3 Surface-Water Hydrology

This section characterizes the quarry area hydrology, including the spatial and temporal distribution of precipitation, quarry-area drainage, stream and spring flow, and water diversions by the City of Santa Cruz and CEMEX. The hydrogeology of the area springs is evaluated in Section 4.

Annual data are typically expressed in water years. For example, water-year (WY) 2005 began October 1, 2004 and ended September 30, 2005. Available data are evaluated through WY 2005.

Streamflow rates are usually expressed in cubic feet per second (cfs) whereas groundwater discharge from springs and wells is often presented in gallons per minute (gpm). From a water-supply perspective, monthly and annual flow volumes are commonly expressed in acre-feet (ac-ft). This report presents flow data in multiple units to facilitate their comparison.

3.1 Precipitation

Table 5 provides a summary of past and present precipitation stations at and near Bonny Doon Quarry and within the surrounding region. A continuous monthly precipitation record for the quarry is available for WYs 1970-92 (Table 6), which on the whole was a slightly drier than average period. Although records may exist, there appears to be a precipitation data gap for the quarry for WYs 1993-97 and 2001-02. Partial years of recording rain gage data are available for WYs 1998-2000 and 2003-05 (Table 7). Partial years were also recorded at the nearby shale quarry and Whitesell property during WYs 1998-99. Recording rain gages have been operating at the Liddell Spring landslide and Liddell Creek East Branch stations since WY 2001. Based on these various records, mean annual precipitation at the quarry is estimated to range between about 34 and 40 inches per year (in/yr). Upgradient of the quarry, precipitation increases with elevation to as much as 60 in/yr (Table 5).

While the recording rain gage data is useful for evaluating hydrologic responses to precipitation, the partial and short-term records hamper the characterization of wet versus dry years during the recent period of intensive data collection at Bonny Doon Quarry. Nearby stations with applicable, long-term records include Santa Cruz, Ben Lomond 4, San Gregorio 2 SE, and Lockheed (Tables 8 through 11). These stations are summarized in Table 5 and their records for WYs 1996-2005 are presented in Table 6 along with the quarry stations and other nearby short-term stations. Table 12 presents annual records for the Santa Cruz and Lockheed stations extending back to the 1800's.

Based on the information presented in Table 7, the period during WYs 1996-2000 was generally wet with about 125 percent of average precipitation, whereas WYs 2001-04 were generally dry with about 90 percent of average precipitation. Precipitation during WY 2005 was about 120 to 140 percent of average.

Figure 8 is a set of bar charts comparing monthly precipitation during WYs 2001-05 at several different quarry and regional stations. Precipitation is distributed from month to month in a consistent manner among stations. This is consistent with the regional influence of frontal storms that account for nearly all precipitation.

A recent study of the quarry described WY 2004 as having more than average rainfall (PELA, May 2005). As demonstrated in Table 7, this description is incorrect.

Figure 9 is a set of bar charts comparing daily precipitation during WYs 2003-05 for several stations. Daily precipitation appears to be distributed in a similar fashion with the following exceptions:

- Precipitation totals for two days at the quarry office station are anomalous (November 23, 2002 and April 15, 2003, as reported by PELA, May 2005). These daily values appear to include precipitation from prior days of the month, as indicated by the good match between monthly totals (Figure 8).
- Daily precipitation at the quarry office reported for October 2004 through May 2005 (PELA, October 2005) does not match the overlapping portion of record reported previously (PELA, May 2005) and appears to be about two-thirds too small.

The record maintained by Balance Hydrologics at the Liddell Spring landslide and East Branch stations appears to provide the longest and most reliable daily precipitation record for use in this study.

3.2 Quarry Drainage

The map presented in Figure 10 shows the approximate drainage areas upgradient of the quarry, its sediment basins, and Liddell and Plant springs. As numbered in Figure 10, the following subareas are delineated (areas approximate):

1. 30 acres draining to one or more sinkholes that would otherwise drain to the quarry.
2. A 40-acre drainage that encompasses Whitesell Springs and is captured by one or more sinkholes along the northwest quarry boundary (i.e., the “sinking stream” reach of “Whitesell Creek” [PELA, May 2005]); this area would otherwise drain to the Middle Branch of Liddell Creek.
3. The active quarry, quarry expansion area, and the hillslopes draining into the quarry (125 acres), about half of which is the mining area. Based on our observations during 2004-06, this area has no external drainage.
4. The Middle Branch of Liddell Creek above the quarry’s western sediment basin (115 acres).
5. The area downgradient of the quarry that drains to the two eastern sediment basins (90 acres). This is tributary to the East Branch of Liddell Creek. Some of this area may have drained originally to Liddell Spring but is now rerouted to the sediment basins.
6. The swale above Liddell Spring (8 acres).
7. The drainage above Plant Spring (55 acres).
8. The Reggiardo Creek watershed that drains into various sinkholes and swallow holes (650 ac).

According to the EIR's Initial Study (SCCPD, November 2001), the County senior civil engineer concluded that the capacities of the existing sediment basins are adequately sized for the quarry operation, including the proposed amendment area.

The quarry floor (about 8 acres as of late 2002) is lower than the quarry's outlet to drainage ways leading to the quarry's sediment basins. Thus, the fate of precipitation and runoff within the 125-acre drainage area encompassing the quarry includes one or more of the following:

- Percolates through the quarry walls and floor and into any open sinkholes and permeable soils on the slopes above the quarry.
- Evaporates—this is probably limited during the cool wet season when the quarry floor is often shaded.
- Is pumped out—Farallon (August 2001) mentions this possibility, but there are no known reports of this occurring. Walker (November 2006) stated that no pumping from the bottom of the quarry has been done in the last five years.
- Spills into the downstream drainage when sufficiently deep—there are no known reports of this, however.

Other researchers have noted the following regarding quarry drainage:

- Stewart (March 1978) observed a sinkhole above the quarry face receiving surface runoff water. The City of Santa Cruz began to complain of increased Liddell Spring turbidity immediately after this sinkhole area was cleared prior to quarrying.
- Watkins-Johnson Environmental (November 1992) discussed the interception of surface flow by piping related to a former sinkhole.
- SECOR (March 1998) observed collected runoff up to 10 inches deep over approximately 30 percent of the quarry floor during January 1998. This water was turbid and had been flowing when deeper toward an area of exposed bedrock, where it drained into fractures. The flow had been sufficient to scour fine-grained material from the quarry floor.
- During February 1998, RMC placed and compacted about 1,000 cubic yards of fine to medium grained material over an area of exposed, fractured bedrock on the quarry floor (SECOR, March 1998). Also at that time, a sinkhole that captured runoff in the upgradient drainage area tributary to the quarry was filled to control erosion threatening a fire road.
- During March 2000, Farallon (August 2001) observed ponded water across <25 percent of the quarry floor and drainage of <25 gpm into the lower-most quarry depression.

We inspected the quarry during several days of heavy rain in January and February of 2004, and again in March and April of 2006, to help evaluate the fate of precipitation and runoff within the quarry and its contributing drainage area. Runoff from a few acres of access roads traversing up the east and west sides of the quarry from the quarry entrance (i.e., on the south side of the quarry pit) flowed south out of the quarry. All other precipitation and runoff infiltrated into the ground or collected on the quarry floor. We observed open fractures along the quarry benches intercepting a substantial amount of precipitation and runoff. Puddles formed in some low spots along the benches, while other low spots had no ponded water, e.g., where open fractures in the marble bounded the inside edge of the bench. We also noted piping through areas of fill consisting of coarse- to fine-grained marble fragments on the quarry floor. For example, one pipe was visibly open for a depth of about two feet and could be plumbed to a depth of about 5 feet.

To supplement our quarry observations, we installed a pressure transducer and data logger in a pond on the quarry floor. We recorded water levels on a 5-minute interval during a 16-day period from February 17 to March 3, 2004 using a Global Water Instrumentation, Inc. WL15 water-level logger. The water levels were referenced to an arbitrary datum. The data logger was installed inside a 4-inch diameter perforated plastic pipe set about one foot into the quarry floor for stability.

We chose to monitor a large pond near the southern end of the quarry from among a number of ponds scattered around the bottom of the quarry at that time. The selected pond was within the low point of the southern end of the quarry and was separated from ponds toward the northern end of the quarry by slightly higher topography near the quarry's center. Our field observations indicated that water was draining into this pond from adjacent areas during periods of heavy precipitation. All of the ponds contained turbid water during periods of rain, with much of the sediment settling out over days to weeks following the end of rain.

Figure 11 includes a plot of the recorded water levels. Because the pond area increased with rising water levels, the relationship between water level and pond volume is non-linear. Nevertheless, the recorded data provide a useful indication of infiltration into the quarry floor.

The corresponding precipitation record for the Liddell Spring landslide gage is also provided in Figure 11. Precipitation totaled 4.1 inches during the monitoring period, 76 percent of which occurred during the following four events:

Precipitation Event	inches
2/17-18/04	0.95
2/24/04	0.55
2/25/04	1.04
3/1/04	0.58

Precipitation prior to the monitoring period was nearly 22 inches since the beginning of the water year. Precipitation was generally below average during WY 2004 (Table 7).

The recorded pond water levels responded to precipitation events with a relatively rapid rise and fall, separated by a gentle water-level recession between events. Peak pond levels occurred about 4 to 9 hrs after the beginning of the precipitation event. The rate of water-level decline immediately following an event was about 4.5 to 5 in/day, whereas a slower rate of decline between events was about 1 in/day. An anomalous response occurred February 24 when water levels suddenly dropped about 0.4 feet over several hours.

The local rate of reference evapotranspiration is only about 1 to 2 inches per month during February (California Department of Water Resources, 1999). Considering this and the lack of external drainage, it is reasonable to infer that most of the ponded water was lost to infiltration. The water-level response suggests that some type of drain existed above a sill around the perimeter of the pond, allowing rapid infiltration when water levels overtopped the sill. The anomalous water-level drop on February 23 was probably due to a temporary opening of a pipe or conduit, perhaps in response to a quarry blast that occurred about 4 hrs earlier (Figure 11).

Figure 11 also compares the recorded pond levels to the discharge of Majors Creek and the turbidity of Liddell Spring. The flow record for Majors Creek (presented in Section 3.3) represents a nearby surface-water response to precipitation unaffected by karst hydrology. As summarized in the table below, the water level of the monitored quarry pond peaked within 0.6 to 3 hrs of Majors Creek peak discharge; furthermore, the pond and streamflow hydrographs were of generally similar shape, and were dissimilar to the springflow hydrograph (Figure 11). This indicates that pond levels were responding to runoff processes. The turbidity of Liddell Spring began to rise about 5 to 7 hours after the pond levels began to rise, consistent with the time needed for a groundwater tracer to reach the spring from a quarry monitoring well (see Section 4.4.2). Peak spring turbidity occurred within about 6 to 9 hrs of the beginning of the pond level rise, and about 2 to 5 hrs after the peak pond water level. As discussed in Section 4.4.3, peak spring discharge occurred consistently after the spring's peak turbidity, suggesting that spring discharge and turbidity are influenced by separate processes.

Start Precipitation Event	Quarry Pond Peak Level vs. Majors Creek Peak Flow	Quarry Pond Peak Level vs. Liddell Spring Peak Turbidity	Start of Quarry Pond Rise vs. Start of Liddell Spring Turbidity Rise	Start of Precipitation Event vs. Quarry Pond Peak Level	Start of Quarry Pond Rise vs. Liddell Spring Peak Turbidity
	Lag (hrs)				
2/17/04 17:30	0.6	2.2	6.4	6.4	8.4
2/24/04 3:30	1.7	2.3	5.4	3.8	5.7
2/25/04 3:00	0.6	2.8	5.0	8.7	8.9
3/1/04 4:15	2.9	4.7	4.8	6.3	9.3
Average	1.4	3.0	5.4	6.3	8.1

As discussed further in Section 4.6, these results strongly suggest that runoff infiltration through the quarry floor has a direct effect on Liddell Spring turbidity.

The water-level fluctuations recorded by the data logger are consistent with qualitative observations by us and others. Much of the precipitation and runoff within the quarry drainage area never reaches the quarry floor, but is intercepted instead by permeable soils in unmined areas and open fractures along the quarry benches. Some precipitation and runoff ponds on areas of the quarry floor where rapid infiltration is prevented by deposits of crushed marble and soil. However, when water levels rise to the level of exposed open fractures and solution cavities, rapid drainage occurs. Additionally, the occurrence of several closed depressions with no ponded water suggests rapid percolation in other areas of the quarry floor.

The total volume of mean annual recharge into the quarry drainage area can be estimated using a simple water budget. Assuming mean annual precipitation of 38 in/yr, a precipitation-runoff relation for the Santa Cruz Mountains region (Geomatrix, March 1999) suggests 12 in/yr of total streamflow (storm runoff plus baseflow) and 26 in/yr of evapotranspiration. The rate of evapotranspiration within the quarry is probably less given its shadiness, high rates of percolation into exposed fractured marble, and general lack of vegetation. Percolation rates are also high for areas directly underlain by Santa Margarita Sandstone within the area draining to the quarry. Assuming actual evapotranspiration is only 20 in/yr, percolation of the remaining 18 in/yr results in an average of nearly 300 ac-ft/yr of recharge into subareas 1, 2, and 3 of Figure 10, all of which lack external drainage. During the wettest years, this amount may be two or more times greater.

3.3 **Streamflow**

Bonny Doon Quarry is located at the headwaters of the Middle and East Branches of Liddell Creek (Figure 12). This pair of drainages is bounded on the west by the West Branch of Liddell Creek and the San Vicente Creek watersheds, and on the east and north by the Laguna Creek watershed. Immediately west of the quarry area is the Reggiardo Creek watershed, a tributary to Laguna Creek. Of these streams, Reggiardo and Laguna creeks are pertinent to this study because aspects of their hydrology have been linked with the karst hydrology of Liddell Spring (see Section 4). The flows indicated by both gaging and diversion records for Laguna and Reggiardo creeks do not include flows potentially lost to upstream karst swallow holes. Data available for Majors Creek east of Laguna Creek provides a non-karst watershed record for comparison.

Furthermore, the City of Santa Cruz operates diversions on Reggiardo, Laguna, and Majors creeks in addition to its Liddell Spring diversion (Figure 12). These diversions feed into a single pipeline and thus are operated conjunctively. An evaluation of potential impacts to diversions from Liddell Spring requires an overall understanding of these watersheds.

Tables 13 and 14 present the available gaging records for Laguna and Majors creeks. The gaging stations are located immediately upstream of the City of Santa Cruz diversions (Figure 12). The Laguna Creek station is upstream of the Reggiardo Creek confluence. No regular record exists for Reggiardo Creek, which has a drainage area of approximately 1.4 square miles upstream of its confluence with Laguna Creek.

The drainage areas upstream of the Laguna and Majors creek gaging stations are approximately 3.4 and 3.8 square miles, respectively. The USGS gaged both streams during WYs 1970-76. Precipitation was about average or below average during five of those seven years. Total annual flows ranged from approximately 500 to 7,200 ac-ft/yr at the Laguna Creek gage and 900 to 5,500 ac-ft/yr at the Majors Creek gage. Long-term average watershed precipitation and streamflow have been estimated at approximately 53 in/yr and 3,900 ac-ft/yr, respectively, for Laguna Creek and 45 in/yr and 3,200 ac-ft/yr for Majors Creek (Geomatrix, March 1999). The City of Santa Cruz resumed gaging of Laguna and Majors creeks in 2003. Diversion records for these streams are presented in Section 3.5.

Table 13 also gives 16 instantaneous flow measurements for Reggiardo Creek during 2004-06. The maximum gaged flow was nearly 10 cfs in March 2006. The City has additional but unprocessed gaging data for Reggiardo Creek for prior years (C. Berry, Santa Cruz City Water Department, personal communication, July 2006).

The City of Santa Cruz also operates a gage on the channel downstream of Liddell Spring and refers to this station as the East Branch of Liddell Creek. This is just one of the East Branch headwater tributaries and is not the channel delineated on the Davenport USGS topographic map. At least one other minor spring or seep contributes to its flow above the gage. The monthly flow record for WY 2004 is included in Table 15.

3.4 Springflow

Table 16 lists many of the springs in the Bonny Doon area and Figure 10 and subsequent figures show their location. This section describes the springflow hydrology whereas their Section 4 analyzes their hydrogeology, water quality, and sources of recharge.

3.4.1 Liddell Spring

Liddell Spring is located immediately south of the Bonny Doon marble quarry at an elevation of 584 ft msl.[1] As described by Stewart (December 1971), the spring emerges from a cavern 10 ft by 15 ft by 4 ft. It is the largest spring in the region and is sometimes referred to as "Liddell Spring #1" in order to distinguish it from other nearby springs. Although the City of Santa Cruz monitors its monthly diversions from the spring (Section 3.5), total springflow has been recorded only since 1999 and during a few prior years.

Figure 13 and Table 17 present Liddell Spring gaged flows for 1921-22 and 1931-33 (Todd, January 1963). The reported flows ranged between 500 and 1,000 gpm and averaged about 700 gpm. This average and range are considerably below those of more recent gaged flows (Table 15). Assuming these data are accurate, the low flows may have resulted from the effects of the 1917-35 drought, which because of its great duration was more severe than the droughts of either WYs 1976-77 or WYs 1987-94 (Table 12).

Lindsey (July 1968) reportedly provided precipitation and springflow data for the 1959-68 period (Watkins-Johnson Environmental, November 1992). However, neither this report nor its data were available for review.

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[1] Some sources give 588 ft msl.

Table 15 summarizes the recent gaging record for Liddell Spring. This record includes both diverted and non-diverted flows, but is not fully representative of total flows because the meter in the pipeline discharging from the springbox does not measure:

- Flushing flows from the springbox drain valve (approximately 30-50 gpm)
- Peak flows that exceed the pipeline intake's capacity
- The greater hydraulic capacity of the pipeline when an open valve allows flows to discharge ("blow off") to the downstream tributary of the East Branch of Liddell Creek (i.e., the meter is not calibrated for these conditions, resulting in underestimated flows).

A corrected record of total springflow should be possible using detailed diversion and maintenance records and the gaging record for the East Branch tributary downstream of the spring. Such a corrected record was unavailable for this report, however.

For the 44 months with spring gaging data during WYs 1999-2005, monthly average flows ranged between 760 and 1,720 gpm and averaged about 1,100 gpm. Instantaneous gaged flows have ranged from about 600 to 3,100 gpm. Based on the available gaging data, including the City of Santa Cruz's recorded diversions (see Section 3.4.1.1), the total mean annual flow of Liddell Spring is estimated to be approximately 1,500 ac-ft/yr.

Several studies have noted various short- and long-term lag effects between precipitation and Liddell Spring flow (e.g., Brown and Caldwell, 1963; Lindsey, April 1967). Multi-year lag effects are discussed in Section 3.5 using the diversion record as a surrogate for a long-term record of total springflow. Seasonal and storm-event springflow responses to precipitation are evaluated in Section 4.4.5. The diversion water quality is presented in Section 3.5.1 and the spring's overall water quality is discussed in Section 4.3.

3.4.2 **Plant Spring**

Plant Spring, another but smaller karst spring, is located about 1,400 ft east of Liddell Spring at an elevation slightly above 700 ft msl (Figure 10). It has been referred to also as Liddell Spring #2, East Liddell Spring, and Quarry Spring. It and three nearby minor springs and seeps (PELA, May 2005) form the headwaters of the East Branch of Liddell Creek as mapped on the Davenport USGS topographic map.

Figure 13 includes a plot of Plant Spring flow gaged during 1921-22 (Todd, January 1963). The reported flows ranged between 50 and 350 gpm and averaged about 160 gpm. More recently the average flow was described as about 400 gpm (EMKO, 1999).

PELA (May 2005, Appendix C) monitored Plant Spring discharge, turbidity, temperature, and specific conductance for two years between November 2002 and November 2004. Flows averaged 184 gpm (about 300 ac-ft/yr) and ranged from 66 to 338 gpm. The combined flow of three nearby springs and seeps was estimated at <10 gpm.

3.4.3 **Other Springs**

PELA (May, 2005) provided the most recent inventory of springs and seeps on the quarry properties and surrounding area. These include several minor springs and seeps near Liddell and Plant springs. Other springs include the following (listed from high to low elevation by watershed):

- Middle Branch of Liddell Creek watershed:
  - Whitesell Spring – three small springs with a combined total flow of <10 gpm that emerge from the edge of the Santa Margarita Sandstone outcrop at elevations ranging from 1,100 to 1,200 ft msl. Flow from these springs drains into sinkholes and/or fractures along the western edge of the marble quarry (Watkins-Johnson Environmental, November 1992).
  - Seeps north of conveyor belt (10 gpm or less; about 850 ft msl).
  - Hillside Pipe Spring adjacent to waste disposal area C (about 700 ft msl).
  - Overburden, or Dump, Spring which emerges from a pipe beneath waste disposal area C (10 to 20 gpm; source elevation uncertain).
- Reggiardo Creek watershed:
  - Several springs that emerge from the Santa Margarita Sandstone and form the headwaters of Reggiardo Creek, the largest of which flows at about 60 gpm and the others at 5 gpm or less. These range in elevation from 1,360 to 1,600 ft msl.
  - Strong Spring – three small springs emerging from the Santa Margarita Sandstone and schist north of Smith Grade at elevations of about 1,250 ft msl.
  - Reggiardo Creek channel springs – one or more springs along the channel downstream of Smith Grade (approximately 950 ft msl).
  - Williams Spring – emerges from the hillslope west of Reggiardo Creek nearly due east of Liddell and Plant springs. Its flow was described as "minimal" in June 1992 (Watkins-Johnson Environmental, November 1992). The spring's elevation has been reported at both 830 ft msl (PELA, May 2005) and 1,200 ft msl (Watkins-Johnson Environmental, November 1992).
- Laguna Creek watershed:
  - Laguna Creek channel springs – more that ten springs and seeps along Laguna Creek and its tributaries between Ice Cream Grade and the City of Santa Cruz diversion, with a combined total flow of roughly 300 gpm (700 to 1,600 ft msl).
- Mill Creek watershed:
  - Martin Road Spring – emerges near the contact of the Santa Margarita Sandstone and granitic basement rock north of Martin Road at an elevation of about 1,500 ft msl (approximately 15 gpm).

We observed two springs emerging from the quarry walls in April 2006, each flowing about 10-15 gpm. One spring was feeding a large pond in the northwest corner of the quarry. The second spring was flowing out onto the quarry floor on the east central side of the quarry (Plate 2). The flow from this spring appeared to be percolating into the quarry floor. The occurrence of these two springs was probably related to above average rainfall during WYs 2005 and 2006.

3.5 Water Production

3.5.1 City of Santa Cruz Diversions

About 30 percent of the City of Santa Cruz's water supply is derived from its North Coast pipeline, which conveys water diverted from Liddell Spring and Laguna, Reggiardo, and Majors creeks to the City's Graham Hill Water Treatment Plant. The Reggiardo Creek diversion is piped to the Laguna Creek intake and is not separately metered. Thus, references to the Laguna Creek diversion hereafter implicitly include the Reggiardo Creek diversion. As stated above, an evaluation of potential impacts to Liddell Spring diversions requires an overall understanding of the City's North Coast diversions.

The City's pre-1914 appropriative water rights for these sources have allowed unlimited diversions up to the pipeline's capacity. Figure 14 and Table 18 present the annual production from these sources since WY 1972, the first year that complete records are available from the City. Of the 3,300 ac-ft/yr total average diversion, Liddell Spring has supplied 1,250 ac-ft/yr, Laguna and Reggiardo creeks 1,620 ac-ft/yr, and Majors Creek 430 ac-ft/yr. On a percentage basis, Liddell Spring has provided 39 percent of the total average diversion while Laguna and Reggiardo creeks have provided 47 percent and Majors Creek 14 percent. The Reggiardo Creek diversion intake is currently buried in sediment such that its contribution is very minor (M. Baldzikowski, City of Santa Cruz Water Department, written communication).

Liddell Spring and Majors Creek provide greater percentages of the total North Coast diversion during dry periods, whereas Laguna Creek provides a greater portion of the total during wet periods. Majors Creek provides less of the total during wet periods because the pipeline capacity is mostly met by the other two diversions, which originate at higher elevations. Total annual diversions from all three sources range from 1,700 to nearly 5,000 ac-ft/yr. Monthly diversions range up to 550 ac-ft, or about 4,100 gpm averaged over the month.

Prior to June 1994, the City's North Coast pipeline directly served some customers. This limited the allowable turbidity of diverted flows to about 2 nephelometric turbidity units (NTU). Since then, the turbidity threshold of divertible flows has risen to about 10 to 25 NTU (T. Tompkins, City of Santa Cruz Water Department, personal communication, February 27, 2006). Based on the precipitation-diversion double mass curves in Figure 15, this does not appear to have resulted in a substantial shift in the overall rate of diversion.

Figures 16, 17, and 18 present the records for each diversion's specific conductance, nitrate concentration, and turbidity since WY 1974 (a longer period of record is presented for Liddell Spring below). Samples typically are collected on a bi-weekly basis and only reflect the quality of water actually diverted. For example, turbid storm flows that are allowed to bypass the diversion are not reflected by these data. Also, changes in sampling method and/or measuring technique may be responsible for some of the data variability and apparent shifts in values.

The specific conductance of Laguna and Majors creek diversions follows a similar annual pattern, gradually rising through the dry season as a result of an increasing contribution from groundwater discharge, and then quickly decreasing as a result of dilution at the outset of wet-season runoff (Figure 16). The specific conductance of Liddell Creek diversions follows an inverse seasonal trend, peaking during the middle of the wet season and gradually falling during the dry season. This suggests that high hydraulic heads resulting from wet-season recharge cause the discharge of more mineralized groundwater than during other times of year. Liddell Spring diversions appear to have experienced a roughly 50 µS/cm increase in specific conductance between the 1980's and 1990's. The specific conductance of all three diversions became relatively erratic and somewhat lower beginning in 2001, perhaps as a result of the unprecedented preceding six years of above-average precipitation (Table 12).

The nitrate concentrations of Laguna and Majors creek diversions have been relatively stable at generally <1 and <2 mg/L, respectively (Figure 17). The nitrate concentrations of Liddell Spring diversions were <2 mg/L prior to 1977 and have since typically ranged from about 1 to 5 mg/L, with a few values in the range of 5 to 10 mg/L. Nitrate concentrations generally peak in Laguna Creek diversions during spring, in Majors Creek diversions during autumn, and in Liddell Spring diversions during early to mid-winter.

From the mid-1970's through the mid-1990's, the turbidities of Liddell Spring and Laguna Creek diversions generally ranged between about 0.1 and 10 NTU (Figure 18). Although overall turbidity trends for both diversions have remained flat, the incidence of turbidities between 10 and 100 NTU increased beginning in the mid-1990's, perhaps because of the cessation of customers relying on the North Coast pipeline, which allowed the diversion of more turbid flows. The turbidity of Majors Creek diversions exceeds that of the other two diversions, without any significant trend through the period of record.

3.5.1.1 Liddell Spring

Liddell Spring has been a source of water for the City of Santa Cruz since 1913. Historically, Liddell Spring has provided a reliable water supply in terms of both quantity and quality. Stewart (March 1978) noted the following: the springbox built in 1959 never needed cleaning; during the early 1960's the spring provided the City's entire supply for up to three weeks during stormy periods when other sources were too turbid; the available diversion could be predicted many months in advance due to the springflow's gradual rise and fall.

Table 19 presents the available diversion record for Liddell Spring. Since WY 1972, Liddell Spring has provided 7 to 14 percent of the City's annual supply. Annual diversions average 1,250 ac-ft/yr (775 gpm) and range within ±33 percent of average. Average diversions for each month of the year narrowly range between 7 and 9 percent of the average annual total. Peak-month diversions range up to 200 ac-ft, or nearly 1,500 gpm (3.3. cfs) averaged over the month. The maximum diversion capacity is about 2,000 gpm (2.9 million gallons per day [mgd]).

Table 20 compares the diverted versus gaged flows of Liddell Spring for WYs 1999-2005. For the months with gaging data, diversions equaled 90 percent or more of the flow about 80 percent of the time. Although lower rates of diversion as a percent of total flow tend to occur during winter and early spring, diversions can be assumed to be roughly representative of total flows. This is because (a) Liddell Spring is a preferred source of typically good quality water, (b) its divertible flows are always less than the City's instantaneous water demand, and (c) its use allows other sources to remain in storage (i.e., Loch Lomond and groundwater).

Lindsey (April 1967) theorized on the role of antecedent moisture in the behavior of Liddell Spring, stating that flow conditions were heavily influenced by at least the preceding two years of precipitation. Table 21 presents the results of a multiple regression analysis of the correlation between annual diversions and current-year and prior-year precipitation for WY 1972-2001 diversions from both Liddell Spring and Laguna Creek.[2] Maximum correlations for both diversions were achieved using precipitation for the current year plus three prior years. However, the contribution of each year to the overall correlation varied considerably between diversions. Laguna Creek diversions are most strongly correlated to precipitation during the current year and first prior year—an expected result for such a watershed. Conversely, Liddell Spring diversions are more highly correlated to the three prior years' precipitation than to the current year's precipitation. These results support Lindsey's contention stated above. The spring's response to precipitation within seasonal and storm-event timeframes is addressed in Section 4 of this report.

Figure 19 presents a water quality record for the Liddell Spring diversion that extends before and after the beginning of Bonny Doon Quarry operations in 1969. Specific conductance and nitrate concentrations were lower during a relatively intensive 1967-70 monitoring period when compared to data collected after 1980. Several years of substantially elevated seasonal turbidity began in 1970 and minimum turbidity values appear to have been slightly elevated through the remainder of the 1970's. Changes in sampling method and/or measuring technique could be responsible for some of the apparent shifts in data values.

Based on monitoring data for 1997-2005, presented in Section 4.3, the turbidity of Liddell Spring increases to as much as 1,000 NTU in response to storms. As a rule of thumb, precipitation in excess of one inch in a twenty-four hour period results in a turbidity reading requiring the City to turn-out the diversion (T. Tompkins/Santa Cruz Water Department, as cited by Watkins-Johnson, November 1992). Remote monitoring allows the springflow to be turned-out by remote control to prevent excessive turbidity from entering the North Coast pipeline. The diversion must be restarted manually, however, causing an interruption typically longer than the period of elevated turbidity. According to anecdotal accounts, elevated turbidity currently persists for days following storm events, whereas sometime in the past these periods of elevated turbidity lasted only hours (T. Tompkins, City of Santa Cruz Water Department, personal communication, February 27, 2006). This assertion cannot be tested given that hourly turbidity data have only been collected since 1997.

[2] A similar analysis for Majors Creek is unwarranted because the City's diversions are a poor representation of its total flow.

3.5.1.2 Laguna and Reggiardo Creeks

Laguna Creek has been a source of water for the City of Santa Cruz since 1890. Diversions from its tributary Reggiardo Creek are piped to the Laguna Creek intake and are not separately metered. Thus, references to the Laguna Creek diversion implicitly include the Reggiardo Creek diversion. The Laguna and Reggiardo creek intakes are at approximate elevations of 620 and 630 ft msl, respectively. The diversion capacity of the combined diversion is 6.5 cfs (4.2 mgd).

Table 22 presents the available diversion record for Laguna and Reggiardo creeks. Since WY 1972, they have provided 3 to 24 percent of the City's annual supply. Annual diversions average about 1,600 ac-ft/yr (2.2 cfs) and range between about 15 and 175 percent of average. Average diversions for each month of the year range between 4 and 13 percent of the average annual total. Peak-month diversions range up to about 400 ac-ft, or 6.5 cfs (nearly 3,000 gpm) averaged over the month.

Table 22 also provides 19 instantaneous diversion measurements for just Reggiardo Creek during relatively dry periods of 2003-05. The measured diversions were only about 10 gpm (0.02 cfs) or less. Diversions are limited by the sediment burying the intake, and measurements at wetter times are not currently possible (M. Baldzikowski, City of Santa Cruz Water Department, written communication).

Table 23 compares Laguna and Reggiardo creek diversions to the gaged flows of Laguna Creek upstream of its confluence with Reggiardo Creek for WYs 1971-77 and 2003-05. For the months with gaging data, diversions equaled 75 percent or more of Laguna Creek's gaged flow about 65 percent of the time.

3.5.1.3 Majors Creek

Majors Creek has been a source of water for the City of Santa Cruz since 1916. Table 24 presents the available diversion record for Majors Creek. Since WY 1972, Majors Creek has provided 1 to 8 percent of the City's annual supply. Annual diversions average about 450 ac-ft/yr (0.6 cfs) and range between 20 and 270 percent of average. Average diversions for each month of the year range between 3 and 13 percent of the annual total. Peak-month diversions range up to about 160 ac-ft, or 2.7 cfs (1,200 gpm) averaged over the month. The maximum diversion capacity is about 1.9 cfs (1.2 mgd).

Table 25 compares Majors Creek diversions to its gaged flows for WYs 1971-76 and 2004. For the months with gaging data, diversions equaled 70 percent or more of Majors Creek's gaged flow about 45 percent of the time. The percentage of flows diverted tends to be greatest in late summer and early autumn when pipeline capacity is available.

3.5.2 **RMC Diversions**

CEMEX diverts up to 21 gpm (927,000 gal/month) from Plant Spring, mostly for dust control at the quarry. CEMEX diverts up to 350 gpm from upper San Vicinte Creek and 130 gpm from Mill Creek for operation of the cement plant (Engineering-Science, April 1991).

4 Hydrogeology

This section presents a hydrogeologic conceptual model of the groundwater system underlying the quarry, proposed expansion area, and overall Liddell Spring recharge area. The primary components and boundaries of this system are as follows:

- A large block of granitic and metasedimentary rocks containing the weathered marble (i.e., karst) groundwater system tributary to Liddell Spring.
- The entire watersheds of Laguna and Reggiardo creeks upstream of the City of Santa Cruz diversions. These watersheds encompass all of the recognized karst sinks potentially tributary to Liddell Spring, as well as other nearby karst springs. Other than noted below, karst connections to adjacent watersheds to the east, west, and north appear lacking.
- Both large and small remnants of Santa Margarita Sandstone directly overlying the granitic and metasedimentary rocks, which are important areas of groundwater recharge tributary to the karst system. These may include sandstone areas that extend west into the adjacent Mill Creek watershed.
- A southern, downgradient boundary consisting of various geologic units that abut the apparent termination of the karst system. Exposed granitic rock along portions of this boundary may serve as a barrier to the continued downgradient flow of groundwater. Between Liddell Spring and Laguna Creek, karst groundwater may flow directly into exposures of Santa Margarita and Lompico sandstone along this boundary.

The remaining elements of the hydrogeologic conceptual model presented below are as follows:

- The nature and structure of the groundwater system's hydrogeologic units (Section 4.1).
- The conditions under which groundwater occurs within these units (Section 4.2).
- The water quality of groundwater, springflow, and stream baseflow as a supporting indicator of groundwater occurrence, movement, and recharge (Section 4.3).
- The vertical and horizontal movement of water and sediment through the subsurface, including pathways indicated by groundwater and springflow responses to precipitation and tracer tests (Section 4.4).
- The balance of estimated groundwater inflows and outflows (Section 4.5).

Based on this conceptual model, Section 4 concludes with an assessment of groundwater responses to past and current quarry activities (Section 4.6).