. Ferndell and Redwood springs have contributed to the Mount Hermon water supply.

The Pasatiempo hilltops reach elevations of 800 ft msl, about 600 ft above the San Lorenzo River to the west. Vegetation ranges from Ponderosa pine and chaparral, characteristic of the area's sandy soils, to woodland and redwood forest. Mean annual rainfall is about 42 to 45 in/yr.

The Hanson (formerly Kaiser) sand quarry is undergoing closure. The reclaimed quarry is expected to remain mostly open space and most runoff will continue to be retained on site. Roaring Camp and private undeveloped land adjacent to Henry Cowell State Park occupy a significant portion of the remaining recharge area.

SLVWD's active production wells Paso-6 and Paso-7 are located within 1,200 ft of each other within a 28-ac parcel of the Santa Cruz County Probation Center at elevations of 700 to 800 ft msl near the center of the Pasatiempo area. SLVWD operations encompass inset parcels totaling 1.2 acres. Two former wells (Paso-1 and Paso-5) are within 600 ft of Paso-6. Former production wells Paso-2, Paso-3, and Paso-4 operated within residential areas of SLVWD's Southern Service Area about 2,000 to more than 5,000 ft east and southeast of the currently active wells. SLVWD has a shallow (MW-2) and deep (MW-1) monitoring-well pair adjacent to Paso-6. Two wells actively operated by Mount Hermon Association (MHA), MH-2 and MH-3, are respectively about 500 and 2,500 ft northwest of the nearest SLVWD well, Paso-6. One of the supply wells for Hanson Quarry, H-4A, is about 600 ft southeast from Paso-7; the quarry's other two supply wells are along the northeast Pasatiempo subarea boundary. When the quarry was operating, about half or more of its groundwater production was estimated to percolate back into the aquifer (Johnson, 2002).

5.1.4 Camp Evers

Camp Evers refers to the south-central portion of Scotts Valley near the intersection of Mount Hermon Road and Scotts Valley Drive. This area has become highly developed since the 1970s. It occupies a small alluvial plain elevated at just over 500 ft msl between Bean and Carbonera creeks. The thin alluvial layer that overlies much of Camp Evers obscures the near-surface exposure of both the Santa Margarita and Lompico sandstones.

As defined here, the Camp Evers groundwater subarea extends north to Bean Creek and encompasses a total of about 550 acres (0.9 sq mi) (Figure 5-5). It is bordered by the Pasatiempo subarea to the west and southwest, the Olympia and Mission Spring subareas to the north across Bean Creek, and the remainder of the Scotts Valley groundwater area to the east and northeast. A granitic outcrop limits groundwater movement across Camp Evers' southeastern boundary. Camp Evers groundwater conditions are reported on annually by SVWD (e.g., ETIC, 2007).

Camp Evers is an area of significant historical and ongoing groundwater production from wells operated by SVWD, mutual water companies, businesses, residences, and remedial operations. SLVWD operates a well in the Camp Evers area since its 2006 annexation of the area formerly served by the Mañana Woods Mutual Water Company. This second well of the former water company, referred to here as MWd-2, is located on a 0.21-acre parcel near Mount Hermon Road and Kings Village Shopping Center, about 0.5 mi north of the Mañana Woods residential area (which lies mostly within the Pasatiempo subarea). Groundwater pumped at this location requires treatment due to the well's interception of one or more contaminant plumes underlying Camp Evers.

Currently active SVWD wells SV-9 and SV-10A are about 1,000 north and 1,300 ft west, respectively, from MWd-2. Non-SVWD wells supply the Spring Lakes, Vista Del Lago, and Montevalle communities and the Valley Gardens golf course. These wells are about 1,000 to 3,000 ft from MWd-2.

Recycled water delivered by SVWD is an additional source of water within Camp Evers. Since 2005, more than 100 AF/yr (33 MG/yr) has been delivered for use within the greater Scotts Valley area.

5.1.5 Mission Springs

The Mission Springs and Olympia subareas (Figure 5-4) comprise more or less a single groundwater subbasin, along with portions of the Camp Evers and Scotts Valley areas to the south and east (Figure 5-2). This report evaluates these subareas separately because SLVWD's Olympia wells, located toward the western edge of the Olympia subarea, are expected to have little direct influence on groundwater in the Mission Springs subarea.

As delineated in this report, the Mission Springs subarea encompasses 2.3 square miles (1,440 ac) between Lockhart Gulch and Bean Creek. Ruins and Mackenzie creeks traverse the subarea from north to south. Subarea wells supply individual residences and the Mission Springs Conference Grounds. The spring that Mission Springs was named after in the early 1900s tends not appear as a mapped hydrologic feature. When flowing, this spring may originate from a perched groundwater zone. SLVWD's Olympia wells are about 5,000 ft from the Mission Springs Conference Grounds. The Conference Grounds well is located near the confluence of Lockhart and Ryder gulches along the Olympia-Mission Springs subarea boundary.

5.1.6 Scotts Valley

The remainder of the Scotts Valley groundwater area includes roughly 8 square miles of the Bean, Carbonera, and possibly Branciforte creek watersheds south of the Zayante fault and east and northeast of the Camp Evers and Mission Springs subareas (Figure 5-2). The Santa Margarita Sandstone is less saturated and begins to pinch-out in this area. SVWD wells draw from the deeper Lompico and Butano sandstones, for which the contributing recharge areas are poorly defined. Wells SV-11A and SV-11B are about 1 mile from MWd-2 and more than 2 miles from the Olympia wells, whereas wells SV-3B and SV-7A in northern Scotts Valley are more than 2 miles from MWd-2 and about 3 miles from the Olympia wells.

5.2 Hydrogeology

The hydrogeology of the groundwater subareas defined above has been evaluated and described by several prior studies. Reports by Johnson provide assessments of the Quail Hollow (1988, 2001), Olympia (1989), and Pasatiempo (2002) subareas. Reports by Todd Engineers (e.g., 2003) and ETIC (2007) provide groundwater summaries of the overall Scotts Valley area.

This section describes (a) the hydrogeologic units that comprise the area's multi-aquifer and aquitard groundwater system and (b) the occurrence, movement, and storage of groundwater within this system.

5.2.1 Hydrogeologic Units

Figure 5-6 is a geologic map of the area encompassing the groundwater subareas described above. The geologic formations exposed in this area are as follows:

Geologic Unit[a]	Geologic Period[a]		Approximate Local[b] Maximum Thickness (ft)	Locally[b] Significant	
				Aquifer	Aquitard
Alluvium & terrace deposits	Quaternary		<100		
Purisima Formation	Tertiary	Pliocene	200		
Santa Cruz Mudstone		Miocene	250		×
Santa Margarita Sandstone			450	×	
Monterey Formation			~1,200		×
Lompico Sandstone			400	×	
Vaqueros Sandstone[c]		Oligiocene	~2,000+		
Zayante Sandstone[c]					
Butano Sandstone		Eocene	>2,000	×	
Locatelli Formation		Paleocene	300?		
granitic rocks	pre-Tertiary				×
schist					

[a]Modified after Clark, 1981.
[b]South of Zayante fault, east of Ben Lomond fault, and west of Carbonera Creek.
[c]Not apparent south of Zayante fault.

Figure 5-7 is a schematic cross section depicting the general structural relation of locally significant aquifers and aquitards in the study area. The Santa Margarita Sandstone is hydrogeologically important within each subarea, whether as the primary aquifer, a leaky shallow aquifer, and/or prime recharge area. The Lompico Sandstone is of equal or greater importance as an aquifer in the Pasatiempo, Camp Evers, and Scotts Valley areas. Where present, the Monterey Formation forms a major aquitard between these sandstones. Relatively new, deep municipal wells have encountered deeper sandstone units interpreted as Butano Sandstone and possibly other formations. Some wells include screened intervals within zones interpreted as Locatelli Formation. Alluvial deposits are generally thin or of limited areal extent and do not constitute productive aquifer zones, but are important with regard to recharge and conveying groundwater discharge to stream baseflow.

The geologic formations listed above and mapped in Figure 5-6 are described below from youngest to oldest (with the exception of schist which has no relevance to the identified subareas).

5.2.1.1 Alluvium and Terrace Deposits

Mapable bodies of alluvium underlie a portion of the San Lorenzo River valley floor adjacent to the Quail Hollow area and portions of Bean and Carbonera creeks in the Mission Springs, Camp Evers, and Scotts Valley areas. In each case the alluvium abuts–and may be significantly derived from–eroded exposures of Santa Margarita Sandstone. Although generally too shallow to contribute directly to wells, the alluvium may facilitate hydraulic communication between the sandstone aquifer and stream channel. As such, alluvium directly east of the San Lorenzo River is included as part of the Quail Hollow subarea.

A broad body of shallow alluvium associated with an ancestral drainage pattern extends across the Camp Evers area, portions of which convey recharge into the directly underlying Santa Margarita and Lompico sandstone aquifers.

Superficial terrace deposits are mapped on benches adjacent to streams and along the crest of the southern Pasatiempo area.

5.2.1.2 Purisima Formation

The Purisima Formation is a regionally important aquifer where it thickens east of Carbonera Creek. In the study area, however, it occurs as relatively minor eroded remnants less than 200 ft thick that cap the ridges separating area streams.

5.2.1.3 Santa Cruz Mudstone

Directly underlying the Purisima Formation, the Santa Cruz Mudstone extends more broadly across the area's ridges. Locally less than about 250 ft thick, the mudstone is many thousands of feet thick in other parts of the county. The low-permeability mudstone limits direct rainfall recharge. Soils overlying both the mudstone and Purisima Formation retain sufficient moisture to support forest evapotranspiration. Runoff from the mudstone may percolate into adjacent exposures of Santa Margarita Sandstone. The Santa Cruz Mudstone does not confine groundwater within the underlying Santa Margarita Sandstone because the sandstone tends not to be fully saturated.

5.2.1.4 Santa Margarita Sandstone

One of the region's most productive aquifers, the Santa Margarita Sandstone is a fine- to coarse-grained, moderately sorted, and poorly consolidated arkosic sandstone containing gravel and cobble lenses. Drillers' logs commonly identify it as "white sand." The formation generally becomes more consolidated with depth and is cemented where fossiliferous. It reaches a regional maximum thickness of about 450 ft in the Quail Hollow and Olympia areas, although some of its thickness has been removed by quarrying.

The Santa Margarita Sandstone was deposited onto an eroded, irregular surface of mostly Monterey Formation within an ancient tidal seaway. Productive wells are partly explained by the inferred distribution of a broad band of high energy, coarse-grained deposits between Scotts Valley and the coast west of Santa Cruz (Phillips, 1981; Figure 5-6). The formation's highest permeabilities and most productive wells are associated with these deposits, which extend across most of the groundwater subareas addressed here.

5.2.1.5 Monterey Formation

The Monterey Formation consists of an upper sandy siltstone that grades downward into a mudstone. In some areas its total thickness exceeds 2,000 ft. The formation's relatively low permeability helps support water-table conditions in the overlying Santa Margarita Sandstone while at the same time confining groundwater in the underlying Lompico Sandstone. Where the Monterey Formation is absent in southeastern and eastern Scotts Valley, the two sandstones are in direct contact and difficult to distinguish.

The upper siltstone contains interbeds of fine- to medium-grained sandstone that range up to several tens of feet thick. Such layers yield groundwater to some Scotts Valley area wells, although often of poor water quality. The formation also yields water to wells where it is both highly fractured and overlain by exposed sandstone recharge area (e.g., LCWD wells in the northern Quail Hollow area). The test bore for SLVWD monitoring well MW-B did not encounter productive zones within the upper 600 ft of Monterey Formation underlying Quail Hollow.

5.2.1.6 Lompico Sandstone

The Lompico Sandstone is a fine- to medium-grained arkosic sandstone ranging up to approximately 400 feet thick. It is typically finer grained, more cemented, and less permeable than the Santa Margarita Sandstone. However, the two sandstones are difficult to distinguish, both lithologically and hydraulically, where the Monterey Formation is absent. Moderately deep sections of sandstone that were previously interpreted to be Santa Margarita Sandstone are now recognized as Lompico

Sandstone (Cloud, 2001). Cloud (2001) also recognized shalely subunits within the Lompico Sandstone, which result in multiple zones of at least partial confinement within the formation.

5.2.1.7 Vaqueros and Zayante Sandstones

The Vaqueros and Zayante sandstones are widely exposed north of Zayante fault, where they have a stratigraphic thickness of about 3,000 ft[11], and appear to be stratigraphically absent south of the fault. These rocks are juxtaposed with Butano Sandstone across the fault to the south. The potential for groundwater movement across the fault is uncertain. Wells with municipally significant yields have not been associated with the Vaqueros or Zayante sandstones.

5.2.1.8 Butano Sandstone

The Butano Sandstone is an arkosic sandstone with siltstone interbeds and a stratigraphic thickness of about 5,000 ft (Clark, 1981). It appears to be at least 2,000 ft thick where exposed south of the Zayante fault. Previous studies did not identify the Butano Sandstone as a significant aquifer (e.g., Akers and Jackson, 1977). Relatively new and deep municipal wells in the north Scotts Valley area, however, have encountered productive aquifer zones below the expected bottom of the Lompico Sandstone (e.g., SV-3B & -7). This deep unit is interpreted to be a section of Butano Sandstone at least 600 ft thick (ETIC, 2006). Similarly, a new, deep well in the Mount Hermon area (MH-3) encountered sandstone beneath the expected depth of the Lompico Sandstone that may be Butano Sandstone.

The Santa Margarita, Lompico, and Butano sandstones are all arkosic, meaning they are derived from weathered and eroded granitic rock. As a result, the formations are sometimes difficult to distinguish where they are in direct contact. Additionally, it appears that drillers sometimes log these sandstones as “granite” due to their mineralogical similarities. For this reason, the Butano Sandstone may underlie the area more extensively than interpreted by previous studies.

5.2.1.9 Locatelli Formation

The Locatelli Formation is a sandy siltstone with a thin basal sandstone. As mapped and interpreted, it directly underlies the Lompico Sandstone from the southwestern slopes of the Pasatiempo area eastward beneath Camp Evers. This suggests a complete absence of Butano Sandstone beneath the southern limb of the Scotts Valley syncline in this area. Several wells in southern Scotts Valley have screened intervals at these depths. In north Scotts Valley, the Locatelli Formation has been inferred beneath about 600 ft of Butano Sandstone (ETIC, 2006).

5.2.1.10 Granitic Rocks

The study area is underlain by basement rock consisting of quartz diorite and granodiorite. Where sufficiently weathered and fractured, these rocks may be moderately permeable within shallow depths. However, the aquifer properties of granitic rocks are not significant within the study area. Granitic rock exposed along Carbonera Creek probably forms a partial barrier to groundwater flow.

5.2.2 Hydrogeologic Structure

The San Lorenzo Valley consists of three geologic terranes: 1) the exposed granitic basement rock of Ben Lomond mountain uplifted west of the Ben Lomond fault; 2) a thick, down-dropped sequence of sharply folded older Tertiary formations north of Zayante fault; and 3) south of Zayante fault and east of Ben Lomond fault, a thinner sequence of gently folded, younger Tertiary rocks uplifted on granitic basement (Figure 1-5).

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[11] i.e., the composite thickness of type sections defined by Clark (1981), which may overestimate actual thickness.

The subareas associated with SLVWD's groundwater sources lie within this third terrane, which is dominated by the Scotts Valley syncline. As mapped by Clark (1981), the syncline axis extends from Boulder Creek southeast through Scotts Valley (Figure 5-6). The synclinal fold is most developed in the Lompico Sandstone and Monterey Formation. Bedding within the Santa Margarita Sandstone and the buried erosional surface of the Monterey Formation dips more gently. The Santa Margarita Sandstone is thickest along the syncline axis, indicating that downwarping continued during deposition. These and other formations are draped over a structural high of granitic basement rock that forms the southeastern boundary of the Camp Evers subarea.

Clark (1981) estimated that vertical movement along the Ben Lomond fault has been about 500 ft, sufficient to offset the Lompico Sandstone where it occurs along both sides of the fault. North of the Zayante fault, formations have down-dropped several thousand feet relative to formations south of the fault. The Bean Creek fault is aligned with the east-west portion of Bean Creek where it cuts through exposed Monterey Formation between the Olympia and Pasatiempo subareas; the nature and significance of offset along this fault are uncertain. The sub-parallel pattern of streams flowing from north to south across Quail Hollow, Olympia, Missions Springs, and Scotts Valley suggests a major fracture pattern south of the Zayante fault.

5.2.2.1 Structural Contour Maps

Figures 5-8 and 5-9 are structural contour maps of the estimated bottom of the Santa Margarita Sandstone and top of the Lompico Sandstone, respectively. The contours are based on mapped contacts (Clark, 1981), previously constructed contour maps (Johnson, 2001; 2002; Todd, 2003; ETIC, 2006), and a review of more recently available well logs. Figure 5-10 shows the contoured thickness of the Monterey Formation, calculated as the difference between the elevation contours of the previous two maps.

The influence of the Scotts Valley Syncline is evident in all three maps. The sandstones are deepest and the Monterey Formation is thickest along the syncline axis. The Pasatiempo and Camp Evers subareas are located on the syncline's far southern limb whereas the other groundwater subareas overlie portions of both the northern and southern limbs of the syncline.

5.2.2.2 Hydrogeologic Cross Sections

Figures 5-11 through 5-14 present geologic cross sections A-A' through D-D'. These generally are consistent with the structural contours shown in Figures 5-8 and 5-9, although the geology has been modified slightly to be consistent with wells projected onto the line of section. The estimated groundwater surfaces shown on these cross sections are supported and discussed in Section 5.2.5.

Each cross sections reflects the structural influence of the Scotts Valley Syncline. In the Quail Hollow area, the bottom of the Santa Margarita Sandstone lies below 350 ft msl along the syncline axis, and reaches elevations of 800 and 1,200 ft msl at the far ends of the syncline's south and north limbs, respectively (see section A-A', Figure 5-11). The base of the sandstone appears to fall below 200 ft msl in a depression along the syncline axis west of Newell Creek (section C-C', Figure 5-13). The Lompico Sandstone occurs deep below the Quail Hollow area and is separated from the overlying Santa Margarita Sandstone by as much as 1,200 ft of Monterey Formation. The Lompico Sandstone that occurs on the flank of Ben Lomond Mountain west of the Ben Lomond fault appears juxtaposed against Monterey Formation east of the fault, limiting the opportunity for significant groundwater flow across the fault.

In the Olympia and Mission Springs subareas, the base of the Santa Margarita Sandstone lies below 150 ft msl within a large depression along the top of the Monterey Formation (Figure 5-8). As in the

Quail Hollow area, the Lompico Sandstone is deeply buried beneath the Monterey Formation across the Olympia and Mission Springs subareas (sections B-B' and C-C', Figures 5-12 and 5-13).

In the Pasatiempo and Camp Evers subareas along the syncline's southern limb, the Lompico Sandstone dips upward to shallow depths while the Monterey Formation thins and becomes absent (sections B-B' and D-D', Figures 5-12 and 5-14). The two sandstones are in direct contact along a band ranging from 500 to 2,500 ft wide that extends from the southwest corner of the Pasatiempo area, through the Camp Evers area, and into Scotts Valley (Figure 5-10). In the Pasatiempo subarea west of Hanson Quarry, Santa Margarita Sandstone fills a narrow trough along the top of the Monterey Formation, which may help explain the occurrence of Ferndale and Redwood springs (Figure 5-8).

5.2.3 Hydrogeologic Boundaries

SLVWD's groundwater resources occur within various hydrogeologic boundaries. The most common boundary occurs where exposed aquifer formations have been truncated by erosion. In the absence of underlying rock of significant permeability, little groundwater flow may continue beyond these boundaries, causing groundwater to discharge to springs and streams. The Santa Margarita Sandstone has been removed by erosion along the circumference of nearly the entire area except where it continues south of Pasatiempo and appears to pinch out beneath younger formations east of Scotts Valley. The Lompico Sandstone has been removed by erosion north of its outcrop near the Zayante fault, along the western boundary of the Pasatiempo subarea, and beneath younger formations in the Pasatiempo, Camp Evers, and southern Scotts Valley areas. In northern Scotts Valley, however, it appears to extend eastward beneath younger formations.

Boundaries to groundwater flow also occur along major faults. The Lompico Sandstone is truncated by the Ben Lomond fault where buried beneath younger formations east of Quail Hollow. Exposed Butano Sandstone is bounded by the Zayante fault along the north. The potential for groundwater flow across these faults is limited by the sandstones' offset and juxtaposition with less permeable rock, as well as the occurrence of low-permeability fault gouge that typically occurs within fault zones.

The subarea hydrogeologic boundaries may be summarized as follows:

Quail Hollow: Groundwater within the Santa Margarita Sandstone aquifer of the Quail Hollow area is nearly isolated with the exception of flow into adjoining river alluvium along the west and through a minor isthmus of sandstone that extends east to the Olympia subarea across Zayante Creek. Groundwater that leaks into the upper Monterey Formation, such as induced by pumping wells (e.g., the LCWD wells), remains within the subarea. The Lompico Sandstone, given its great depth beneath the Monterey Formation, is of little hydrogeologic significance in the Quail Hollow subarea (or the Olympia and Mission Springs subareas; Figure 5-10).

Olympia: The Olympia subarea boundary occurs where the Santa Margarita Sandstone has been removed by erosion along the north, west, and southwest. The aquifer continues east into the Mission Springs subarea and southeast into the Camp Evers subarea.

Pasatiempo: The western and southwestern boundaries of the Pasatiempo subarea occur where both the Santa Margarita and Lompico sandstones have been truncated by erosion. The sandstones dip down to the northeast, away from this boundary, limiting the likelihood of springs and groundwater outflow. Some groundwater may leak outward through the underlying Locatelli Formation. The northern boundary occurs where Santa Margarita Sandstone has been eroded away along Bean Creek, coinciding with the occurrence of Ferndell, Redwood, and other springs. The continuity of the underlying Lompico Sandstone across the Bean Creek fault to the north is uncertain, and perhaps unimportant given its roughly 600-ft depth beneath the Monterey Formation at the fault. Groundwater flow across the southern boundary is limited by the subsurface pinching-out of the Lompico Sandstone over a structural high of granitic rock. Rather, groundwater discharges to Eagle and Powder Mill creeks and a small tributary to Carbonera Creek. Both sandstones are continuous to the east and northeast into the Camp Evers subarea. Along the northeast boundary, shallow groundwater drains to Dufours Creek, tributary to Bean Creek (Figure 5-5).

Camp Evers: The Santa Margarita and Lompico sandstone aquifers underlying the Camp Evers alluvial plain are continuous with all four adjacent subareas: Pasatiempo, Olympia, Mission Springs, and Scotts Valley. A granitic structural high forms a low-permeability boundary along the southeast side of Camp Evers. As with the Pasatiempo area, the significance of the Bean Creek fault as a boundary for the north-dipping Lompico Sandstone is uncertain.

Mission Springs: The Mission Springs subarea is also fully continuous with its four adjacent subareas, and bounded on the north where the Santa Margarita Sandstone has been truncated by erosion.

Scotts Valley: The remainder of the Scotts Valley area is continuous with the Mission Springs and Camp Evers subareas and relatively unbounded otherwise given that deep wells completed in the Lompico and Butano sandstones in northern Scotts Valley may influence groundwater flow over a wide area, ranging north at least to the Zayante fault and east into the Branciforte Creek watershed.

5.2.4 Aquifer Properties

Reasonable estimates of aquifer properties help explain and predict conditions in the groundwater subareas that supply SLVWD wells. Relevant properties include the following:

Transmissivity is the capacity of a unit-width of aquifer to transmit water through its entire saturated thickness as a function of the hydraulic gradient. Transmissivity equals the effective horizontal hydraulic conductivity of an aquifer (see below) multiplied by its saturated thickness. Groundwater flow is a product of the transmissivity, the hydraulic gradient, and the aquifer width perpendicular to the direction of flow. Transmissivity may be estimated directly from well-test data. This report expresses transmissivity in units of feet squared per day (ft^2/day); another common unit is gallons per day per foot (gpd/ft).

Hydraulic conductivity is the proportionality constant between the rate of groundwater flow and the hydraulic gradient (i.e., transmissivity normalized for aquifer thickness). In this case, groundwater flow is defined as the hydraulic conductivity multiplied by the hydraulic gradient and the cross-sectional area of flow. Hydraulic conductivity tends to be much greater horizontally than vertically because of the layering that occurs within most geologic units. The units of hydraulic conductivity used in this report are feet per day (ft/day).

The degree of ***aquifer confinement*** greatly influences the groundwater response to pumping. A confined aquifer is fully saturated and pressurized below a low-permeability layer (i.e., an aquitard). In this case, changes in groundwater pressure do not affect aquifer thickness or transmissivity. In the case of an unconfined aquifer, saturated thickness and transmissivity vary with the height of the water table. Semi-confined conditions occur where an aquifer is fully saturated beneath an aquitard, but the aquitard leaks (e.g., in response to the downward gradients induced by deep wells). Perched groundwater conditions exist where a shallow, water-table zone occurs locally above a deeper, regional water table, separated by an aquitard and less than fully saturated conditions.

Storativity (or storage coefficient) is the volume of water released from an aquifer per unit surface area, per unit decline in hydraulic head (a dimensionless ratio). Under fully confined conditions, this is entirely a function of the compressibility of water and the aquifer matrix. The compressibility of water alone is responsible for a storativity of approximately 1×10^{-7} per vertical foot of aquifer. Thus, a 100-ft thick confined aquifer has a storativity of at least 1×10^{-5}. Under semi-confined conditions, the effective storage coefficient is influenced by aquitard leakage and typically ranges between 0.001 and 0.01.

Specific yield is the storage coefficient under water-table conditions. It represents the volume of water that drains from a unit volume of saturated, unconfined aquifer as a result of gravity. Values typically range from 0.01 to 0.25 (i.e., 1 to 25 percent), somewhat less than aquifer porosity.

For a given rate and duration of pumping, a well's depression of the piezometric surface (i.e., drawdown cone) is determined primarily by aquifer transmissivity and storage coefficient. In the case of a confined or leaky aquifer, the cone of depression remains above the top of the aquifer, representing a change in groundwater pressure but not saturated aquifer volume. In the case of an unconfined aquifer, the water table is drawn down, diminishing the volume of saturated aquifer. Other factors being equal, the diameter and depth of a pumping well's drawdown cone are influenced by the relative magnitude of aquifer transmissivity and storage coefficient as follows:

Aquifer Condition	Storage Coefficient	Trans-missivity	72-hr Drawdown Cone	
			Diameter	Depth
Confined	Small	Low	Large	Deepest
		High		Moderately Shallow
Un-confined	Large	Low	Small	Moderately Deep
		High		Shallowest
Leaky	Moderate	Low	Moderately Small	Deep
		High		Shallow

For a given set of aquifer properties, the diameter and depth of the drawdown cone increases with increasing pumping rate or duration, except that the drawdown cone of a leaky aquifer stabilizes after a relatively short period of time.

The following table provides aquifer property estimates for the groundwater subareas based on previous interpretations of well-test data (Tables 5-1c & -3c; Johnson, 2000, 2001a, 2001b). Groundwater conditions tend to be unconfined in the Santa Margarita Sandstone and leaky in the Lompico Sandstone, although conditions vary from unconfined to confined in the latter. Test data for wells screened in the Butano Sandstone (e.g., SV-3B & -7A) were not available for review.

Hydro-geologic Unit	Subarea		Trans-missivity (ft^2/day)	Tested Saturated Thickness (ft)	Hydraulic Conduc-tivity (ft/day)	Storage Coefficient (dimensionless): Specific Yield	Storage Coefficient (dimensionless): Storativity
Santa Margarita Sandstone	Quail Hollow	range	400 - 1,500	40 – 120	2 - 40	0.12 - 0.20	d
		average[a]	700	90	6+	0.18	
	Olympia	range	2,000 - 4,000	118 – 155	13 - 34	0.17 - 0.25	d
		average[a]	2,500	130	20	0.20	
	Camp Evers[b]	max	≥6,000	60	>100	0.18	d
Monterey Formation	Olympia[c]	range	50 - 500	150 – 270	0.05 – 3	0.01 - 0.03	1E-5 - 0.005
		average[a]	e	e	0.15	e	e
Lompico Sandstone	Pasatiempo, Camp Evers, Scotts Valley	range	300 - 2,500	175 – 430	1 – 7	0.04 - 0.08	1E-5 - 0.02
		average[a]	2,000	400	5	0.06	e

[a]Interpreted representative average.
[b]Watkins-Johnson groundwater remediation site.
[c]Plum Valley site.
[d]Non-applicable given unconfined conditions.
[e]Variable as a function of aquifer conditions.

Observations drawn from the above summary that are relevant to understanding the behavior of the groundwater system include the following:

- The transmissivity of the Santa Margarita Sandstone aquifer in portions of the Olympia area (~2,500 ft^2/day) is up to several times greater than the sandstone's transmissivity in the Quail Hollow subarea (~700 ft^2/day), consistent with the greater hydraulic conductivity and saturated thickness (Figure 5-15) of the sandstone in the Olympia subarea.
- The Santa Margarita aquifer is consistently unconfined with a specific yield generally approaching 20 percent.
- Although atypical, the very high hydraulic conductivity of the Santa Margarita Sandstone tested at a remedial site near Camp Evers indicates the occurrence of high permeability zones within the aquifer, typically near its base.
- Where occurring at relatively shallow depths, the hydraulic conductivity of the Lompico Sandstone is within the lower range of values for the Santa Margarita Sandstone. Because of its relatively large thickness, however, the transmissivity of the Lompico Sandstone (~2,000 ft^2/day) is similar to a typical Santa Margarita Sandstone transmissivity.
- Estimated storage coefficients are consistent with semi-confined to confined conditions in the Lompico Sandstone aquifer of the Pasatiempo, Camp Evers, and Scotts Valley areas.
- Where deeply buried, the Lompico and Butano sandstones are expected to be fully confined and have transmissivities considerably lower than where the sandstones occur at relatively shallow depths (e.g., at SVWD wells TW-19, SV-3B, & SV-7A).
- Deep aquifer zones within the Locatelli Formation also appear confined, but have relatively little significance relative to the sandstone aquifers.
- The Monterey Formation contains permeable sandy subunits, such as interpreted at well SV-9 in Camp Evers (Cloud, 2006). The relatively low significance of these zones is demonstrated by the dramatic declines in SV-9 production and water quality that coincided with the dewatering of 150 ft of overlying Santa Margarita Sandstone since the 1980s.

5.2.5 Groundwater Occurrence, Movement, and Storage

For each groundwater subarea, this section describes the aquifer conditions (e.g., confined, unconfined, or leaky), the pattern of groundwater flow, and the estimated volume of groundwater storage.

Figure 5-15 presents contours representative of both the estimated water table and the production-zone piezometric surface during recent years. These contours are based on previously prepared maps (Johnson, 2001; 2002; Todd, 2003; ETIC, 2007) and recent water-level data. The water table contours also are informed and constrained by the topography and elevations of perennial streams and springs. The orientation of multiple production-zone piezometric surfaces deep within the Lompico and Butano sandstones differs substantially from the water table, but is poorly known away from a few monitored production wells. Profiles of the estimated water table and piezometric surface are shown in cross sections A-A' through D-D' (Figures 5-11 through -14).

Figure 5-16 presents contours of the average saturated thickness of the Santa Margarita Sandstone estimated for recent years. These contours represent the difference between the estimated water table and bottom of the Santa Margarita Sandstone as depicted in Figures 5-15 and 5-8, respectively. Groundwater storage is estimated as the saturated aquifer volume multiplied by the assumed aquifer porosity.

Although groundwater is always moving, it is though of as stored water because of its slow velocity. Estimates of groundwater storage do not represent extractable volumes of water, especially in the case of confined and semi-confined aquifers. The ratio of annual recharge to storage can be indicative of groundwater production sustainability during droughts, especially in the case of unconfined aquifers.

Section 5.4 evaluates the supporting groundwater level data in greater detail. Groundwater quality is described broadly in this section and more thoroughly in Section 5.5. The groundwater discharges described below are accounted for in the groundwater budgets presented in Section 5.6.

5.2.5.1 Quail Hollow Subarea

The Quail Hollow groundwater resource occurs within the Santa Margarita Sandstone under unconfined conditions. The water table mimics the topography as a result of (a) rainfall recharge that mounds beneath the area's hills and ridges and (b) groundwater discharge to springs and streams (Figure 5-15). As a result, the water table has a saddle-like shape, descending from north and south along the limbs of the Scotts Valley Syncline (cross section A-A', Figure 5-11), and descending to streams and springs to the east and west (cross section C-C', Figure 5-13). The sandstone tends not to be saturated at the far, up-folded ends of the syncline limbs. Perennial streams and springs are generally an expression of the water table. The groundwater surface flattens but maintains a similar shape during drought conditions (Johnson, 2001).

The pattern of groundwater flow is perpendicular to the water-table contours. Groundwater moves toward the center of Quail Hollow from the north and south, toward springs and streams to the east and west, and toward pumping wells. A groundwater divide separates flow east toward Zayante Creek from flow west toward Newell Creek, the San Lorenzo River, and SLVWD wells. Groundwater discharges directly from the aquifer into Newell Creek, and from adjacent valley-floor alluvium into the San Lorenzo River. Under drought conditions, groundwater flows beneath portions of Newell Creek toward the river.

Quail Hollow springs occur where the water table intersects the ground surface. Most area springs occur where the sandstone pinches out west of Zayante Creek, forcing groundwater mounded above the Monterey Formation to emerge. From north to south, springs along the far east side of Quail Hollow include Quail Hollow Circle, Azalea, Olympia Circle, McHenry, and Arcadia springs. Each of these springs has contributed to local domestic water supplies. The ponds at Quail Hollow Ranch also are spring-fed. Except for McHenry Spring (30 to 300+ gpm), few springflow measurements are available. Diversions from Azalea Spring are sold as bottled water.

Rough estimates of the average contribution of Quail Hollow groundwater to stream and spring baseflow are as follows: 1.5 cfs (700 gpm) to Newell Creek; 1.1 cfs (500 gpm) to the San Lorenzo River; and 2.1 cfs (900 gpm) to Zayante and Lompico creeks and their tributary springs (Johnson, 2001 and 2003).

Average annual production from SLVWD's Quail Hollow wells is equivalent to the continuous production of about 200 gpm (Table 5-1b). Whereas SLVWD's wells are toward the center of the subarea, many residential wells occur along the aquifer perimeter where the sandstone's saturated thickness is limited, thus requiring well completions into the underlying Monterey Formation. These residential wells are typically capable of producing 1 to 20 gpm.

Groundwater discharging to springs and wells from Quail Hollow is generally of good quality with very low concentrations of total dissolved solids. Nuisance concentrations of some water quality constituents are discussed in Section 5.5.

Groundwater leakage from the sandstone aquifer into the underlying Monterey Formation is probably limited to that which is induced by local pumping. LCWD wells along Quail Hollow's northern ridge each produce up to 50 gpm from fractured Monterey Formation.

Groundwater in the Lompico Sandstone is confined deeply beneath Quail Hollow, is probably of poor water quality, and has little if any interaction with shallow aquifer zones in the Santa Margarita Sandstone and upper Monterey Formation.

Saturated Santa Margarita Sandstone underlies about 1,100 acres of the Quail Hollow area; has an average and maximum thickness of about 60 and 120 ft, respectively; and an approximate volume of nearly 70,000 AF (Figure 5-16). Assuming a porosity of about 20 percent, total groundwater storage in the sandstone aquifer averages nearly 14,000 AF. By one estimate, groundwater storage in the sandstone aquifer fluctuated about ±2,500 AF during the 1984-2000 climatic cycle (±18 percent of average total storage), with no net change in groundwater levels (Johnson, 2001). SLVWD's Quail Hollow groundwater model, which represents both the sandstone and underlying Monterey Formation, simulated a groundwater storage fluctuation of approximately ±5,000 AF during that same period (again with little net storage change; Johnson, 2003). This suggests that the formations underlying the sandstone aquifer have some significance with regard to groundwater storage.

5.2.5.2 Olympia and Mission Springs Subareas

Similar to Quail Hollow, groundwater occurs under unconfined conditions within the Santa Margarita Sandstone aquifer of the Olympia and Mission Springs subareas (see cross sections B-B' & C-C', Figures 5-12 & -13). Although partially overlain by Santa Cruz Mudstone and Purisima Formation, the Santa Margarita Sandstone is not fully saturated and groundwater remains unconfined. The sandstone is unsaturated to the north and southeast along the outer limbs of the syncline (Figure 5-16). Additionally, the base of the sandstone rises to the west such that the sandstone is mostly eroded along Zayante Creek. As a result, the saturated aquifer is not in direct contact with lower Bean Creek or any of Zayante Creek, except where a small isthmus of sandstone connects to Quail Hollow. The Santa Margarita Sandstone aquifer extends south beneath Bean Creek into Camp Evers and east beyond Mission Springs into Scotts Valley, before appearing to pinch-out in the vicinity of Carbonera Creek.

Groundwater in the Olympia and Mission Springs subareas is recharged by rainfall and runoff percolation, especially where the Santa Margarita Sandstone is exposed. The direction of groundwater flow is generally from the north and northeast to the south and southwest (Figure 5-15). The groundwater gradient is relatively gentle across the southern half of these subareas due to (a) high aquifer transmissivity, (b) structural containment within the synclinal depression, and (c) the spread of the Camp Evers pumping depression into southern Mission Springs.

Groundwater movement is primarily toward (a) the gaining reaches of Bean Creek and its tributaries downstream of Ruins Creek, (b) SLVWD's Olympia wells and other wells serving local water needs, and (c) the Camp Evers pumping depression centered south of Bean Creek. The groundwater contribution to Bean Creek baseflow downstream of Scotts Valley has been estimated to total nearly 4 cfs (1,700 gpm), of which a significant portion originates from the Olympia and Mission Springs subareas (Johnson, 2002).

The combined average annual production of SLVWD's Olympia wells is equivalent to a continuous 260 gpm (Table 5-1b). Other wells serve individual residences and the Mission Springs Conference Grounds. The quality of groundwater in the Olympia Santa Margarita Sandstone aquifer is generally good, although upward leakage from the Monterey Formation is suspected to contribute high iron and manganese (see Section 5.5).

As in Quail Hollow, Lompico Sandstone groundwater is confined deep beneath the Monterey Formation, is likely of poor quality, and has little interaction with shallow aquifer zones. Pumping depressions formed in the deep Lompico and Butano sandstone aquifers of central and northern Scotts Valley may extend beneath Mission Springs. However, little downward leakage is expected given the Monterey Formation's greater than 500-ft thickness west and north of Bean Creek (Figure 5-10).

Saturated Santa Margarita Sandstone occurs beneath an estimated 2,000 or more acres of the combined Olympia and Mission Springs area. The estimated average and maximum saturated thickness is 130 and 250 ft, respectively, and the approximate volume of saturated aquifer is 280,000 AF (Figure 5-16). Assuming an aquifer porosity of 20 percent, total groundwater storage is roughly 56,000 AF, of which about 52 percent (29,000 AF) occurs within the Olympia subarea. The saturated aquifer continues east into portions of Scotts Valley, however this study does not estimate its volume east of Bean Creek. Past fluctuations in groundwater storage within the Olympia and Mission Springs subareas are difficult to estimate from available data. A long-term groundwater level decline of nearly 1 ft/yr is apparent in SLVWD's longest operating and most heavily pumped well, Oly-2. However, such a trend is less apparent in the monitored former production well, Oly-1 (see Section 5.3). An expanded groundwater monitoring network is needed to better define fluctuations and trends in the groundwater storage of the Olympia subarea.

5.2.5.3 Pasatiempo Subarea

The Pasatiempo subarea is underlain by a broad groundwater mound that is sustained by rainfall recharge into more than 1,000 acres of exposed Santa Margarita Sandstone (Figure 5-15). Former SLVWD wells Paso-1 through Paso-5 all produced at least partially from the unconfined Santa Margarita Sandstone in the Pasatiempo area. SLVWD no longer produces from this aquifer because (a) it has been largely dewatered along the eastern flank of the subarea in response to the Camp Evers pumping depression, (b) it has yielded groundwater with significantly elevated nitrate concentrations, and (c) SLVWD established deeper wells that produce an adequate groundwater quantity and quality from the underlying Lompico Sandstone.

Since 1990, groundwater levels in the Santa Margarita Sandstone have been relatively stable within the structural trough that extends north along the top of the Monterey Formation (Figure 5-8), as evidenced by the monitoring record for Paso-6-MW2 (see Section 5.4). The saturated sandstone is as much as 100 ft thick within this trough, making it an effective collector of recharge from across a large portion of the Pasatiempo subarea, where the saturated thickness is generally less than 50 ft. Based on the saturated-aquifer isopach map provided in Figure 5-16, the estimated volume of groundwater storage in the Pasatiempo Santa Margarita Sandstone is less than 3,000 AF (Figure 5-16).

Groundwater discharge from this aquifer-filled trough contributes to Mount Hermon's Ferndell and Redwood springs (mapped features on the USGS Felton quadrangle). Ferndell Spring discharges 20 to 150 gpm and Redwood Spring discharges 10 to 80 gpm. The water quality of these springs has been impaired by septic-tank leachate. Groundwater discharges to Dufour Creek along the northeast Pasatiempo boundary at an average rate of roughly 100 gpm, and may derive partially from Camp Evers perched groundwater. Along the south, Pasatiempo shallow groundwater discharges to Eagle and Powder Mill creeks, tributaries to the San Lorenzo River.

SLVWD's current Pasatiempo wells produce groundwater from the Lompico Sandstone where it directly underlies (a) the Monterey Formation at well Paso-6 and (b) the Santa Margarita Sandstone at Paso-7 (see cross sections B-B' & D-D', Figures 5-12 & -14). Well-test analyses indicate that the Lompico Sandstone's productive aquifer zones are replenished by leakage from the overlying Santa

Margarita Sandstone. This leakage must pass through the Monterey Formation, where present, and the uppermost units of the Lompico Sandstone. Leakage may be facilitated by fractures associated with the structural trough. Since 2001, production from SLVWD's Pasatiempo wells has averaged about 250 gpm on a continuous basis (Table 5-1b).

MHA wells MH-1 and MH-2 are located 400 to 600 ft northwest of Paso-6 and also produce from the Lompico Sandstone underlying the Monterey Formation. These wells exhibit a more confined-aquifer response than does Paso-6 (Johnson, 2001). About 2,000 ft north of Paso-6, MHA's recently constructed MH-3 is screened in both the Lompico Sandstone and a deeper, unidentified sandstone (section B-B', Figure 5-12). The combined annual production of MHA wells has averaged about 120 gpm on a continuous basis since 2001 (Table 5-3b).

Production wells associated with Hanson Quarry are screened in various aquifer zones underlying the Pasatiempo subarea (Table 5-3a). The operating quarry used groundwater at an average continuous rate of about 200 gpm, of which a significant portion repercolated into shallow aquifer zones. Current use for quarry reclamation is considerably less.

Groundwater flow within the Lompico Sandstone is predominantly toward SLVWD and MHA production wells, and east and northeast toward the Camp Evers pumping depression. As discussed further in Section 5.4, static groundwater levels in SLVWD's two active Pasatiempo wells have declined about 130 ft since 1991, an average decline of about 8 ft/yr. The Lompico Sandstone aquifer remains fully saturated where semi-confined at Paso-6, whereas at Paso-7 the Lompico Sandstone's saturated thickness appears to have diminished. The lowered groundwater levels result from (a) the gradient needed to induce leakage from overlying zones, (b) the combined groundwater production of SLVWD and MHA (and formerly Hanson Quarry), and (c) the gradient imposed by groundwater outflow to the Camp Evers pumping depression.

The water quality of the Santa Margarita and Lompico sandstone aquifers in the Pasatiempo subarea is generally good with low mineral concentrations (see Section 5.5). The generally similar water-quality of the two aquifers is consistent with the interpretation that groundwater in the Lompico Sandstone is derived largely from Santa Margarita Sandstone leakage. The quality of water produced from former, relatively shallow SLVWD wells (Paso-3, -4, & -5) reflected contamination from local wastewater disposal.

The nearly 2-square-mile Pasatiempo subarea has roughly 3,000 AF of groundwater storage in the exposed Santa Margarita Sandstone, most of which occurs in the structural trough leading to Ferndell and Redwood springs (Figure 5-16). The volume of groundwater within the Lompico Sandstone underlying the Pasatiempo subarea may approach roughly 10,000 AF assuming an average effective saturated thickness of 200 ft and a porosity of 6 percent. However, much of this occurs within deep, semi-confined and confined zones, and thus cannot be considered operable storage available for use during drought. Groundwater pumping has reduced groundwater storage by one to several thousand acre-feet in areas where the Lompico Sandstone has become less than fully saturated.

5.2.5.4 Camp Evers

Developed aquifer zones within the Camp Evers subarea include the largely dewatered Santa Margarita Sandstone, the Lompico Sandstone, and sandstone interbeds within the Monterey and Locatelli formations. The Santa Margarita Sandstone directly overlies the Lompico Sandstone across much of southern Camp Evers, similar to the Pasatiempo subarea. The two sandstones are separated by an increasing thickness of Monterey Formation across the northern half of Camp Evers (Figure 5-10; cross sections C-C' and D-D', Figures 5-13 & -14). Groundwater within the Santa Margarita Sandstone is unconfined whereas groundwater within deeper units tends to be partially to fully confined.

Groundwater originating from recharge, aquitard leakage, and subsurface inflow from adjoining subareas flows radially inward into the Camp Evers pumping depression (Figure 5-15). The influence of pumping wells on the pattern of groundwater flow is demonstrated by the control and interception of contaminant plumes by several of the major production wells (e.g., MWd-2, SV-9, & -10; ETIC, 2007).

Groundwater levels within the Camp Evers pumping depression have declined as much as 150 ft since 1980. As a result, the Santa Margarita Sandstone is completely dewatered within much of the area. Groundwater levels are currently within the Lompico Sandstone at elevations below 325 ft msl near the pumping depression's center. Cemented zones within the Santa Margarita Sandstone and possibly alluvium appear to perch or mound shallow groundwater in areas of northern Camp Evers and southern Mission Springs, which may help sustain Bean Creek baseflow despite the underlying pumping depression (Johnson, 2002).

SLVWD operates well MWd-2 in the Camp Evers area. This well draws from the Lompico Sandstone and produced at an average continuous rate of about 35 gpm during the past year (Table 5-1b). SVWD's Camp Evers wells have produced at a combined average rate of about 240 gpm since 2000 (Table 5-3b). SV-9 appears to draw from sandstone interbeds in the Monterey Formation whereas SV-10 and SV-10A produce from the Lompico Sandstone. Additional users of Camp Evers groundwater include the Spring Lakes, Vista Del Lago, Valley Gardens, and Montevalle developments, and groundwater remediation operations.

The natural quality of Camp Evers groundwater is good, with slightly higher concentrations of total dissolved solids than in the Quail Hollow, Olympia, and Pasatiempo subareas. However, Camp Evers groundwater has been significantly impacted by chemical releases from several facilities. Additionally, the influence of poor quality groundwater originating from the Monterey Formation has increased as groundwater levels have fallen.

Johnson (2002) estimated that groundwater storage in the Santa Margarita Sandstone aquifer declined by 7,000 to 8,000 AF in the Camp Evers and Pasatiempo subareas since the 1980s, most of which was associated with the Camp Evers pumping depression. Probably less than 2,000 AF of groundwater storage remains within the Santa Margarita Sandstone in the Camp Evers area (Figure 5-16).

Within the nearly 1-square-mile Camp Evers subarea, the volume of groundwater in the Lompico Sandstone is roughly 8,000 AF, assuming an average saturated thickness of 250 ft and a porosity of 6 percent. Groundwater pumping has reduced storage by as much as 2,000 AF in areas where the Lompico Sandstone appears to have become unconfined (Johnson, 2002). The Camp Evers area also draws on groundwater stored in adjacent subareas.

5.2.5.5 Scotts Valley

Although SLVWD does not operate wells in the remainder of the Scotts Valley area, conditions there have the potential to influence groundwater resources elsewhere. The Santa Margarita Sandstone pinches out toward the eastern margin of Scotts Valley and is largely dewatered in the vicinity of pumping depressions associated with active SVWD production wells. In central Scotts Valley, wells SV-11A and SV-11B produce a combined average of about 350 gpm from the Lompico Sandstone confined beneath up to 100 ft or more of Monterey Formation. In northern Scotts Valley, wells SV-3B and SV-7A produce a combined average of nearly 600 gpm from both the Lompico and Butano sandstones where they are confined beneath 500 ft or more of Monterey Formation (see section D-D', Figure 5-14). Groundwater produced from these relatively deep zones is more mineralized than groundwater from shallow aquifer zones elsewhere in the area.

The SVWD Scotts Valley wells are assumed responsible for relatively large and deep depressions in the piezometric surface (Figure 5-15). This is because of increased aquifer confinement and lower aquifer transmissivity where the Lompico and Butano sandstones are deeply buried (Figure 5-14). Pumping levels are as deep as 100 ft below sea level (SV-7A). Static water levels have declined more than 100 ft within the central Scotts Valley pumping depression (wells SV-11A & -11B) and about 200 ft in the northern Scotts Valley depression (SW-3B & -7A). Although the deep-aquifer piezometric surface is poorly documented away from these wells, the two pumping depressions probably overlap and may influence groundwater conditions in Camp Evers and eastern Mission Springs.[12] These deep pumping depressions induce widespread leakage from shallower zones. Directions of groundwater flow into and through these deep zones is expected to differ from the pattern of flow indicated by the estimated water table contours (Figure 5-15). The volume of groundwater within these deep aquifers, and the leaky zones overlying them, is probably many tens of thousands of acre-feet.

5.3 Infrastructure and Operations

This section describes SLVWD's groundwater-production infrastructure and operations. Section 7.1 provides a more complete description of system-wide storage, distribution, and operations.

5.3.1 Production Wells

For more than twenty years SLVWD has operated three groups of production wells, referred to as the Quail Hollow, Olympia, and Pasatiempo wellfields. Each wellfield currently has two active production wells. The Mañana Woods supply wells in Camp Evers became SLVWD's fourth location of groundwater production in 2006.

Figures 5-17 through 5-20 present profiles illustrating the geology, construction, and representative water levels of SLVWD's active and former production wells. This information is also summarized in Table 5-1. A description of the location and above-ground conditions of these well sites was provided in Section 5.1.

All of SLVWD's active wells were drilled using reverse rotary methods and constructed with 12-inch diameter stainless steel casing and wire-wrap well screens (except MWd-2, which has a 10-inch casing).

The wellfield descriptions presented use the below use the terms "maximum monthly rate of production" and "available drawdown." These are defined as follows:

Maximum instantaneous rate of production–a function of well construction, pump size, system back pressure, and initial water levels; probably not sustainable on a long-term basis.

Maximum monthly rate of production–highest rate of recorded monthly production, as ranked in Table 5-8. Assumed to represent a well's effective peak rate of potential production under sustained demand and relatively ideal conditions (e.g., high initial water levels). Expressed in this section in units of gallons per minute (i.e., maximum volume pumped in a calendar month divided by the number of minutes in the month).

Available drawdown is the difference between a well's static (i.e., non-pumping) water level and the lowest desirable or practical pumping water level. Maintaining pumping water levels above the top of a well's screened interval is desirable, whereas maintaining water levels above the pump's suction intake is essential. Pumping levels drawn down below the top of a well's screens

[12] Simulations using a calibrated, defensible groundwater model would aid the interpretation of the deep piezometric surface.

cause (a) diminished production and (b) cascading water and water aeration, the latter of which accelerates physical and chemical wear on the well and pump assembly. Pumping levels drawn below the top of a well's screens suggests that water levels have declined since the well was constructed and/or that the aquifer is being highly stressed.

A well's available drawdown is limited ultimately by the depth of its pump suction intake. Pumps are often set between or below a well's screened intervals so as to allow continued pumping during low water-level periods. It is not preferable to place a well's pump directly opposite its screens unless the pump is suitably shrouded. Increasing available drawdown by constructing a well to some depth below the bottom of an aquifer may result in diminished water quality, as may occur with wells drilled into the top of the Monterey Formation. Available drawdown, aquifer properties, groundwater quality, and the local water balance constrain production more than the infrastructure associated with the groundwater supply.

5.3.1.1 Quail Hollow

SLVWD constructed its active Quail Hollow wells, QH-4A and QH-5A, in 2000 and 2001. These were same-site replacements for SLVWD's 30-year old QH-4 and QH-5. The ground surface elevations of the two well sites differ by 80 ft, but the elevation range of each well's single screened interval are about the same, approximately 375 ft msl ±30 ft, near the base of the Santa Margarita Sandstone (Figure 5-17).

QH-4A is a 260-ft deep well with a 125-ft sanitary seal and 70 ft of well screen. QH-5A is a 174-ft deep well with a 112-ft seal and 40 ft of screen. Since 2004, static and pumping water levels have averaged respectively about 175 and 195 ft below ground surface (bgs) in QH-4A and 110 and 135 ft bgs in QH-5A.

Each Quail Hollow well is equipped with a 20 horse power (hp) submersible pump. Under optimal conditions and efficiency, the maximum instantaneous rate of production is approximately _ gpm for QH-4A and _ gpm for QH-5A.

Maximum monthly production rates for QH-4A and QH-5A are 360 and 185 gpm, respectively, which both occurred in July 2005, for a combined maximum monthly pumping rate of 545 gpm (Table 5-8). Production is often restricted by limited available drawdown, however, given that (a) pumping water levels are typically about 10 ft or more below the top of well screens and (b) minimum pumping levels have been only 13 and 4 ft above the suction intakes of QH-4A and QH-5A, respectively.

Prior to 1995, SLVWD operated wells at three additional locations, i.e., QH-3, -7, and -8. The saturated aquifer thickness at QH-3 was limited due to a locally shallow depth to the top of the Monterey Formation. Production from QH-7 and QH-8 was constrained by relatively poor aquifer characteristics.

SLVWD plans to construct a third Quail Hollow production well in order to provide needed redundant capacity. Well sites in the vicinity of Quail Hollow Ranch are being considered in order to minimize potential interference with the existing two active wells.

5.3.1.2 Olympia

SLVWD's two active Olympia wells, Oly-2 and Oly-3, were constructed in 1981 and 1990, respectively. Both wells are 310 ft deep and have a 160-ft sanitary seal and 60 hp pump (Figure 5-18).

Oly-2 has two 20-ft intervals of well screen near the base of the Santa Margarita Sandstone. Its average static and pumping water levels are approximately 190 and 220 ft bgs. Under optimal conditions and efficiency, its maximum instantaneous rate of production is approximately _ gpm. Its maximum monthly production rate is nearly 500 gpm, which occurred during July and August of drought years 1987-89.

Oly-3 has a single 70-ft screened interval near the base of the Santa Margarita Sandstone. Its static and pumping water levels average about 200 and 235 ft bgs; its maximum instantaneous rate of production under optimal conditions and efficiency is about _ gpm; and its maximum monthly production rate approaches 430 gpm (which occurred in July 1993 and August 1996). The maximum monthly production rate for Oly-2 and Oly-3 combined was 775 gpm in August 1994.

The pumping water levels of both of the active Olympia wells are sometimes drawn down below the top of their respective well screens. Minimum pumping water levels have been within 36 and 16 ft of the Oly-2 and Oly-3 suction intakes, respectively. SLVWD constructed Oly-3 as a replacement well for the much older Oly-1 located on an adjacent parcel.

5.3.1.3 Pasatiempo

SLVWD constructed its two active Pasatiempo wells in 1990 (Figure 5-19). SLVWD constructed Paso-6 as an essentially same-site replacement for Paso-1 and Paso-5, and constructed Paso-7 as a replacement for Paso-3 and Paso-4, which were located 2,000 to 3,000 ft east. The well screens of both wells are within the Lompico Sandstone.

Paso-6 is 790 ft deep with a 381-ft sanitary seal. Its three screened intervals have a total combined length of 100 ft. Its maximum instantaneous rate of production under optimal conditions and efficiency is about _ gpm. Since 2004, the average static and pumping water levels have been about 420 and 445 ft bgs, respectively, its maximum instantaneous pumping rate has been approximately _ gpm, and it has achieved maximum monthly production rates above 280 gpm. Minimum pumping levels have remained more than 100 ft above the top of the well screens and are 250 ft above the suction intake since the pump was set deeper in 2003.

Paso-7 is 540 ft deep, has a 260-ft deep sanitary seal, and two screened intervals with a total combined length of 90 ft. Its maximum instantaneous rate of production under optimal conditions and efficiency is about _ gpm. Since 2004, its static and pumping water levels have respectively averaged about 385 and 455 ft bgs, its maximum instantaneous pumping rate has been about _ gpm, and its maximum rate of monthly production has been generally less than 250 gpm. Its peak rate of monthly production occurred in August 1992 at 280 gpm. Minimum pumping water levels have come within 11 ft of the *bottom* of the well screens and 20 ft of the pump intake.

The maximum combined monthly production rate for MHA wells was approximately 200 gpm in June 2004. Since 2004, average pumping levels in MH-1 and MH-2 have been >400 ft bgs, 100 to 200 ft below the top of well screens. In contrast, new production well MH-3 appears to have several hundred feet of available drawdown given that its screened intervals are below –100 ft msl.

5.3.1.4 Camp Evers

The Mañana Woods Mutual Water Company constructed MWd-2 in 1988 as a replacement for its original well constructed 100 ft away at the same site in 1969. MWd-1 had experienced corrosion problems possibly associated with the large decline in Camp Evers water levels that began in the 1980s. MWd-1 is maintained as a backup well and has an instantaneous capacity of 70 gpm.

MWd-2 is 380 ft deep, has a 160-ft deep sanitary seal, and has three screened intervals totaling 100 ft that span the Santa Margarita and Lompico sandstone contact (Figure 5-20). During 2006-07, its static and pumping water levels averaged 170 and 230 ft bgs, respectively, and its maximum monthly pumping rate was 60 gpm. Its instantaneous pumping capacity is 130 gpm. Water levels are commonly drawn down below the upper screened interval.

Two other Camp Evers municipal wells, SV-9 and SV-10, were constructed in 1980 and recently have had pumping levels about 150 ft below the top of their screens (Table 5-3b). These wells and replacement well SV-10A have maximum monthly pumping rates ranging between 200 and 500 gpm. Since 2000, these wells have had a combined maximum monthly pumping rate of 630 gpm, about ten times the maximum monthly rate for MWd-2.

5.3.1.5 Scotts Valley

Although separate from SLVWD's water supply system, SVWD operates wells within a shared groundwater basin and has a major influence on both local and regional groundwater conditions.

The current average pumping levels of SVWD's two active wells in central Scotts Valley, SV-11A and SV-11B, are roughly 50 ft below the top of their well screens. Average pumping levels for the two deep wells in northern Scotts Valley (SV-3B and -7A) are within ±50 ft of sea level as a result of pumping drawdowns exceeding 250 ft (Table 5-3b). Since 2000, these central and northern Scotts Valley well pairs have combined maximum monthly pumping rates of approximately 700 and 1,100 gpm, respectively.

5.3.2 Operations, Treatment, Conveyance, and Surface Storage

SLVWD's wells run automatically on demand as determined by water levels in certain storage units.

Modest changes in discharge can be achieved manually by valving to adjust back pressure. For example, pumping rates can be reduced as water levels approach the suction intake; however, no power is saved.

If possible, a pump can be set deeper in a well to increase available drawdown. In the case of Paso-7, the suction intake is now set as low as possible for this well (Figure 5-19).

The replacement of each well's pump and motor can be reasonably expected about every three years. However, earlier replacement is often required because of worse than expected wear resulting from power-supply irregularities and non-optimal pumping conditions. Downtimes associated with pump and motor replacement range from 3 to 5 days, or 1 to 2 days in an emergency.

Table 5-6 and Figure 5-21 present average and maximum monthly groundwater production for SLVWD's Quail Hollow, Olympia, and Pasatiempo wells. Table 5-7 expresses average monthly production as a percent of annual production.

See Section 7.1 for more complete documentation of SLVWD's overall distribution system, including the groundwater contribution to system losses.

5.3.2.1 North System

Production from SLVWD's Quail Hollow wells is chlorinated at the wellhead as it is pumped directly into the distribution system. In addition to chlorination, production from the Olympia wells is treated at the wellhead for high iron and manganese by the addition of poly-phosphate. This method of treatment is suitable for combined iron and manganese concentrations of less than 3 mg/L; SLVWD Olympia well maximum is 1.7 mg/L (see Table 5-12). Because this treatment does not actually remove these minerals, the water still may have a metallic taste and the minerals may precipitate from the water once heated.

Chlorinated groundwater is pumped directly into SLVWD's northern distribution system under pressure from 60 horse power (hp) pumps in each Olympia well, 20 hp Quail Hollow well pumps, and the two Quail booster pumps (700 gpm capacity). The Quail Hollow and Olympia wells are within the system's Quail pressure zone and operate in response to water levels in the Quail tanks (capacity of 0.45 MG or 1.4 AF).

The need for additional groundwater production is indicated when storage in the Quail tanks declines below a threshold level. Production from the Olympia wells is constrained by the capacity of a segment of 6-inch pipeline along Quail Hollow Road that leads most directly to the Quail tanks. Section 7.1 provides more complete documentation of the distribution system.

Since 2001, QH-4A and QH-5A respectively produce about 55 and 45 percent of total Quail Hollow production; Oly-2 and Oly-3 respectively produce about 60 and 40 percent of total Olympia production; and, the Quail Hollow and Olympia wells respectively produce about 45 and 55 percent of North System groundwater production (Table 5-5).

The Quail Hollow wells operate regularly throughout the dry season beginning when stream diversions decline to below Northern Service Area demand. The Olympia wells operate when demand exceeds the combined production of stream diversions and the Quail Hollow wells; thus, their use is more seasonal and coincident with periods of peak demand (Figure 5-21).

Based on long-term averages, summer groundwater production (July–September) accounts for approximately 40 percent of annual production from the Quail Hollow wells and 50 percent of annual production from the Olympia wells. Winter (January–March) production is 2 percent or less of annual production during relatively wet periods and up to 12 percent during drought periods (Table 5-7).

5.3.2.2 South System

Production from SLVWD's Pasatiempo wells is pumped directly into SLVWD's South System under pressure from the 60 hp pumps in Paso-6 and Paso-7. At the wellhead this production is chlorinated and treated with poly-phosphate for iron. SLVWD Pasatiempo well maximum iron concentration is 1.1 mg/L (see Table 5-13). As the sole water source for the South System, these wells operate throughout the year, and continuously during periods of high demand. Storage in the South System is limited to three tanks with 0.3 MG (0.9 AF) total capacity.

Since 2001, Paso-6 and Paso-7 produce about 60 and 40 percent, respectively, of total Pasatiempo groundwater production (Table 5-5). On average, summer groundwater production (July–September) accounts for approximately 35 percent of the annual total and winter production (January–March) accounts for about 16 percent. Total production varies relatively little between wet and dry periods (Table 5-7). Compared to the North System, the higher percentage of winter production reflects that groundwater is the South System’s sole water supply.

5.3.2.3 Mañana Woods

Groundwater pumped from MWd-2 is treated for volatile organic compounds using a series of three granular activated carbon (GAC) adsorption beds. The treatment capacity is 36.5 MG/yr, with a maximum daily rate of 0.17 mgd and a peak hourly rate of 130 gpm. The lead adsorption bed must be replaced three to nine times per year.

The Mañana Woods water system currently remains separate from SLVWD’s South System.

5.4 Historical Groundwater Production and Water Levels

SLVWD's monthly record of groundwater production is complete back to 1984, with partial records back to 1972 (Table 5-4). SLVWD's record of groundwater levels extends back to the 1960s, and is most complete since the mid-1970s.

Tables 5-4 through 5-9 provide the following summaries of the groundwater production record for each SLVWD well and group of wells:

Table 5-4: The annual production record expressed in (a) calendar years and (b) water years

Table 5-5: Average and maximum rates of production for recent, long-term, and drought periods
Table 5-6: Average and maximum production values for each month of the year
Table 5-7: Average production by month and quarter expressed as percents of annual production
Table 5-8: Ranked annual production
Table 5-9: Highest ranked monthly production

SLVWD's complete monthly pumping record is appended in Table A-2. Table 5-10 provides the annual pumping record for selected other groups of wells in the area.

Figure 5-22 is a plot of SLVWD's annual groundwater extractions and stream diversions since 1984. This plot illustrates how groundwater extractions from the North-System wells, especially the Olympia wells, help compensate for the variability of annual stream diversions.

Characterizing average rates of groundwater production is complicated by several factors, including:

- Variations in the demand for groundwater in response to a climatic cycle lasting 20 years or more.
- Changes in the configuration of SLVWD's active wells, as influenced by basin conditions and well-replacement cycles lasting 15 to 30 years.
- Arbitrary downtimes related to maintenance that are unrelated to groundwater availability.
- A trend of increasing water demand (average increase of roughly 30 AF/yr (10 MG/yr) for 30 years; Figure 2-3b), along with changes in the temporal and spatial patterns of water use.

For example, an average of the past several years (e.g., 2001-06) reflects current patterns and rates of demand but does not adequately account for periodic dry years. A period-of-record average (e.g., 1984-2006) better represents the full climatic cycle but is inconsistent with current infrastructure and water demand. To assess these factors, Tables 5-4 through 5-7 provide averages for long-, mid-, and short-term periods, with and without including partial-record years.

Recent average groundwater production from SLVWD wells is approximately as follows (from Table 5-5):

	Northern Area		Southern Area		SLVWD Total
	Quail Hollow	Olym-pia	Pasa-tiempo	Mañana Woods	
AF/yr	325	420	410	65	1,220
MG/yr	105	135	135	20	395

During drought periods, groundwater production in the Northern Service Area is about 10 to 15 percent greater than average due to reduced stream diversions. Whereas in the Southern Service Area, conservation causes production to be 10 to 20 percent lower than average during extended drought periods (Table 5-5).

Approximate annual minimum and maximum production may be summarized as follows (Tables 5-4 & -10):

	Northern Area				Southern Area			
	Quail Hollow		Olympia		Pasatiempo		Mañana Woods	
	min.	max.	min.	max.	min.	max.	min.	max.
AF/yr	110	515	150	550	205	445	55	75
MG/yr	35	170	50	180	65	145	18	25
(year)	(1998)	(1980)	(1986)	(2001)	(1984)	(2002)	(2006-07)	(1999)

The recent decline in Mañana Woods annual production reflects (a) wet conditions during WYs 2005-06 and (b) the metering of each service connection since annexation by SLVWD.

Recent average groundwater production by selected other major users in the area is as follows (Table 5-10):

	Mt. Hermon Assoc.	Hanson Quarry (pre-2004)	SVWD			
			Camp Evers	Scotts Valley	N. Scotts Valley	Total
AF/yr	195	350	380	590	950	1,920
MG/yr	65	115	125	190	310	625

Other groundwater producers include Spring Lakes, Vista Del Lago, Montevalle, Valley Gardens, and several remediation sites, all of which are in the Camp Evers area.

Figure 5-23 shows the historical and geographic distribution of groundwater production among the various SLVWD, SVWD, and other selected wells in the area. As is evident in this figure, annual groundwater production by SLVWD's Quail Hollow and Olympia wells has cycled up and down since the 1980s, whereas groundwater production by SLVWD's Pasatiempo wells has trended upward. The majority of SVWD's groundwater production has shifted northeastward as Scotts Valley water demand increased and groundwater levels declined.

Figure 5-24 presents representative groundwater level hydrographs for the subareas of groundwater of production portrayed in Figure 5-23. Since the 1980s, static groundwater levels have trended both up and down in the Quail Hollow production wells, declined slightly in the Olympia production wells (~1 ft/yr), and declined significantly within SLVWD's Pasatiempo production wells (6 to 8 ft/yr) and SVWD's Camp Evers and Scotts Valley production wells (~6 to 15 ft/yr). Pumping levels in SVWD's north Scotts Valley wells have declined at even greater rates (>20 ft/yr).

Figure 5-25 superimposes representative static and pumping groundwater level hydrographs for each SLVWD well group. As described above and in more detail in the following subsections, Quail Hollow and Olympia groundwater levels exhibit little or no long-term trend, whereas Pasatiempo groundwater levels have been trending significantly downward.

SLVWD measures static water levels by shutting the well off and allowing the water level to recover for roughly one hour or less. These levels may represent incomplete recovery and/or the influence of other pumping wells.

5.4.1 Quail Hollow

Figure 5-26 presents static groundwater level hydrographs for SLVWD's Quail Hollow production and monitoring wells. The production wells draw from the center of a groundwater mound between Newell and Zayante creeks in the unconfined Santa Margarita Sandstone aquifer (see section C-C', Figure 5-13, and Figure 5-15). Groundwater levels respond to rainfall recharge, pumping wells, and groundwater discharge to area springs and streams, and tend to peak in April after 90 percent of average water-year rainfall has fallen. The static groundwater levels of pumping wells fluctuate 20 to 40 ft annually and as much as 80 ft throughout a climatic cycle. In addition to the variable influence of groundwater pumping and recharge, these fluctuations are accentuated by (a) the lack of significant groundwater inflow into the area and (b) the constant loss of groundwater outflow to surrounding springs and streams. Nevertheless, there is no apparent long-term decline in Quail Hollow groundwater levels.

Figure 5-27 compares static and pumping groundwater levels for QH-4/-4A and QH-5/-5A with annual pumping and rainfall records and the top of each well's screened interval. Pumping levels fall below the top of well screens during more than half of all years, especially during drought, which diminishes production rates and increases wear on the pumps and wells. Groundwater levels and groundwater production both declined during the 1987-94 drought. Groundwater levels fully recovered following the drought, helped in part by breaks in production during the replacement of both QH-4 and QH-5. Recent peak production (nearly 400 AF/yr or 130 MG/yr) is about equal to peak production from QH-4 and QH-5 prior to the 1987-94 drought, but less than total peak production when QH-3 and QH-8 were also active (>500 AF/yr or >165 MG/yr). The absence of a long-term decline in Quail Hollow groundwater levels suggests that long-term average production equal to or greater than 300 AF/yr (100 MG/yr) is sustainable.

SLVWD relies on its Quail Hollow wells during a greater portion of time than its Olympia wells, due in part to the more favorable quality of Quail Hollow groundwater (see Section 5.5). Also, years of peak Quail Hollow production have generally occurred during or immediately following average to wet periods. During dry years, when SLVWD relies most on production from groundwater storage, Quail Hollow production rates have declined due to falling water levels. Efforts to save more Quail Hollow groundwater for drought periods might be offset partially by increased losses to springs and streams. Strategies for optimizing Quail Hollow groundwater storage and production during expected climatic cycles can be explored using SLVWD's Quail Hollow groundwater model (Johnson, 2003). Distributing production to a third active well would reduce drawdown in the existing wells, help sustain production during sustained drought conditions, and possibly increase the sustainable average rate of production.

Recent water level and production data for LCWD’s wells in northern Quail Hollow were unavailable for review.

5.4.2 Olympia

Figure 5-28 compares (a) Oly-2 and Oly-3 static and pumping groundwater level records, (b) the top of their respective well screens, (c) annual pumping and rainfall records, and (d) static water levels for Oly-1, which has not been pumped significantly since 1991. These wells draw from unconfined Santa Margarita Sandstone near the western edge of a large body of groundwater stored beneath Lockhart Gulch, Ruins Creek, and the middle reaches of Bean Creek (see cross sections B-B' and C-C', Figures 5-12 & -13, and Figure 5-16). Because the aquifer is partially contained within a structural depression, the potential loss of groundwater storage to area streams is relatively low compared to Quail Hollow. Static levels monitored in Oly-1 have been relatively flat since the mid-1980s. This suggests that the slight long-term decline in Oly-2 and Oly-3 levels (~1 ft/yr) may reflect cumulative local drawdown rather than a widespread decline in Olympia groundwater storage. Pumping levels often fall below the top of well screens, which reduces rates of production and increases wear on the pumps and wells.

The static groundwater levels of Oly-2 and Oly-3 have fluctuated 10 to 40 ft annually, and nearly 70 ft during the period of record. Annual water-level fluctuations are relatively small considering that peak seasonal production is nearly twice that of SLVWD's Quail Hollow wells. This is consistent with the relatively high aquifer transmissivity of the Olympia area (see Section 5.2.4). During the 1987-94 drought, groundwater levels remained fairly constant while production ranged from about 300 to 500 AF/yr (100 to 165 MG/yr), indicative of the area’s favorable groundwater storage and relatively high transmissivity. Although highly variable from year to year, production from the Olympia wells has been trending upward by about 3 AF/yr (1 MG/yr), on average, indicating that these wells help satisfy the long-term increase in Northern Service Area water demand. Fairly stable Olympia groundwater levels suggest that long-term average production equal to or greater than 400 AF/yr (130 MG/yr) is sustainable.

5.4.3 Pasatiempo

As shown by the series of hydrographs presented in Figures 5-29 through 5-32, the water levels of SLVWD's Pasatiempo wells have a complex and varied history as influenced by multiple aquifer zones and proximity to other groundwater pumping in the Pasatiempo and Camp Evers areas.

Well Paso-2 is located several thousand feet south and southeast from SLVWD's other Pasatiempo wells (Figure 5-5) and has not operated significantly since the 1970s (Figure 5-29). Its relatively unvarying groundwater levels are mounded in a thin zone of Santa Margarita Sandstone over low-permeability basement rock.

Water levels recorded in Paso-1, Paso-4, and Paso-6-MW2 are representative of the Santa Margarita Sandstone aquifer near and east of the County Probation Center. Paso-5, also near the Probation Center, produced mostly from the Santa Margarita Sandstone but also from a thin zone at the top of the Lompico Sandstone beneath the Monterey Formation. Their combined record (Figure 5-29) indicates that the Santa Margarita Sandstone exposed across the top of the Pasatiempo subarea was substantially saturated prior to the early 1980s, especially following wet WYs 1982-83. Water levels then declined by as much as 80 ft through 1990, due in part to increasing production from the Santa Margarita Sandstone (e.g., from Paso-5) and the start of the 1987-94 drought. A slow water-level recovery began in 1991, rising about 30 ft or more by wet WY 1998. This recovery began before the end of the drought and appears related to a complete shift in production to the deeper Lompico Sandstone once Paso-6 and Paso-7 were constructed. The apparent lack of a full water-level recovery in the Santa Margarita Sandstone (i.e., to early-1980s levels) suggests that shallow groundwater, mounded above the Monterey Formation and other low permeability layers, leaks down to deeper aquifer zones from which Paso-6, Paso-7, and other area wells draw.

Former SLVWD well Paso-3 was near the Pasatiempo boundary with Camp Evers (Figure 5-5) in an area where the Santa Margarita Sandstone directly overlies the Lompico Sandstone (Figure 5-10). Although initially producing from both aquifers, Paso-3 water levels declined sharply after 1985, falling 150 ft by 1995 despite little or no production after 1990 (Figure 5-29). Water levels in Paso-6 and Paso-7 declined immediately in parallel with the trend evident in Paso-3 since 1985 (Figure 5-29). Since 1991, water levels in Paso-6 and Paso-7 have declined more than 120 ft.

Other Pasatiempo production wells constructed between 1985 and 1992 also targeted the Lompico Sandstone aquifer, including two MHA wells and a high-capacity well for the sand quarry. A significant portion of the quarry's water use percolated back into the ground, but did not necessarily replenish the deep aquifer zones from which it was pumped.

Total production from the Lompico Sandstone in the Pasatiempo area roughly doubled between the late 1980s and the early 2000s (Figure 5-29), resulting in fairly steady water level declines in all Lompico Sandstone wells (e.g., MH-2, Figure 5-29). Compared to more confined aquifer conditions at Paso-6, Paso-7 water levels declined sharply during the drought and rebounded more substantially in response the following wet WYs 1995-98. Paso-6 and Paso-7 water levels have stabilized during the past three years, partly in response to (a) the leveling off of SLVWD production, (b) reduced pumping during wet WYs 2005-06, (c) SLVWD's reallocation of some Paso-7 production to Paso-6 in order to comply with more stringent arsenic standards (see Section 5.5), (d) the end of quarry operations in 2004, (e) the shift of some MHA production to the new MH-3, and (f) reduced production from SVWD's Camp Evers wells. Paso-6 water levels have stabilized despite a production increase from generally less than 200 AF/yr prior to 2000 to more than 300 AF/yr recently. Conversely, Paso-7 water levels have stabilized partially in response to a production decrease from nearly 300 AF/yr during the 1990s to less than 150 AF/yr in recent years.

Figure 5-30 compares static and pumping groundwater level hydrographs for Paso-6 and Paso-7 with annual pumping and rainfall records, and the top of well screens. These wells draw from semi-confined Lompico Sandstone near the County Probation Center (see cross sections B-B' and D-D', Figures 5-12 & -14, and Figure 5-19). Static groundwater levels in Paso-6 and Paso-7 fluctuate about 10 to 30 ft annually, with long-term declines as discussed above. Pumping levels are 20 to 70 ft below static levels and remain above the top of well screens in Paso-6, but often fall below the top of well screens in Paso-7, which impacts production and increases wear.

Since 1984, production from SLVWD's Pasatiempo wells has trended upward by an average of approximately 11 AF/yr (3.5 MG/yr) and now total about 350 to 450 AF/yr (115 to 150 MG/yr). Meanwhile, total recorded pumping in the Pasatiempo, Camp Evers, and Scotts Valley areas increased by about 100 AF/yr (33 MG/yr) between the mid-1970s and the early 2000s, reaching a peak of more than 3,000 AF/yr (1,000 MG/yr) (Figure 5-32). Cessation of quarry pumping and reductions in municipal production during wet WYs 2005-06 have contributed to a recent stabilization of water levels. However, shallow zones may continue to dewater from the leakage needed to stabilize the deep, overlapping pumping depressions. Whether or not SLVWD's current rates of production from its Pasatiempo wells are sustainable under future average and drought conditions is uncertain.

5.4.4 Camp Evers

As shown in Figure 5-31, groundwater production by SVWD in the Camp Evers area increased substantially after construction of SV-9 and SV-10 in 1980. By the early 1990s, production by SVWD in Camp Evers was about 2.5 times greater than SLVWD production in Pasatiempo, and about 1.5 times greater than SLVWD and Mount Hermon Pasatiempo production combined. Similar to Paso-3, these wells initially produced from the Santa Margarita Sandstone as well as deeper zones. Water levels began declining steeply in SV-9 and SV-10 one to several years before Paso-3, falling as much as 180 ft by the late 1990s. These declines were roughly parallel to those in Paso-3, -6, and -7. SV-9 and SV-10 water levels stabilized after 1995, in part due to their gradually diminishing rates of production. Recent water levels in SLVWD's MWd-2 are similar to those of SVWD's Camp Evers wells (Figure 5-31).

The following observations suggest that production from SV-9 and SV-10 contributed to water level declines in SLVWD's Pasatiempo wells: (a) area water levels (e.g., Paso-3) had been relatively steady prior to the construction of SV-9 and SV-10; (b) the downward trend in area groundwater levels began in SV-9 and SV-10 first; (c) production from SVWD wells was substantially greater than SLVWD's Pasatiempo production; (d) the declining water level trends were all fairly parallel; and (d) water-level elevations in SV-9 and SV-10 always have been lowest in the area, inducing a regional gradient toward them. Pumping by the Spring Lakes, Vista Del Lago, Valley Gardens, and Montevalle developments, as well as various remediation sites, contributed to the creation of the Camp Evers pumping depression.

Pumping from SLVWD's Pasatiempo and Mañana Woods wells has averaged roughly 17 percent of total recorded production in the Pasatiempo, Camp Evers, and Scotts Valley areas. This percentage is smaller if production by other private wells is included. Although Pasatiempo and Camp Evers water levels appear to have stabilized in recent years, the water level history and long-term increase in total pumping suggest that additional water-level declines may occur as the regional aquifer continues to adjust to these conditions.

It is possible that Pasatiempo and Camp Evers groundwater levels may stabilize as a result of Hanson Quarry closure and reduced production from SV-9 and SV-10A. Although groundwater storage has been reduced significantly since the 1980s, groundwater gradients may now be sufficient to sustain groundwater flow to major pumping wells without significant further declines in water levels.

5.4.5 Scotts Valley

As shown in Figure 5-32, a pumping depression developed in the vicinity of SVWD's El Pueblo Yard in central Scotts Valley beginning in the mid-1980s. In this area, SVWD's older wells were screened in both sandstone formations (e.g., SV-3 and -7), whereas its newer wells are screened only in the Lompico Sandstone (e.g., SV-11). By 1995, water levels had declined approximately 150 ft as pumping from these wells roughly doubled in response to increased demand and drought. These declines were roughly parallel and reached similar minimum elevations as SVWD's Camp Evers wells, indicating that these pumping depressions may overlap within the Lompico Sandstone aquifer.

Since the early to mid-1990s, production from SVWD's newest wells in north Scotts Valley (SV-3B and -7A) has allowed significant reductions in production from its Camp Evers and central Scotts Valley wells (Figure 5-32). Production from deep aquifer zones in the Lompico and Butano sandstones in north Scotts Valley have accounted for 70 percent of total SVWD production, on average, since 1995. As a result, static water levels have declined about 250 ft, with pumping levels about 250 ft lower and nearly 100 ft below sea level. After recovering during the late 1990s, water levels in SVWD's central Scotts Valley wells began declining again despite reduced production. This suggests that the north and central Scotts Valley pumping depressions overlap.

5.5 Groundwater Quality

The quality of water pumped from wells typically represents a blend of multiple groundwater zones. This section summarizes SLVWD's groundwater quality record and discusses various constituents of concern. The quality of water delivered by the distribution system is addressed in Section 7.1.

Tables 5-11, -12, and -13 provide the general water quality records for SLVWD's Quail Hollow, Olympia, and Pasatiempo wells. These records are summarized in Table 5-14 and plotted in Figures 5-33 and 5-34. The overall mineral concentration, ionic water type, and constituents of concern for each well group may be summarized as follows:

Groundwater Subarea	SLVWD Wells	TDS (mg/L)	Water Type	Detected Constituents of Concern	Treatment (other than chlorination)
Quail Hollow	QH-4A & -5A	very low 70-130	calcium-bicarbonate	QH-5A: nitrate, trace TCE, MTBE	none
Olympia	Oly-2 & -3	moderate to moderately high 300-600	calcium-sulfate	iron, manganese, sulfate, TDS	phosphate, blending
Pasatiempo	Paso-6	very low ~100	calcium-bicarbonate	iron, arsenic	phosphate, blending
	Paso-7		sodium-bicarbonate	none	none
Mañana Woods	MWd-2	moderate 400	calcium-sulfate	benzene, MTBE, & trace of other gasoline compounds	GAC package plant

5.5.1 Quail Hollow

The low-TDS, calcium-bicarbonate groundwater produced from SLVWD Quail Hollow wells (<130 mg/L) reflects the aquifer flushing achieved by the area's high rate of rainfall recharge into mostly exposed Santa Margarita Sandstone. Historically, TDS concentrations have varied little (Figure 5-

33). A very slight upward trend may reflect upward leakage from the underlying Monterey Formation or the influence of septic tanks.

Nitrate concentrations trended upward in several of SLVWD Quail Hollow wells from the 1970s through the early 1990s (Figure 5-34a). HEA (1982) measured nitrate-plus-ammonia concentrations as high as 200 mg/L (as NO_3) in shallow groundwater downgradient of area leachfields, and predicted that nitrate concentrations would reach about 15 mg/L by the 1990s. Peak concentrations occurred during WY 1987 in all four SLVWD operating wells, ranging from 10 to 28 mg/L (compared to a maximum contaminant level [MCL] of 45 mg/L). Using a groundwater flow model, Johnson (1988) demonstrated that Quail Hollow nitrate concentrations were correlated to the number of septic tanks in each well's capture zone, and explained that peak concentrations may be associated with late-season, drought-year pumping. Nitrate concentrations have been fairly stable in recent years, averaging less than 3 mg/L in QH-4A (which has relatively few developed lots in its capture zone) and about 11 mg/L in QH-5A (Figure 5-34a). Concentrations have the potential to spike again to previous peak levels.

The solvent trichloroethylene (TCE) has been detected in groundwater pumped from QH-5 and QH-5A since 1994 (Figure 5-34b). Concentrations have been generally below the 5 μg/L MCL, with the exception of four samples in the late 1990s when a maximum of 11 μg/L occurred (coincident with reduced production prior to QH-5's replacement). Since 2001, concentrations have been below 1.3 μg/L and appear to be declining. The TCE probably originated from spills or septic-tank disposal of cleaning products by one or more local residences. Johnson (2001) estimated that a TCE spill of as little as 0.5 liter could account for the observed concentrations.

In 2006, the gasoline additive methyl tert-butyl ether (MTBE) was detected at concentrations up to 1.6 μg/L in seven monthly samples of QH-5A discharge. The California primary and secondary MCLs for MTBE are 5 and 13 μg/L, respectively. The MTBE may have originated from residential automobile maintenance and may be linked to the TCE source.

High iron concentrations sometimes occurred in groundwater pumped from SLVWD's former Quail Hollow wells (e.g., QH-3 & -8), but are not associated with its current wells (Table 5-11).

The now-closed Ben Lomond county landfill west of Newell Creek has been monitored as a source of groundwater contamination since the 1980s. Concentrations of volatile organic compounds (VOCs) have declined to mostly non-detectable levels in downgradient monitoring wells (Geosyntec, 2007). Although elevated mineral concentrations also have declined, iron concentrations remain very high in some area wells. CH2M HILL (1994) concluded that the Ben Lomond Landfill was not a potential source of contamination to SLVWD's wells east of Newell Creek.

Recent water quality information for LCWD wells was unavailable for review.

5.5.2 Olympia

Groundwater produced from SLVWD's Olympia wells is of a hard, calcium-sulfate type with moderate TDS concentrations and elevated concentrations of sulfate, iron, and manganese. TDS concentrations have been historically variable, ranging from below 300 to more than 600 mg/L, at times exceeding the recommended secondary drinking water standard of 500 mg/L (Figure 5-33).

After peaking near 600 mg/L in the mid- to late-1980s, Oly-2 TDS concentrations declined to less than 400 mg/L by 2001. Conversely, TDS concentrations in Oly-3 have risen from near 400 mg/L in 1991 to approximately 600 mg/L in recent years. These variations in TDS concentration reflect the opposing contributions of (a) low-TDS recharge from where the aquifer is exposed to the south and west (similar to Quail Hollow conditions) and (b) more mineralized groundwater from the large volume of groundwater storage beneath the Santa Cruz Mudstone to the north and east (see Section 5.2.5.2). About 300 ft apart, the two wells roughly split the radial groundwater flow into their essentially shared pumping depression. As such, Oly-2 receives low-TDS groundwater flow from the south and southwest and Oly-3 receives more mineralized groundwater from the east and northeast. Consistent with this interpretation, the TDS of Oly-2 began declining about the same time that Oly-3 became operational (Figure 5-33). A similar phenomenon was noted in Oly-1 when Oly-2 was constructed (Johnson, 1989).

The large volume and low piezometric gradient of groundwater stored in the Olympia subarea result in long groundwater residence times. This increases the water-quality influence of the overlying Santa Cruz Mudstone and underlying Monterey Formation. Groundwater influenced by the Monterey Formation (a) tends to have an elevated TDS concentration, (b) is generally hard, (c) has concentrations of iron and manganese in excess of recommended standards, and (d) may have poor odor and taste due to high sulfate.

Groundwater from SLVWD's Olympia wells has (a) concentrations of iron and sulfate that approach and sometimes exceed secondary drinking water standards (Figures 5-34d &f) and (b) manganese concentrations nearly always above the secondary standard (Figure 5-34e). In response, SLVWD introduces a poly-phosphate additive to the discharge at each wellhead to bring iron and manganese concentrations into compliance (see Section 5.3.2.1). These and other groundwater quality concerns (e.g., hardness, taste, and order) are also addressed through the blending that occurs in the Quail tanks and elsewhere in the system. The Olympia wells are not impacted by high nitrate, consistent with the small amount of development in the subarea.

5.5.3 Pasatiempo

As described in Section 5.2.5.3, Pasatiempo wells encounter groundwater under three aquifer conditions: (1) the relatively shallow water table aquifer in the Santa Margarita Sandstone (e.g., the former Paso-1), (2) the Lompico Sandstone aquifer semi-confined beneath the Monterey Formation (e.g., Paso-6), and (3) Lompico Sandstone directly beneath the Santa Margarita Sandstone (e.g., Paso-7). The TDS of the generally mixed-bicarbonate groundwater in all three aquifers is low to very low. This supports the interpretation that Lompico Sandstone groundwater is derived locally from groundwater leaked down from the overlying Santa Margarita Sandstone. Although maintaining low TDS, leakage that includes flow through the Monterey Formation (e.g., Paso-6) results in elevated concentrations of iron and arsenic.

The TDS concentrations of groundwater produced from SLVWD's Pasatiempo wells are similarly low and stable compared to the higher and more variable Olympia wells (Figure 5-33).

As shown in Figure 5-34d, concentrations of iron in groundwater produced from Paso-6 range up to 1 mg/L, typically exceeding the secondary standard of 0.3 mg/L. Similar to the Olympia wells, SLVWD introduces poly-phosphate into the flow at the Paso-6 wellhead in order to achieve compliance with the iron standard. Groundwater pumped from SLVWD's Pasatiempo wells does meet the secondary standard for manganese, however (Table 5-13).

The federal MCL for arsenic was lowered from 50 to 10 µg/L in 2006. During that year, arsenic concentrations in water produced from Paso-6 ranged from 6 to 11 µg/L, sometimes exceeding the MCL (Figure 5-34c). Compliance with the standard is achieved through blending with production from Paso-7, which has arsenic concentrations ranging from 1 to 3 µg/L.

Former SLVWD wells Paso-2, -3, and -4 encountered groundwater nitrate contamination from past wastewater disposal. SLVWD's current wells do not have high nitrate, consistent with locally sparse development and the presence of a semi-confining layers.

Water quality information for MHA's new, deep well, MH-3, was not available for review.

5.5.4 Camp Evers and Scotts Valley

Groundwater TDS concentrations in the Camp Evers area range from 100 to 1,000 mg/L. As sampled by SLVWD in 2007, groundwater produced from MWd-2 has a TDS of approximately 400 mg/L and acceptable concentrations of iron, manganese, nitrate, and arsenic. However, MWd-2 intercepts one or more VOC-contaminant plumes, as do other wells in the Camp Evers area (ETIC, 2007). Groundwater produced from MWd-2 is run through a granular activated carbon (GAC) treatment system to reduce VOC concentrations to below MCLs.

The following VOCs were detected in groundwater pumped from MWd-2 in 2007:

VOCs Detected in MWd-2 Prior to Treatment	2007	MCL
	(µg/L)	
benzene	5.8	1 primary
MTBE	37	5 secondary
		13 primary
ethylbenzene	0.1	300 primary
tertiary butyl alcohol	5.0	not established
toluene	0.6	150 primary

These chemicals derive from gasoline and its breakdown products. MWd-2's GAC treatment system was constructed and now operates through a settlement with by the responsible companies. This treatment system reduces contaminant concentrations to below MCLs. It is included in SLVWD's annexation of the Mañana Woods system.

The TDS of groundwater pumped from SVWD's SV-9 has been trending upward since the 1990s and now ranges from about 600 to 1,100 mg/L (ETIC, 2007), in part due to high sulfate. This suggests that the dewatering of the Santa Margarita Sandstone within the Camp Evers pumping depression has reduced leakage of good quality water down to SV-9's remaining production zone within the Monterey Formation. Also in the Camp Evers area, groundwater pumped from wells SV-10 and SV-10A have exceeded the secondary standards for iron and manganese consistently since 1999.

Groundwater produced from the Lompico Sandstone aquifer by SVWD wells SV-11A & SV-11B in central Scotts Valley periodically exceeds the MCL for arsenic, similar to Paso-6, and consistently exceeds secondary standards for iron and manganese (ETIC, 2007).

5.6 Groundwater Budget

This section estimates the balance of groundwater inflows and outflows from each subarea where SLVWD produces groundwater. The simplest expression of a water balance is:

$$\text{Inflows} - \text{Outflows} = \text{Change in Storage}$$

Inflows in excess of outflows result in increased storage; outflows in excess of inflows require withdrawals from storage. Additionally, changes in storage can affect rates of inflow and outflow, such as by causing available recharge to be induced or rejected (e.g., a lowered water table induces streamflow percolation).

Potential subarea groundwater inflows include (a) rainfall recharge, (b) applied-water recharge (i.e., deep percolation of irrigation, wastewater, system leaks), (c) streamflow percolation, and (d) subsurface inflow.

Groundwater outflows include (a) springflow, (b) stream baseflow, (c) pumping wells, (d) phreatophyte evapotranspiration, and (e) subsurface outflow into a neighboring subarea.

There is a wide degree of uncertainty associated with estimates of these components of the groundwater budget. Whereas SLVWD's metered wells provide an excellent record of groundwater production, there are no direct measurements of water-balance components such as rainfall recharge.

Rainfall recharge can be approximated using the following water balance:

$$\text{Rainfall} - \begin{matrix}\text{Storm}\\ \text{Runoff}\end{matrix} - \begin{matrix}\text{Evapotrans-}\\ \text{piraton}\end{matrix} = \begin{matrix}\text{Rainfall}\\ \text{Recharge}\end{matrix}$$

For example, the rainfall recharge that contributes to the average annual baseflow of the San Lorenzo River upstream of the USGS Big Trees gaging station may be estimated as follows (from Figure 3-16):

$$46 - 10 - 29 = 7 \text{ (in/yr)}$$

Average annual rainfall recharge is significantly higher in sandy areas with relatively low runoff and evapotranspiration (e.g., in the vicinity of SLVWD wells):

$$46 - 4 - 20 = 22 \text{ (in/yr)}$$

Conversely, a lower recharge estimate applies to clayey areas with higher runoff and evapotranspiration (e.g., soils over Monterey Formation):

$$46 - 14 - 30 = 2 \text{ (in/yr)}$$

Development tends to reduce rainfall recharge as a result of runoff and evaporation from impervious surfaces.

Applied-water recharge originates from (a) groundwater pumped from local wells (both SLVWD and private) and (b) water imported from SLVWD’s other sources (e.g., its stream diversions). The proportions of each vary considerably by location, season, and climatic cycle.

The subarea groundwater budgets discussed below are summarized in Figure 5-35. Recharge estimates include areas of exposed Monterey and Locatelli formations lying between each subarea boundary and the surrounding streams (referred to as “aquitard outcrop” in Figure 5-35). The following discussion of estimated subarea groundwater budgets is expressed in units of acre-feet only (for brevity).

5.6.1 Quail Hollow

The groundwater budget of the Quail Hollow area has been estimated by both conceptual model (Johnson, 2001) and simulations using a calibrated computer model (Johnson, 2003; 2005). Recharge from rainfall, applied water, and retained quarry runoff are the major sources of groundwater inflow. Groundwater outflow is mostly to springs, stream baseflow, and pumping wells (Figure 5-35).

Relatively minor inflows and outflows include: subsurface flows across Quail Hollow’s boundaries (see Section 5.2.3); channel percolation (minor because streams are generally gaining); and phreatophyte evapotranspiration. Estimates of these relatively minor components are within the ranges of uncertainty among the other, more significant budget terms.

Rainfall recharge averages 20 in/yr or more across exposures of Santa Margarita Sandstone and about 2 in/yr or less where the Monterey Formation is exposed, as estimated in the introduction to Section 5.6 above. In the Quail Hollow area, total recharge rates are somewhat higher as a result of applied-water recharge and retained quarry runoff. Applied water is estimated to contribute recharge of up to 2 in/yr in residential areas (Johnson, 2001). A similar volume of recharge (~200 ac-ft/yr) is estimated to result from runoff retention within Quail Hollow Quarry (Johnson, 2001; 2003). Total average annual recharge is approximately 3,900 AF/yr in the Quail Hollow subarea assuming effective recharge rates of (a) 23 in/yr across nearly 1,940 acres of exposed sandstone and alluvium and (b) 2 in/yr across roughly 1,300 acres of adjacent exposed Monterey Formation.

Based on an analysis of gaging records (Johnson, 2001) and model calibration (Johnson, 2003), Quail Hollow groundwater contributes a total of 3,500 AF/yr on an average annual basis to stream baseflow and springflow, distributed as follows: (a) 1,200 AF/yr to Newell Creek, (b) 800 AF/yr to Love Creek and the San Lorenzo River, and (c) 1,500 AF/yr to Lompico and Zayante creeks, including tributary springs and diverted springflow.

SLVWD and LCWD groundwater production is assumed to respectively average 330 (Table 5-5) and 70 (Johnson, 2001) AF/yr. Pumping by private wells has been estimated at less than 100 AF/yr (Johnson, 2001).

In summary, average annual Quail Hollow groundwater recharge is distributed among groundwater outflows approximately as follows:

Effective Net Recharge		Newell Creek Baseflow		San Lorenzo River & Love Creek Baseflow		Lompico & Zayante Creek Baseflow & Eastside Springs		SLVWD Pumping		LCWD Pumping		Other Pump-ing	
3,900	≈	1,100	+	800	+	1,500	+	330	+	70	+	≤100	(AF/yr)

The estimated balance of average inflows and outflows is consistent with the apparent lack of a significant long-term change in Quail Hollow groundwater storage (Section 5.4.1). Since 1984, Quail Hollow groundwater storage is estimated to have varied as much as 2,000 to 3,000 AF annually and 5,000 to 10,000 AF cumulatively during the past 20-year climatic cycle (Johnson, 2001; 2003).

5.6.2 Olympia

Inflows to the Olympia groundwater subarea include (a) rainfall recharge, especially across areas of exposed Santa Margarita Sandstone, (b) runoff percolation into sandy soils, (c) runoff retention in retired quarry pits, (d) applied-water recharge from sparsely distributed residences, and (e) streamflow percolation along Lockhart Gulch. Outflows include (a) pumping wells, (b) contributions to Zayante and Bean creek baseflow, and (c) possibly subsurface outflow toward pumping depressions in the adjacent Mission Springs and Camp Evers subareas (Figure 5-35). Johnson (1989) provided a detailed estimate of the Olympia subarea groundwater budget.

The Santa Margarita Sandstone is overlain by the Santa Cruz Mudstone and Purisima Formation across slightly more than half (55 percent) of the Olympia subarea (referred to as “mudstone cap” in Figure 5-35). The largest area of exposed sandstone, about 700 acres, occurs along the western and southwestern margin of the subarea. This area is overlain primarily by highly permeable Zayante soils (Table 3-11) and encompasses three sand quarries in various stages of closure (see Section 5.1.2). The fully reclaimed old Olympia quarry immediately west of SLVWD's Olympia wells retains runoff from upgradient drainage areas. Enhanced runoff percolation and reduced evapotranspiration are likely associated with the other two quarries to some degree. Runoff from upgradient exposures of mudstone and Purisima Formation has a high percolation potential once reaching the exposed sandstone, prior to reaching Zayante Creek.

Effective recharge rates are lower across the northern and eastern portion of the Olympia subarea because the sandstone is exposed only as a narrow band along the subarea boundary. Furthermore, the soils overlying these areas generally are not of the highly permeable Zayante series. Streamflow percolation may occur along Lockhart Gulch given that the regional water table is generally below the streambed elevation. However, perching layers may limit deep percolation. During dry periods, Lockhart Gulch is not a significantly gaining stream until approaching its confluence with Bean Creek. This baseflow may "ride over" perching layers known to occur locally within the sandstone (see Section 5.2).

Applied-water recharge is supplied by private wells and SLVWD's northern system along the western side of the Olympia subarea, and by private wells only along the eastern side. Thus, the effective recharge rate is slightly greater than rainfall recharge along the west and there is a small net loss from consumptive groundwater use along the east.

Olympia average annual recharge from rainfall, runoff, and applied water is estimated to equal approximately 2,000 AF/yr assuming the following effective recharge rates:

- Western and southwestern areas draining to lower Zayante Creek and Bean Creek:
  - 22 in/yr for 670 acres of exposed Santa Margarita Sandstone (mostly overlain by Zayante soils)
  - 15 in/yr for 220 acres of exposed Santa Cruz Mudstone and Purisima Formation (includes runoff percolation on adjacent sandy areas)
- Northern and eastern areas draining to upper Zayante Creek and Lockhart Gulch:
  - 12 in/yr for 160 acres of exposed Santa Margarita Sandstone (includes very little area of Zayante soil)
  - 5 in/yr for 780 acres of exposed Santa Cruz Mudstone and Purisima Formation (similar to the rate of recharge estimated for the Purisima Formation in the Soquel Creek watershed [Johnson and others, 2004]).
- Areas of exposed Monterey Formation lying between the sandstone outcrop and adjacent Zayante and Bean creeks: 2 in/yr across a total of 350 acres

The average annual contribution of Olympia groundwater to the baseflow of surrounding streams is estimated as follows:

- 500 AF/yr to Zayante Creek – portion of Zayante Creek's 2,000 AF/yr of average annual baseflow estimated from gaging records (Johnson,2001) (other 1,500 AF/yr from Quail Hollow; see Section 5.6.1).
- 750 AF/yr to Bean Creek – portion of approximately 2,700 AF/yr of total average annual baseflow estimated from gaging records (Johnson, 2002). Includes contribution from Lockhart Gulch. Groundwater may discharge partially from perched zones.

Since 2001, SLVWD has produced an average of 420 AF/yr from its Olympia wells.

Groundwater pumping by Mission Springs Conference Grounds and rural residences throughout the combined Olympia and Mission Springs subareas is estimated at roughly 300 AF/yr, split equally between the two subareas (for comparison, average annual groundwater production by Mount Hermon Association is about 200 AF/yr; see Section 5.6.4).

In response to the large pumping depression centered within Camp Evers, subsurface groundwater outflow to the adjoining Mission Springs and Camp Evers subareas is estimated at roughly 200 AF/yr. Both (a) groundwater discharge to stream baseflow and (b) subsurface outflow to adjoining subareas are assumed to occur based on the conceptualization of multiple groundwater zones and gradients, i.e., shallow perched zones, a water-table zone, and a semi-confined zone in the underlying Lompico Sandstone (Section 5.2.5.4).

In summary, a highly approximate groundwater budget for the Olympia subarea is as follows:

Effective Net Recharge		Zayante Creek Baseflow		Bean Ck & Lockhart Gulch Baseflow		SLVWD Pumping		Other Pumping		Sub-surface Outflow	
2,000	≈	500	+	750	+	420	+	150	+	200	(AF/yr)

This balance assumes no substantial ongoing net change in Olympia groundwater storage. The small, gradual water-level decline observed at SLVWD's Olympia production wells is assumed not to represent a widespread storage decline. Furthermore, declines in groundwater storage as a result of the Camp Evers pumping depression may have stabilized given that production from SVWD's SV-9 and SV-10A now averages nearly half of that during the mid-1980s to mid-1990s (Table 5-10 & Figure 5-30).

5.6.3 Mission Springs

Although SLVWD does not produce groundwater from within the Mission Springs subarea, this subarea is contiguous with the Olympia and Camp Evers subareas and contributes significantly to the overall groundwater budget. Groundwater inflows include rainfall and applied-water recharge; streamflow percolation along Lockhart Gulch on the west and Bean Creek on the east; and subsurface inflow from Scotts Valley along the east and possibly Olympia along the west. Groundwater outflows include pumping by the Mission Springs community and widely distributed rural residences, contributions to the baseflow of Bean Creek and its tributaries, and subsurface outflow to Camp Evers and Scotts Valley (Figure 5-35).

Similar to the eastern side of the Olympia subarea, the Santa Margarita Sandstone is overlain by younger, less permeable formations across more than half (57 percent) of its area and is exposed mainly within a narrow band encircling the subarea with only minor Zayante-soil coverage. Assuming average annual effective groundwater recharge rates of (a) 12 in/yr across 620 acres of exposed sandstone, (b) 4 in/yr across 820 acres of Santa Cruz Mudstone and Purisima Formation, and (c) nominal recharge within 360 acres of adjacent exposed Monterey Formation, the average annual recharge volume is approximately 900 AF/yr.

The estimated water table surface (Figure 5-15) indicates (a) a regional groundwater gradient into the Mission Springs subarea from Scotts Valley to the northeast and (b) gradients inward to an apparent extension of the Camp Evers pumping depression at the southern end of Mission Springs (Figure 5-15). Based on the rough balance of Mission Springs inflows and outflows presented below, a couple hundred acre-feet per year or more may flow into the subarea as groundwater from the adjacent Scotts Valley and Olympia subareas.

As discussed above for the Olympia subarea, streamflow percolation may occur along Lockhart Gulch where the streambed lies above both regional and perched water tables. More substantial streamflow percolation occurs along Bean Creek between the Mission Springs and Scotts Valley subareas. During non-stormflow periods, Bean Creek has a dry, broad, sandy channel that extends approximately 1.4 miles downstream from where it crosses onto the Santa Margarita Sandstone near Redwood Glen Camp (Johnson, 1976). Seasonal stormflow percolation along this reach has not been estimated but is likely substantial, and may contribute to both Mission Springs and Scotts Valley groundwater.

As discussed above, groundwater pumping in the Olympia and Mission Springs subareas is estimated to be roughly 300 AF/yr and about evenly split between the two subareas.

Also as described above, Bean Creek is estimated to gain approximately 2,700 AF/yr of average annual baseflow between the Ruins and Zayante creek confluences (Johnson, 2002). Based on the rough balance of subarea inflows and outflows discussed in this section, the Mission Springs contribution to the baseflow of Bean Creek and its tributaries is estimated to equal approximately 750 AF/yr.

Based again on a rough balance of subarea inflows and outflows, subsurface groundwater outflow from Mission Springs to Camp Evers and possibly Scotts Valley is estimated to be several hundred acre-feet per year. Most of this outflow occurs through the Santa Margarita Sandstone given that the Lompico Sandstone is deeply buried beneath 800 ft or more of Monterey Formation in the Mission Springs subarea (Figure 5-10).

In summary, a rough groundwater budget for the Mission Springs subarea is as follows:

Effective Areal Recharge	+	Channel Perco-lation	+	Sub-surface Inflow	≈	Bean Creek & Tributary Baseflow	+	Pumping	+	Sub-surface Outflow	
900		300				750		150		300	(AF/yr)

As with the Olympia subarea, there is an implicit assumption that groundwater storage is trending neither up nor down in the Mission Springs subarea. This assumes that the decline in groundwater storage associated with the Camp Evers pumping depression has stabilized as a result of reduced production from SV-9 and SV-10A. However, SVWD's shift in groundwater production from Camp Evers to central and northern Scotts Valley (Figure 5-31) may result in renewed groundwater storage losses as the Scotts Valley pumping depressions extend westward into Mission Springs.

5.6.4 Pasatiempo

Pasatiempo groundwater is replenished by rainfall and applied-water recharge. Groundwater outflows include pumping wells, springs, stream baseflow, and subsurface outflow (Figure 5-35). The Pasatiempo groundwater budget was estimated previously by Johnson (2002).

The Pasatiempo subarea is overlain mostly with Santa Margarita Sandstone and Zayante soils. Recharge rates vary, however, by landuse. About 30 percent of the area is undeveloped or lightly developed; 40 percent is residential; and 30 percent is quarry undergoing closure. The following table subdivides the area into six recharge zones and estimates average annual rates of rainfall and applied-water recharge for each, consistent with the information and analysis presented above and in Section 3:

Recharge Zone	Area	Rain-fall	Storm Runoff	Rain-fall ET	Rainfall Recharge		Applied-Water Recharge		Total Recharge	
	(ac)	(in/yr)			(in/yr)	(AF/yr)	(in/yr)	(AF/yr)	(in/yr)	(AF/yr)
Relatively undeveloped; outcrop: Santa Margarita Sandstone	340	44	4	20	20	567	0	0	20	567
Lompico Sandstone	82	44	8	26	10	68	0	0	10	68
Mount Hermon community*	120	44	8	24	12	120	6	60	18	180
Hansen Quarry (in closure)*	310	44	2	20	22	568	0	0	22	568
SLVWD-served residential area*	348	43	10	24	9	261	4	116	13	377
Subtotal / Weighted average	1,200	44	6	22	16	1,580	2	176	18	1,760
Monterey & Locatelli formations	250	44	13	29	2	42	1	21	3	63
Total	1,450					1,620				1,820

*Also Santa Margarita Sandstone outcrop.

Of the estimated 2,700 AF/yr of average annual baseflow gain along Bean Creek from above Ruins Creek to Zayante Creek, roughly 500 AF/yr is assumed to originate from Pasatiempo groundwater discharge, including flow from Ferndell and Redwood springs (Johnson, 2002). An additional 400 AF/yr is estimated to discharge to other bordering drainages based on gaging data for Eagle Creek along the southwestern subarea boundary (ETIC, 2007) and a rough balance of other subarea inflows and outflows.

Subsurface groundwater flows to and from the Pasatiempo subarea are influenced by (a) the recharge mound formed beneath the Pasatiempo plateau, (b) geologic structure, and (c) groundwater pumping. As shown in Figure 5-15, the water table has a radially outward gradient from the center of the subarea. Upturned beds of underlying aquitard and a structural high of granitic rock result in relatively little subsurface flow to the west and south. Depending on the degree to which the Bean Creek fault acts as a hydraulic barrier, the new deep well MH-3 could draw groundwater from the Lompico Sandstone as it dips steeply beneath Bean Creek and the Olympia subarea (Figure 5-12). Groundwater outflow from Pasatiempo into Camp Evers is estimated at roughly 300 AF/yr based on the gradient toward the Camp Evers pumping depression, favorable geologic structure, and a rough balance of other subarea inflows and outflows.

Since 2000, SLVWD and MHA have produced 410 and 200 AF/yr on average from their respective Pasatiempo wells. Groundwater production by Hanson Quarry was reduced significantly when closure began in 2004 (Table 5-10).

In summary, a rough, recent-average groundwater budget for the Pasatiempo subarea is as follows:

Effective Areal Recharge		Bean Ck & Tributary Baseflow & Springs		Other Ground-water Discharge		SLVWD Pumping		MHA Pumping		Subsurface Flow to Camp Evers	
1,800	≈	500	+	400	+	410	+	200	+	300	(AF/yr)

Although groundwater storage may have declined since the early 1980s (see Section 5.2.5), this rough balance of inflows and outflows implies that groundwater storage is currently trending neither up nor down in the Pasatiempo subarea. The cessation of groundwater production for quarry operations and reduced production by SVWD in neighboring Camp Evers may be partially responsible for the apparent stabilization of groundwater levels in Paso-6 and Paso-7 (Figure 5-32). If these levels remain relatively stable, it suggests that groundwater gradients toward the producing aquifer zones are sufficiently steep to supply SLVWD's current production, in equilibrium with other current rates of inflow and outflow.

5.6.5 Camp Evers

Groundwater in the Camp Evers subarea is replenished by (a) rainfall and applied-water recharge and (b) subsurface inflow. Groundwater outflows include (a) pumping wells, (b) discharge to baseflow, and possibly (c) subsurface outflow (Figure 5-35).

Groundwater recharge into Camp Evers alluvium and exposed Santa Margarita Sandstone is influenced by land use, as estimated in the following table:

Recharge Zone	Area (ac)	Rain-fall (in/yr)	Storm Runoff (in/yr)	Rain-fall ET (in/yr)	Rainfall Recharge (in/yr)	Rainfall Recharge (AF/yr)	Applied-Water Recharge (in/yr)	Applied-Water Recharge (AF/yr)	Total Recharge (in/yr)	Total Recharge (AF/yr)
Residential	120	43	10	24	9	90	4	40	13	130
Commercial	280	42	20	18	4	95	4	95	8	190
Rural residential	150	42	8	24	10	130	4	50	14	180
Total / Weighted average	550	42	15	21	7	315	4	185	11	500

The Camp Evers pumping trough draws groundwater inflows from the Pasatiempo and Mission Springs subareas, and possibly the Olympia and Scotts Valley subareas. Based on a rough balance of subarea inflows and outflows, subsurface inflows to Camp Evers may average as much as 500 AF/yr.

Current average annual production from SLVWD's Mañana Woods well and SVWD's two Camp Evers wells (SV-9 & -10A) is estimated at 65 and 400 AF/yr, respectively. Pumping by others in Camp Evers has been estimated at more than 300 AF/yr (e.g., Spring Lakes, Vista Del Lago, and Montevalle communities; the Valley Gardens golf course; and groundwater remediation operations; Todd Engineers, 1998). The use of recycled water is replacing some of this production.

Groundwater perched above the Camp Evers pumping depression may discharge to Bean Creek and its tributary Dufours Creek. To the southeast, some Camp Evers groundwater may flow toward Carbonera Creek. The pumping depression formed by SVWD's Pueblo wells (currently SV-11A & -11B) may induce deep subsurface outflow from Camp Evers. Together, these outflows are estimated to be roughly 200 AF/yr or more.

In summary, a highly approximate groundwater budget for the Camp Evers subarea is as follows:

Effective Areal Recharge	+	Sub-surface Inflow	≈	SLVWD Pumping	+	SVWD Pumping	+	Other Estimated Pumping	+	Bean Creek & Tributary Baseflow	+	Sub-surface Outflow	
500		500		65		400		300+			200+		(AF/yr)

Johnson (2002) estimated that the reduction in groundwater storage during the formation of the Camp Evers pumping trough in the 1980s and 1990s accounted for about 500 AF/yr of the subarea's average annual groundwater production. As a result, the Santa Margarita Sandstone was largely dewatered, losing an estimated 7,000 acre-feet of groundwater storage, with additional losses from the upper zones of the Lompico Sandstone aquifer. In recent years, production from SVWD's Camp Evers wells has declined by nearly half and groundwater levels have appeared to stabilize. Thus, the above balance of inflows and outflows assumes no further declines in groundwater storage. Groundwater gradients may now be sufficient to sustain groundwater flow to major pumping wells. However, the amount of groundwater storage available for use during droughts has been significantly reduced, and poor quality groundwater is being drawn into producing zones (e.g., as experienced by SV-9; see Section 5.5.4).

5.6.6 Scotts Valley

Across the remainder of Scotts Valley, groundwater inflows include rainfall and applied-water recharge, subsurface inflow from adjoining areas, and streamflow percolation. Groundwater outflows include contributions to Bean and Carbonera creek baseflows, subsurface outflow to adjoining subareas, and groundwater production (Figure 5-35).

Assuming an average annual recharge rate of 8 in/yr over 8 square miles, the Scotts Valley groundwater area may receive at least 3,000 AF/yr of groundwater inflow. Groundwater production from SVWD's four active Scotts Valley wells averages about 1,500 AF/yr (Table 5-10). At roughly 50 percent of estimated average annual recharge, this suggests that much of the current production may be derived from reductions in groundwater storage as these pumping depressions continue to form.

5.7 Groundwater Management and Protection

5.7.1 Institutional

SLVWD tracks the production and water levels of its seven currently active wells on a monthly basis. Instantaneous readings are accessible through its SCADA system. Additionally, SLVWD monitors water levels in five other Quail Hollow wells (MW-A,-B,-C; QH-8; QH-ranch), one inactive Olympia well (Oly-1), and a Pasatiempo monitoring well pair and inactive production well (MW-1, MW-2, Paso-2). SLVWD conducts routine water quality monitoring in accordance with State and Federal regulations.

SVWD conducts similar activities and presents its findings in annual reports in accordance with its groundwater management plan authorized by the State under AB3030 (sections 10750-10756 of the California Water Code).

The Santa Cruz County Water Advisory Commission oversees water supply and protection issues within SLVWD's boundaries (other than the portion within the City of Scotts Valley). The Commission has proposed a conjunctive use feasibility study for the Santa Margarita Basin in a grant request for water resource projects under State Proposition 50 for integrated regional water management.

The Santa Margarita Groundwater Basin Advisory Committee was formed in 1995 as a forum for cooperative groundwater management of the groundwater resources evaluated in this report. The Committee members are SLVWD, SVWD, LCWD, the City of Scotts Valley, and the County of Santa Cruz. The Committee typically meets twice annually.

5.7.2 Recharge-Area Protection

Drinking Water Source Assessment and Protection (DWSAP) reports were prepared for each active SLVWD well during 2001-02 as mandated by the California Department of Health Services. These reports delineate each well's area of contributing groundwater flow and recharge (i.e., capture zone) and identify potential contaminating activities within them. Figure 5-36 is a map showing the estimated 10-year protection zone of each active SLVWD well, i.e., the area within which groundwater potentially could reach the well in 10 years or less. Each of SLVWD's three active well pairs (QH-4A & -5A; Oly-2 & -3; and Paso-6 & -7) has a single protection zone because contaminants drawn close to one well may be available for capture by the other depending on how the wells are operated. The estimated capture zone for MWd-2 is preliminary pending SLVWD's completion of a DWSAP report for this well.

SLVWD's Quail Hollow, Olympia, and Pasatiempo wells are susceptible to the effects of potential landuse changes associated with closing quarries. Quarry closures could significantly alter patterns of runoff, evapotranspiration, and percolation. On-site runoff retention may be no longer be required and the regrading of stockpiled fine-grained material could reduce the percolation of rainfall and runoff.

Additional water protection issues identified in the DWSAPs are summarized below.

5.7.2.1 Quail Hollow

The 10-year protection zone estimated for QH-4A and QH-5A encompasses approximately 200 acres (Figure 5-36). Recharge averaging at least 20 in/yr across this area is sufficient to supply average production of 330 AF/yr. Land uses in the recharge area include residential, undeveloped chaparral and parkland, and sand quarrying. Primary factors contributing to potential water-quality vulnerability include: (1) the high percolation capacity of the Santa Margarita Sandstone and associated Zayante soils, (2) the absence of a confining zone above the aquifer, (3) the existence of about 40 residential septic tank systems in the delineated protection zone, and (4) the potential for hazardous-material spills.

The leaching of septic-tank wastewater and possibly landscape fertilizers in residential areas is sufficient to account for the observed gradual rise in groundwater nitrate concentrations (Figure 5-34a). Nitrate concentrations remain well below drinking water standards. Furthermore, the nondetection of fecal coliform indicates that pathogens do not survive transport through the thick and well-aerated unsaturated zone.

The detection of trace concentrations of TCE and MTBE in water produced from QH-5A may be attributable to residential spills or septic-tank disposal of solvent and gasoline. As estimated previously, the detected TCE can be explained by a spill of only 0.5 liter of solvent (Johnson, 2001). These chemicals have not been detected in QH-4A or other nearby wells, and thus migration from the source may be fully controlled by operation of QH-5A.

Because of the soil and sandstone's high permeability, the potential for groundwater contamination from spills is significant. This risk is managed at Quail Hollow Quarry by regulated above-ground fuel storage and fueling operations. Accidental or illegal spills could occur along Quail Hollow Road. Limited development and access associated with quarry operations and Quail Hollow Ranch County Park provide some degree of recharge area protection. The closed Ben Lomond Landfill is across Newell Creek and not within the capture zone of SLVWD's Quail Hollow wells.

5.7.2.2 Olympia

The estimated 10-year protection zone for Oly-2 and Oly-3 encompasses about 200 acres (Figure 5-36). The total recharge area needed to supply these wells' average production of 420 AF/yr is roughly twice as large, assuming an effective average recharge rate of about 12 in/yr. Land use in the recharge area includes a closed sand quarry, undeveloped open space including timberland, and rural residential development.

Factors contributing to the protection of Oly-2 and Oly-3 water quality include: (1) the mostly rural and undeveloped nature of the recharge area, (2) the position of much of the aquifer beneath a mudstone cap, (3) well screens at depths greater than 200 ft bgs, and (4) sanitary seals 160 ft deep. There are no streets or residences within the protection zone.

Factors contributing to the potential water-quality vulnerability of Oly-2 and Oly-3 include the high percolation capacity of the exposed Santa Margarita Sandstone near and generally west of the wells. The 10-year capture zone contains virtually no development, whereas the total recharge area may contain many residences on septic tanks along East Zayante Road and Lockhart and Ryder gulches. Horse stables are located along the western fringe of the recharge area. The produced water quality shows no indication of impairment as a result of landuse activities.

5.7.2.3 Pasatiempo

The groundwater protection zone estimated for Paso-6 and Paso-7 encompasses about 450 acres and includes the MH-2 production well and the largest of Hanson Quarry's supply wells (Figure 5-36). The area's landuse includes the Santa Cruz County Probation Center and the mostly undeveloped land surrounding it; a portion of the Roaring Camp redwoods railroad and other undeveloped land adjacent to Henry Cowell State Park; a portion of Hansen Quarry; and portions of the Mount Hermon and Pasatiempo Pines residential neighborhoods.

Factors contributing to the protection of Paso-6 and Paso-7 water quality include: (1) the semi-confinement of the Lompico Sandstone aquifer beneath the Monterey Formation locally, (2) confinement of the Lompico Sandstone's lower production zones beneath upper shalely and cemented interbeds, (3) sanitary seals 260 to 380 ft deep, and (4) the generally low level of development within most of the capture area.

Factors contributing to potential water-quality degradation include: (1) wastewater leachfields and fuel storage near the County Probation Center, (2) strong downward vertical gradients between the upper, unconfined Santa Margarita Sandstone and the deeper Lompico Sandstone, (3) residential leachfields and sewer lines near the protection-zone margins, especially to the southeast where the Monterey Formation aquitard is absent and Lompico Sandstone interbeds are upturned directly beneath the Santa Margarita Sandstone, and (5) potential spills associated with area roadways, Hanson quarry, and the Roaring Camp stream train.

Groundwater produced from deep within the Lompico Sandstone aquifer by Paso-6 and Paso-7 shows no signs of impairment as a result of landuse activities. Wells completed in the shallower Santa Margarita Sandstone aquifer, however, have experienced elevated nitrate as a result of wastewater disposal. Those wells have been destroyed, and much of southern Scotts Valley is now sewered.

5.7.2.4 Camp Evers

SLVWD is preparing a DWSAP report for MWd-2. Figure 5-36 shows a preliminary estimate of the MWd-2 10-year capture zone based on (a) the estimated capture zones for nearby production wells SV-9 and SV-10A (Todd Engineers, 2001) and (b) the configuration of the Camp Evers MTBE plume (Todd Engineers, 2003; ETIC, 2007). The estimated capture zone has an area of approximately 80 acres. An average recharge rate of 10 in/yr across this area would be sufficient to supply the well's average production of about 70 AF/yr. The shape of the capture zone could change substantially in response to changes in the way other area wells operate. For example, if either SV-9 or SV-10A were shut off for an extended period of time, contaminants drawn in close to either of those wells could become available for capture by MWd-2.

Landuse within the capture zone estimated for MWd-2 is suburban commercial and residential. Petroleum leaks associated with service stations near the intersection of Mount Hermon Road and Scotts Valley Drive have been identified as responsible for a contaminant plume that extends nearly 2,000 ft to MWd-2. Other potential sources of contamination in the potential capture zone include septic tanks, a dry cleaner, and other facilities that process and/or store hazardous materials (Todd Engineers, 2001).

5.8 Production Potential

Section 5 concludes with a discussion and estimates of SLVWD's potential for sustained long-term groundwater production from each of its wellfields as a function of hydrogeologic, water-quality, water-budget, and infrastructure constraints. The rough estimates of groundwater storage and production presented above in this section may be summarized as follows:

Groundwater Subarea	Aquifer	Storage Total* (AF)	Storage Change (AF)	Average Recharge (AF/yr)	Subsfc. Inflow (AF/yr)	SLVWD Production Average (AF/yr)	SLVWD Production Average (MG/yr)	SLVWD Production Maximum (AF/yr)	SLVWD Production Maximum (MG/yr)
Quail Hollow	S. Margarita	14,000	±5,000	~4,000	0	300+	100+	517	168
Olympia		29,000	?	~2,000	0	400+	130+	550	179
Pasatiempo	S. Margarita	<3,000	-8,000	~1,800	0	<400	<130	444	145
	Lompico	~10,000							
Camp Evers	S. Margarita	~2,000		500	~500	50+	17+	51	17
	Lompico	~8,000	-2,000						
Mission Springs	S. Margarita	17,000	?	900	~300	0	0	0	0

5.8.1 Quail Hollow

As estimated in the preceding sections, the Quail Hollow subarea is characterized by a large average annual volume of groundwater recharge (nearly 4,000 AF/yr), but a relatively small volume of average groundwater storage (14,000+ AF) and relatively short groundwater residence times.

Production from all wells is estimated to total less than 500 AF/yr and accounts for only about one-eighth of estimated average annual recharge, with the remainder discharging to springs and streams. Because SLVWD's Quail Hollow wells are near the subarea's center, their effect on surrounding spring and stream baseflows is fairly evenly distributed and relatively small. Given Quail Hollow's apparently balanced water budget, SLVWD's average annual groundwater production of 300 to 400 AF/yr appears sustainable. Average production toward the high end of this range may be achievable if a third production well were constructed to replace the former QH-3 and QH-8.

An area considered for construction of a third well is the vicinity of the former Quail Hollow Ranch supply well (QHR) and monitoring well MW-B (Figure 5-3). This area ranges from approximately 900 to 1,600 ft away from QH-4A and QH-5A, which is considerable greater than the nearly 500 ft separating QH-4A from QH-5A, and supports an expectation of reduced well interference. Additionally, this area is also near the subarea's center such that the effect on surrounding spring and stream baseflows is fairly evenly distributed. The QHR site has the advantage of a relatively high aquifer saturated thickness and transmissivity (Johnson, 2001), which supports an expectation of relatively low drawdown. Model calibration to relatively high water levels at MW-B suggests a decrease in aquifer transmissivity in this direction (Johnson, 2003), indicating the potential for greater drawdown and more limited production rates.

Because estimated Quail Hollow groundwater storage is only about four times as large as average recharge, storage becomes significantly diminished during extended periods of reduced recharge. Drought reductions in saturated thickness and hydraulic gradient cause commensurate decreases in well yield and other groundwater discharges. Thus, above-average Quail Hollow groundwater production is difficult to sustain during droughts, when increased groundwater production is most needed. Maximum rates of annual production in excess of 500 AF/yr occurred in 1980 and 1988 following relatively wet periods, whereas production dropped to below 200 AF/yr toward the end of the 1987-94 drought (Figure 5-27).

Because SLVWD's Quail Hollow wells draw from groundwater storage that is mounded mostly above the surrounding streams, the potential to induce additional recharge or groundwater inflow is limited. Percolation may be induced along portions of Newell Creek when the water table is lowered during drought. However, (a) flows available for percolation are limited to typically small releases from Loch Lomond and (b) QH-4A and -5A are hydraulically upgradient of the creek by more than 2,500 ft horizontally and 100 ft vertically.

The degree to which increased groundwater recharge during wet periods can be saved for use during drought is limited by relatively short groundwater residence times and rapid rates of discharge to surrounding springs and streams. Simulations using SLVWD's Quail Hollow groundwater model can be used to help optimize both storage and production during representative climatic cycles.

In summary, SLVWD's Quail Hollow wells provide a reliable summer water supply during average and wet years, and a diminished water supply during drought, with an average annual production of 300 to 400 AF/yr (100 to 130 MG/yr). Optimization of the Quail Hollow groundwater supply might require reduced production during some years in order to sustain higher production during drought. Currently, the wellfield is not operated this way because of the preferred quality of Quail Hollow groundwater compared to that produced from SLVWD's Olympia wells.

5.8.2 Olympia

Compared to Quail Hollow, the Olympia subarea is estimated to receive about half as much average recharge (~ 2,000 AF/yr), but has twice as much groundwater storage (~29,000 AF), with relatively long groundwater residence times.

Production from all wells is estimated to be less than 600 AF/yr, or about 30 percent of estimated average annual recharge. The remaining recharge discharges to surrounding streams and flows as groundwater into the adjacent Mission Springs and Camp Evers subareas. SLVWD's Olympia wells have a limited direct effect on stream baseflow because of (a) the structural high of Monterey Formation that forms a partial barrier between the aquifer and Zayante Creek (Figures 5-12 & -13) and (b) relative large distances separating the wells from Bean Creek and its perennial tributaries (>5,000 ft). Given the Olympia subarea's essentially balanced water budget, SLVWD's average annual groundwater production of more than 400 AF/yr appears sustainable.

Average to above average rates of Olympia groundwater production are relatively sustainable during drought given that (a) estimated Olympia groundwater storage is roughly fifteen times greater than average annual recharge and (b) drought reductions in aquifer saturated thickness and transmissivity are relatively small (Figure 5-28). Furthermore, the relatively low hydraulic gradients and long residence times of Olympia groundwater help maintain groundwater storage during periods of reduced recharge. For these reasons, SLVWD relies on above-average production from its Olympia wells during drought periods when production from its diversions and Quail Hollow wells diminish.

Because of the relatively poor quality of Olympia groundwater and SLVWD's limited ability to treat it (Section 5.5.2), SLVWD's production of Olympia groundwater decreases during average to wet periods when adequate supplies of better quality water are available from its stream diversions and Quail Hollow wells. These water quality constraints appear to result in a roughly balanced groundwater budget.

SLVWD's Olympia wells have a limited capacity to induce additional recharge for the same reasons that they have limited direct effects on surrounding stream baseflows, i.e., a structural barrier toward Zayante Creek and distances of nearly a mile or more to streams in contact with the regional water table. Additionally, because the Santa Margarita Sandstone aquifer is unconfined beneath the Santa Cruz Mudstone, water-table declines have no affect on the rate of leakage from overlying saturated zones.

Compared to Quail Hollow, above-average groundwater recharge during wet periods is stored in the Olympia subarea for relatively long periods of time as a result of Olympia groundwater's flatter hydraulic gradient, discharge limitations, and large storage-to-recharge ratio. It is possible that Olympia production could be increased without significant annual changes in average groundwater levels. However, gradual water declines could represent a significant imbalance over the long term. A supplemental water source (e.g., stream diversions) could be beneficially stored in the Olympia subarea if an adequate means of artificial recharge were feasible. For example, bank filtration of ponded stream diversions in the general vicinity of the retired quarries could provide a water quality suitable for groundwater injection.

The Olympia subarea's relatively large volume of groundwater storage represents a good potential emergency water supply for SLVWD, especially if adequate treatment and pumping capacity were available with less need for blending. SLVWD's pumping capacity could be increased with a third Olympia well located some distance to the north, east, or south of Oly-2 and -3. Excessive pumping lifts and difficult access are drawbacks of upland sites to the east. Sites that combine potentially suitable access, pumping lifts, and saturated aquifer thickness may occur within roughly 1,000 ft to the south and 2,000 ft to the north of the existing wells. Potentially feasible well sites more than 500 ft to the north or south lie outside SLVWD and its owned properties.

Groundwater management in the Olympia subarea would benefit from an expanded groundwater monitoring network that would allow improved analysis of fluctuations and potential trends in groundwater storage. Such is the case in the Quail Hollow area, where data analysis and modeling provide a reasonable understanding of the role of groundwater storage in sustaining production through the climatic cycle. Potential new Olympia monitoring sites include the two general well locations described in the preceding paragraph. Also, a monitoring well would be beneficial along Ryder Gulch east of the Olympia wellfield, similar to the private well that was monitored during a Oly-2 pumping test (Johnson, 1989).

In summary, SLVWD's Olympia wells provide a dependable supply of relatively low quality groundwater compared to its other sources, in large part due to the subarea's relatively large volume of groundwater storage and long groundwater residence times. Average and drought-year production exceeding 400 and 500 AF/yr (130 and 160 MG/yr), respectively, appears sustainable. Greater production could be achieved with increased pumping and treatment capacity, although a long-term imbalance with groundwater inflows could occur unless recharge was somehow augmented. Optimization of the Olympia groundwater supply may require increased treatment capacity and a reduced need for blending.

5.8.3 Pasatiempo

Total groundwater production of more than 1,000 AF/yr from the Pasatiempo subarea during the 1990s and early 2000s (Table 5-10), combined with roughly equal or greater production from the adjacent Camp Evers subarea since the 1980s, has caused groundwater level declines of more than 130 ft at SLVWD's two active Pasatiempo wells. At Paso-6, this decline represents lowered piezometric pressure within the Lompico Sandstone aquifer, which induces downward leakage from the overlying Santa Margarita Sandstone water-table aquifer. Local to Paso-6, the Lompico Sandstone remains fully saturated and the water table in the overlying sandstone remains stable, suggesting groundwater production is partially compensated by reduced groundwater outflow elsewhere. Paso-6 is favorably positioned over a leaky, sandstone-filled trough that collects recharge from a large portion of the Pasatiempo subarea. Water levels have stabilized despite long-term and recent increases in production. Estimated groundwater storage in the overlying Santa Margarita Sandstone aquifer (~3,000 AF) is roughly five times as large as current average annual production by SLVWD and MHA (~600 AF/yr). Leakage from this zone appears to buffer the effect of wet and dry periods and provide the most benefit to Paso-6.

At Paso-7, the 130-ft water-level decline since the 1990s represents a loss of saturated Lompico Sandstone aquifer, which has resulted in significantly diminished production capacity and a loss of one to several thousand acre-feet of groundwater storage. Although Paso-7 groundwater levels have stabilized, current production rates are only about one-third of what they were in the 1990s. Much of the remaining storage occurs in deep semi-confined to confined zones, which have little beneficial operational significance. Groundwater conditions at Paso-7 likely have experienced (a) interference from the operation of Paso-6 and (b) more adverse effects from the Camp Evers pumping trough than at Paso-6.

The potential for groundwater pumping to induce additional recharge is limited–similar to the Quail Hollow and Olympia subareas–although pumping has undoubtedly increased the rate of groundwater leakage into the Lompico Sandstone aquifer. Given that shallow groundwater in the Pasatiempo subarea is essentially mounded relative to surrounding streams and the Camp Evers subarea, the potential for retaining groundwater storage is limited.

SLVWD's average annual production of more than 400 AF/yr from its Pasatiempo wells may be sustainable now that (a) production by Hanson Quarry and SVWD's Camp Evers wells has been reduced and (b) Mount Hermon Association has shifted some of its production to a well further north that draws from deeper aquifer zones (i.e., MH-3). Current total Pasatiempo production of about 600 AF/yr is equal to about one-third of estimated average annual recharge, which is similar to or slightly greater than total Olympia production in proportion to recharge. Alternatively, the apparent recent stabilization of Pasatiempo groundwater levels may reflect short-term reduced demand and increased recharge associated with wet WYs 2005 and 2006, such that water levels may resume their prior falling trends in coming years.

If groundwater levels resume their previously declining trends, SLVWD's recent-average production of more than 400 AF/yr from its two current Pasatiempo wells could become unsustainable. This concern is especially valid for Paso-7, in which pumping water levels have fallen below the upper of two screened intervals. In this case, reduced demand and/or a supplemental water supply would be necessary. SLVWD could increase available drawdown by constructing deeper wells similar to MH-3. However, this may only delay the need for a supplemental water supply as the effects of such deep wells propagate upward over time.

The closure of Hanson Quarry has not been optimized to maintain or enhance recharge. Furthermore, efforts to augment actual and/or in-lieu recharge could be offset by increased groundwater outflow from the subarea.

In summary, SLVWD may be able to sustain its more than 400 AF/yr (130 MG/yr) of groundwater production from the Pasatiempo subarea for a number of years. However, historical trends suggest that total production rates from Pasatiempo and the adjoining Camp Evers subarea may not be sustainable, such that supplemental sources and/or reduced production may become necessary.

5.8.4 Camp Evers

Similar to the Pasatiempo subarea, groundwater levels in the Camp Evers subarea appear to have stabilized in recent years, in large part due to decreased total production (Figure 5-31). As such, production from SLVWD's water supply well for Mañana Woods (MWd-2) appears generally sustainable at its relatively modest current rate of 50 to 60 AF/yr (16 to 20 MG/yr). This rate of production reflects recent reductions in demand following SLVWD's metering of each Mañana Woods connection. Continued treatment for VOC contamination in MWd-2 produced groundwater will be needed for the foreseeable future.

Since the 1980s, reductions in unconfined groundwater storage in the Camp Evers subarea of as much as 10,000 AF indicate a significant loss of operable groundwater storage that could be problematic in the event of a sustained drought. However, MWd-2 production is less vulnerable than that of nearby SVWD wells given that water demand for Mañana Woods is relatively small.

The worsening quality of groundwater produced from SV-9 (i.e., high TDS and sulfate) may portend the occurrence of similar declining water quality elsewhere in Camp Evers. Also, changes in the amount and/or pattern of SVWD groundwater production could adversely affect the migration of contaminant sources currently controlled by SV-9 and -10A. SVWD groundwater production in central and northern Scotts Valley at a rate equal to roughly half of estimated average annual recharge may exacerbate groundwater level declines in the adjacent Camp Evers subarea.