5.0 HYDROLOGY AND WATER QUALITY

This report section characterizes the quarry area hydrology and hydrogeology and provides a discussion of potential project environmental impacts and mitigations. This report section is abstracted from the detailed description and analysis of the quarry area hydrology and hydrogeology provided in Geologic, Hydrologic, and Hydrogeologic Technical Appendix for Draft EIR, Bonny Doon Quarry Proposed Expansion (Nolan Associates, 2007), hereafter referred to as the Geology and Hydrology Technical Appendix (Appendix F). The reader is encouraged to consult the Geology and Hydrology Technical Appendix for more detailed (and technical) discussion of topics included in this section.

In the following discussions, hydrology refers to the movement of water over the ground surface and is principally concerned with factors such as precipitation and stream or spring flow. Hydrogeology refers to the movement of water under ground, and is concerned with the ground water table and the direction of ground water flow. The surface water and ground water flows are always linked—surface water percolates into the ground to feed the ground water supply and ground water emerges into springs or streams--but the interaction of the two in the present area is somewhat unique because of the special qualities of ground water flow through marble rock, such as occurs in and around the quarry.

The movement of both surface water and ground water in the quarry and surrounding area is strongly influenced by the local geology and the following analysis of the project impacts depends on an understanding of the geologic setting, as summarized in Geology, Section 4.0. Because surface water and ground water originate beyond the boundaries of the quarry property and flow through the quarry to areas downstream, it has been necessary to study a large area around the quarry to provide for the analysis of potential Boundary Expansion Area impacts. This larger area is defined as the geologic/hydrologic study area, bounded on the north by Ice Cream Grade, on the west by Bonny Doon and Pine Flat Roads, on the east by Laguna Creek, and on the south by an east-west line drawn approximately through Liddell Spring (Figure 16).

The following sections describe the hydrologic and hydrogeologic setting of the quarry and proposed Boundary Expansion Area based on observations of local topography, geology, precipitation, surface water flow and ground water flow. Following the setting discussion, this chapter presents a model of the paired surface/ground water flow system to serve as a basis for assessing the water quality and water quantity impacts expected from the proposed quarry expansion.

5.1 ENVIRONMENTAL SETTING

The hydrology and hydrogeology environmental setting sections of the EIR are based on:

- a review of available geologic, hydrologic, and hydrogeologic literature describing the geologic/hydrologic study area and previous hydrologic and hydrogeologic consulting reports, maps, and other documents prepared for the quarry;
- review of hydrologic data for the geologic/hydrologic study area, including rainfall records, stream and spring flow records, and water quality records;

- review of the geologic model prepared for the geologic/hydrologic study area by the EIR geologic consultants (Geology and Hydrology Technical Appendix, Appendix F);
- participation in dye tracer studies performed for the quarry operator by P.E. Lamoreaux and Associates (PELA, 2005);
- drilling of one exploratory boring in the quarry to measure ground water levels and to use as an access point for the dye tracer studies;
- monitoring of ponded water levels in the quarry pit;
- collection of well and exploratory boring records for the quarry and surrounding area;

5.1.1 Hydrologic Setting

The Bonny Doon Limestone Quarry is situated on the southwest slope of Ben Lomond Mountain (Figure 22, Topographic Index Map). Precipitation falling on this flank of the mountain enters a system of relatively short, steep, deeply incised, southwest flowing drainages that empty into the Pacific Ocean. The principal drainages in the area are San Vicente, Laguna, and Majors Creeks (Figure 22). The quarry and terrain immediately surrounding the quarry are situated within the watershed of Liddell Creek. Liddell Creek is fed, in part, by two springs issuing from the quarry property, Liddell and Plant Springs.

The Bonny Doon Limestone quarry is located in an area of Mediterranean-type climate that receives most of its rainfall during the winter season. Based on various available records, mean annual precipitation in the quarry area is estimated to range between about 34 and 40 inches per year (in/yr). Annual precipitation increases with elevation to as much as 60 in/yr at the crest of Ben Lomond Mountain, north of the quarry. Most of this rain falls during the winter season between October and April.

The quarry and proposed Boundary Expansion Area occupy the headwaters of the central and eastern branches of Liddell Creek (Figure 23, Quarry and Vicinity Drainage Areas). The drainage area for the quarry and Boundary Expansion Area watershed is about 125 acres. Excavation for the quarry has created a closed basin with no outlet. Therefore, most of the runoff that falls on the quarry watershed flows to the quarry floor and percolates into the ground. Only a small percentage of the runoff is lost to evaporation. An 8-acre swale on the downhill side of the quarry leads to Liddell Spring. Any overflow from the quarry would flow down this swale into Liddell Creek. However, the water level in the quarry does not get high enough to overflow.

The quarry and surrounding lands are underlain by marble. The marble bedrock that underlies the quarry and large portions of the geologic/hydrologic study area is riddled with cavities, fissures, and caverns that formed due to dissolution of the marble by percolating ground water. Other rock types in the area do not dissolve in water. The fissures and caverns formed in the marble sometimes reach the ground surface, were they form open pits called sinkholes, or dolines. Where streams flow into the sinkholes, they are called swallow holes.

Prior to quarrying, there were several sinkholes located where the quarry now is. It is likely that much of the surface runoff prior to quarrying was captured by sinkholes, although there are no specific reports of such capture in the review literature. At present, there are active sinkholes to the north and northeast of the quarry that capture surface flow (Figure 23). Whitesell Creek, which follows the northwest rim of the quarry, and Reggiardo Creek, to the northeast, are both captured (at least in part) by swallow holes (“sinking streams”, Figure 23). Water entering the sinkholes and swallow holes becomes part of the ground water flow regime.

Using the mean annual precipitation of 34 to 40 inches, the 125-acre drainage area of the quarry watershed, the amount of impermeable exposed rock surface, and the fact that the quarry retains and rapidly percolates most of the runoff from this area, the expected recharge to ground water from the quarry and proposed Boundary Expansion Area drainage is in the range of 200 acre-feet per year (ac-ft/yr)(Geology and Hydrology Technical Appendix, Section 3.2, Appendix F). An acre-foot is the amount of water needed to cover an acre of land one foot deep with water. Annual recharge from the quarry and adjacent small basins that drain to sinkholes or swallow holes (drainages 1, 2, and 3, Figure 23) is estimated to be 300 ac-ft/yr. During the wettest years, this amount may be two or more times greater.

5.1.1.1 Drainage Baseline Description

The current Use Permit 3236-U for the Bonny Doon Limestone Quarry requires that finished excavations shall in all cases be graded in such a manner as to prevent the accumulation of storm waters or natural seepage. The Use Permit limits excavation to an elevation no lower than 750 feet above mean sea level (ft msl). In addition, maps and diagrams associated with the Use Permit indicate that the final contours of the Limestone Quarry pit would allow the pit to drain by gravity to Settlement Basin 3.

Most of the quarry pit was drained by gravity to Settlement Basin 3 until the early 1990s, when the pit was excavated below the elevation of the crusher area at the mouth of the pit creating a closed basin. The practice of allowing surface water impounded in the pit to infiltrate into the karst aquifer was recommended by EMCON Associates in 1992. This recommendation has been incorporated into the Conditions of Approval for COC and the 1996 Reclamation Plan Approval 89-0492.

The bottom of the quarry pit has reached its maximum depth over a wide, level area. The current elevation of the quarry pit floor is approximately 752 ft msl and has expanded to near maximum horizontal area. However, the location and elevation of the crusher at the mouth of the quarry pit has not changed and the highest elevation at the mouth of the pit near the crusher has remained consistent at approximately 815 ft msl.

The approved final contour plans would require blasting and excavation of the area at the mouth of the pit near the crusher to lower the elevation by approximately 65 feet, allowing water to drain by gravity from the pit to Settlement Basin 3. These drainage measures approved during mining and for reclamation would not change as a result of the proposed expansion.

5.1.1.2 Springs

One of the principal potential impacts of concern within the proposed Boundary Expansion Area is the possibility that mining of the area would degrade water quality of major springs downstream from the quarry. This section summarizes information regarding the principal springs of interest, Liddell Spring and Plant Spring.

Liddell Spring is located immediately south of the Bonny Doon Limestone Quarry (Figure 23). It is the largest spring in the region and is a significant water source for the City of Santa Cruz. The City of Santa Cruz does not take the entire output of the spring, but diverts part of the flow when water quality at the spring and water demand by the City support it. The City monitors its monthly diversions from the spring for quality and quantity and has gauged total instantaneous spring flow intermittently since 1999.

Data from City of Santa Cruz records show that during water years (WYs)[1] 1999-2005, monthly average flow rates at Liddell Spring ranged between 760 and 1,720 gpm and averaged about 1,100 gpm. Peak gauged flows (rather than monthly average flows) have ranged from about 600 to 3,100 gpm. Based on the available gauging data, including the City of Santa Cruz's record of diversions, the total mean annual flow of Liddell Spring is estimated to be 1,500 ac-ft/yr (Geology and Hydrology Technical Appendix, Appendix F).

Plant Spring is about 1,400 feet east of Liddell Spring (Figure 23). From November 2002 to November 2004, flows averaged 184 gpm (about 300 ac-ft/yr) and ranged from 66 to 338 gpm (Geology and Hydrology Technical Appendix, Appendix F). CEMEX diverts up to 21 gpm (927,000 gallons/month) from Plant Spring, mostly for dust control at the quarry.

Many relatively minor springs occur elsewhere in the area.

5.1.1.3 Water Production at 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. 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. Of the 3,300 ac-ft/yr diverted from all four sources, Liddell Spring has supplied 1,250 ac-ft/yr since WY 1972, or 39 percent.

One measure of water quality that is of importance at Liddell Spring is turbidity. Turbidity is a measure of the amount of suspended fine sediment particles within the water. Turbidity is not by itself considered a health hazard, but higher levels of turbidity can encourage the growth of bacteria. Consequently, most water purveyors strive to supply water with low turbidity levels. 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). Beginning in 1994, the City began piping water directly to its treatment plant from the north coast, before sending it back to its north coast customers. Since then, the turbidity threshold of divertible flows has risen to about 10 to 25 NTU. However, this does not appear to have resulted in a substantial shift in the overall rate of diversion.

Turbidity typically increases during storms and decreases in the time between storms, as does the overall flow at the spring. This relationship is expected and is commonly observed in streams where greater runoff during storms stirs up sediment that causes turbidity. Based on hourly monitoring data for 1997 to 2005, the turbidity of Liddell Spring increases to as much as 1,000 NTU in response to storms. Elevated turbidity currently persists for days following storm

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[1] A water year is the "precipitation year" from October 1 through the following September 30: e.g., WY 2006 would include precipitation from October 1, 2005 to September 30, 2006.

events. According to anecdotal accounts, sometime in the past these periods of elevated turbidity lasted only hours. This assertion cannot be tested given that hourly turbidity data have only been collected since 1997.

Another measure of water quality is specific conductance. Specific conductance is a measure of how well water will conduct electricity and it is an indirect measure of the amount of dissolved minerals that are present in the water. A large amount of dissolved minerals will result in a relatively high specific conductance. The specific conductance of Liddell Creek diversions follows a seasonal trend– peaking during the wet season and gradually falling during the dry season. This trend is the opposite of the specific conductance variation in local streams, which show low specific conductance in the winter and higher conductance in the summer.

In streams, the low wintertime conductance is a result of the rapid runoff of non-mineralized (low conductance) rainfall in the streams. Stream flow in the summer consists mostly of surfacing ground water or soil water that has been stored for some time, allowing it to absorb minerals. The summer stream flow therefore has a higher specific conductance. At Liddell Spring, the highest specific conductances are seen in the winter. This observation indicates that the high wet-season flows cause the discharge of more mineralized ground water from storage than during other times of the year. The winter rainfall is "pushing" older water out of the underground aquifer system rather than simply contributing directly to spring flow.

This process has been confirmed by studies of the relationship between spring flow volume and annual rainfall (Geology and Hydrology Technical Appendix, Section 3.5.1.1, Appendix F). These studies indicate that spring flow at Liddell Spring is more attributable to the amount of rainfall that occurred in several previous years than it is to the rainfall in the year that the spring flow is being measured, i.e., spring flow amounts are heavily influenced by the preceding several years' precipitation. This observation is important in understanding the overall ground water flow system, as will be discussed later in this Chapter.

5.1.2 Hydrogeologic Setting

The hydrogeology of the Quarry and vicinity is dominated by a localized karst ground water system developed in marble bearing metamorphic rocks underlying Ben Lomond Mountain. The term "karst" refers to terrain underlain by limestone or marble where runoff from rainfall drains primarily through a system of underground fissures or caverns rather than in surface streams. The ground surface in areas of karst consists of hollows and pits where water enters the rock and enlarges joints and fissures by solution. The primary components of the ground water system underlying the geologic/hydrologic study area (the quarry, proposed quarry Boundary Expansion Area, and overall Liddell Spring recharge area) are as follows:

- A large block of metamorphic rocks containing the weathered marble (i.e., karst) ground water system tributary to Liddell Spring.
- The entire watersheds of Laguna and Reggiardo creeks above the elevation of Liddell Spring. These watersheds encompass all of the recognized karst sinks potentially tributary to Liddell Spring, as well as other nearby karst springs.
- Both large and small remnants of Santa Margarita Sandstone directly overlying the granitic and metamorphic rocks, which are important areas of ground water recharge tributary to the karst system.

- A southern, down stream boundary consisting of granitic rock that bounds the karst aquifer on its downstream side.

5.1.2.1 Hydrogeologic Units

The hydrogeologic units of primary importance in the vicinity of the Bonny Doon Limestone Quarry include both water-bearing and non-water-bearing rocks. Water bearing units are rocks that readily store and transmit water to springs or wells. Non-water bearing units are relatively impermeable rocks that transmit water slowly, if at all. Saturated, water-bearing rocks are considered to be aquifers. In the geologic/hydrologic study area, the primary aquifers are the marble and Santa Margarita Sandstone. Units that act mostly as barriers to ground water flow include the granitic rocks and schist. The distribution of these rocks in the study area is depicted on Figure 24, Fracture Zones Interconnecting Marble, Sinking Streams, and Springs.

Non-Water Bearing Rocks

The granitic rocks occur regionally in large bodies spanning several square miles, but also as smaller bodies intruded or faulted into juxtaposition with other rocks. Granitic rocks also occur sporadically as thin layers (dikes and sills) a few feet to tens of feet thick injected along faults, joints, or bedding planes in the surrounding metamorphic rock. Exposures of granitic rock surround nearly the entire karst ground water system, which helps to contain and focus ground water flow toward Liddell Spring.

Schist generally has low permeability and generally is not an important water-bearing unit. The schist’s primary hydrogeologic importance is its association with marble inclusions. Bodies of marble occur throughout the schist and are more extensive than previously mapped. Marble may exist in the near- or sub-surface zone wherever schist is mapped or inferred. A large portion of the Santa Margarita Sandstone outcrop appears to be underlain by schist and probably some marble. The schist may transmit ground water where sufficiently fractured or weathered. This may help explain the ground water pathways through schist between apparently isolated bodies of marble, as will be discussed in the section on dye tracer studies, below. Also, sinkholes may form in schist underlain by marble, and karst springs may emerge from schist outcrops if marble is at shallow depth.

Water Bearing Rocks

The Santa Margarita Sandstone is an important aquifer in the Bonny Doon area. It is generally thin (0 to 300 feet thick) and covers underlying granitic rock, schist, and marble like a blanket. It readily absorbs and stores water where it is exposed and transmits that water into the underlying rocks.

The approximately 1.5 acres of landslide deposits immediately east and northeast of Liddell Spring are permeable and transmit ground water (Plate 2, Geology and Hydrology Technical Appendix, Appendix F). Given their limited volume, these deposits have limited importance with respect to ground water yield. However, a spring flow turbidity response observed during construction of a landslide monitoring well indicates a degree of hydraulic connection between the landslide and spring.

The Bonny Doon Limestone Quarry is located within a block of faulted marble roughly 4,000-foot square. It is the largest block of marble evident in the immediate area, and regionally second in size to the body of marble at University of California Santa Cruz, about 5 miles to the southeast. A smaller body of marble occurs in the Reggiardo Creek watershed to the immediate east, which is at least partially juxtaposed with the quarry block. Other apparently smaller bodies of faulted marble occur to the north-northeast along Laguna Creek. Tracer studies discussed later in this summary suggest that these bodies are interconnected into a single karst ground water system. The marble may be more extensive at depth and/or the individual bodies may be interconnected by fractures and marble interbeds within the schist. Areas of marble may directly underlie the large exposure of Santa Margarita Sandstone that occurs about a mile north of the quarry.

Marble has little primary porosity and very low permeability where unfractured and unweathered (that is, it does not store or transmit water very well). Dissolution of the marble by slightly acidic percolating soil water and flowing ground water results in substantial secondary porosity, including "macropores" such as caverns and conduits. These tend to form preferentially along fractures, leaving blocks of low permeability marble between fracture zones.

A roughly diamond-shaped grid of major fracture zones cuts through the quarry area (Figure 24). The fracture zone locations are based largely on the topographic pattern of narrow valleys cutting across the terrain, with intervening steep sided hills or knobs (the fractures are mapped along the valleys). The fractures are also visible in the walls of the quarry.

At least four major fracture zones occur at the quarry, they trend northeast between Liddell Spring and the quarry property's northern boundary. Another four or more major fracture zones trend south-southeast between the western edge of the quarry and Reggiardo Creek. These major fracture zones are spaced roughly 1,000 feet apart on average and form a grid over the quarry area (Figure 24). Liddell Spring is located at the southern, down stream tip of this grid.

Sinkholes tend to align with these fracture zones, with the most prominent sinkholes occurring at or near major fracture intersections. Quarrying and structural mapping reveal the occurrence of buried sinkholes along the top of the marble beneath the Santa Margarita Sandstone. These sinkholes are thought to have formed when the marble was exposed to erosion before the deposition of the Santa Margarita Sandstone, many millions of years ago. Many of the buried sinkholes coincide with active sinkholes or sinkholes that were mined out by the quarry. Swallow holes tend to form where streams flow across marble outcrops, forming sinking stream "reaches" (Figure 24). Sinking-stream reaches along Reggiardo and Laguna creeks intersect fracture zones leading toward the quarry and Liddell Spring. Karst springs tend to occur at the down stream edge of marble outcrops, but also may emerge from other rocks down stream of the exposed marble.

Solution-widened fractures are visible in the quarry walls, commonly forming continuous zones of solution channeling that extend from the original ground surface down several hundred feet to the quarry floor and below. Fractures cut across schist interbeds and igneous sills and dikes such that these rocks do not impede ground water flow through the karst. Fractures and conduits do become blocked for periods of time when bridged with sediment or collapsed marble.

Nolan Associates reviewed 225 borings drilled for the quarry with known locations and elevations. Karst voids and porous zones comprised nearly 10 percent of all the logs, more than half of which were filled with sediment. Five boreholes drilled within or immediately adjacent to the Boundary Expansion Area encountered karst voids 10 to 40 feet tall. Based on these results, the marble's overall porosity may be as much as 5 percent (see Geology and Hydrology Technical Report, Section 4.1.3). Shallow and deep solution cavities are interconnected, consistent with the ongoing dissolution of marble simultaneous with the gradual uplift of Ben Lomond Mountain (in some geologic settings, solution cavities appear to be arranged in distinct layers).

Ground Water Levels

Nine quarry monitoring wells have ground water depths greater than 300 feet and five others have depths greater than 200 feet. Such great depths are rare in the region, and reflect the extraordinarily rapid and deep drainage of ground water into the karst system supplying Liddell Spring. Water supply wells in the Bonny Doon area up stream of the quarry have water levels typically less than 60 feet deep.

Water table elevations are shown on Figure 25, Generalized Ground Water Surface Contours. Two sets of ground water table contours are shown on Figure 25 in the quarry area, a shallow ground water table and a deep ground water table. The shallow ground water surface reflects surficial recharge into the Santa Margarita Sandstone and the deep ground water surface reflects deep conduit flow in the karst aquifer, mostly from stream swallow holes.

The shallow ground water table in the Bonny Doon Area descends gradually towards the area north of the quarry (Figure 25). It then wraps around the quarry marble body in response to ground water drainage into the karst aquifer, causing a water-level drop of several hundred feet over a relatively short distance (Figure 25).

The drop in water table elevation is achieved in a step-like manner over a transition zone a few hundred feet wide where the ground water flows out laterally, filling local cavities in the marble above the deeper water table under the quarry. These transitional pockets of water that fill or partially fill cavities in the transition zone have been encountered during drilling and are considered to be "perched" ground water, that is, ground water that is being temporarily detained above the more permanent water table.

Several monitoring wells on the quarry property have ground water levels representative of the transition between the shallow sandstone aquifer to the north and east of the quarry and the deep marble aquifer beneath the quarry. These levels vary over a 300-foot range, are fairly erratic, and only sometimes correlate to each other and the precipitation record.

A deep water table is also shown on Figure 25. The deep ground water surface represents the top of the permanently saturated zone and is an average of water levels found in separate karst conduits connecting stream swallow holes to the quarry area and Liddell and Plant springs. This surface has a southwest sloping water table, compared to the overall southward regional ground water slope. The southwestern sloping ground water table slope is indicative of rapid flow along southwest trending fracture conduits in the marble and shows the variable character of the karst aquifer.

Ground Water Characteristics

A number of factors were used to characterize ground water in the geologic/hydrologic study area: temperature, "mineral" constituents (ionic makeup), specific conductance, and stable isotope ratios (Geology and Hydrology Technical Appendix, Sections 4.31. to 4.3.4, Appendix F). Nolan Associates found that different water sources had fairly distinct signatures based on the values of these various factors.

Water temperature is an indicator of ground water movement. Water that has been in the aquifer for a long time period will be at about the mean annual air temperature. Water that has recently entered the aquifer from winter storms will be cooler, reflecting cooler winter air temperatures. On the other hand, ground water that is nearing the surface at springs or seeps will equilibrate to seasonal temperatures (summer or winter). Water temperatures at Liddell Spring were a mixture of cool and warm waters, but generally had warmer temperatures during higher winter flows, indicating that long term ground water storage contributes substantially to the higher flows.

"Mineral" constituents refers to the type of elements (ions) dissolved in the water. Ground water will pick up ions from the surrounding rocks. Because rocks vary in composition, the type of ions in ground water can vary between different rock types. Ground water associated with the marble tended to be richer in calcium and bicarbonate, derived from its contact with marble, which is made up of calcium carbonate. Ground water associated with the Santa Margarita Sandstone tended to be richer in sodium and chloride, probably a result of the breakdown of feldspar and other minerals in the sandstone.

Specific conductance, as explained above, is an indirect measure of the amount of dissolved minerals (ions) present in water. Rainfall and stream flow derived directly from precipitation runoff is very low in dissolved minerals. It therefore has a low specific conductance. The longer water resides in surface water or underground, the more enriched it can be in mineral constituents and the higher its specific conductance will be.

The specific conductance measured in deep wells in the quarry area generally has a lower specific conductance than water from shallow wells. The opposite is normally true: deeper water is usually more mineralized and has a higher specific conductance than shallow water, because shallow water is more directly recharged by percolating rainfall. In the quarry area, the deeper water has a lower specific conductance because it consists of stream water flowing more or less directly from swallow holes to the springs through deep karst conduits. The shallow water is more likely to be perched water trapped for some time in soil or in pockets in the marble. The average specific conductance of discharge from Liddell Spring is mid-way between that of captured stream flow in deep conduits and more mineralized water from other recharge sources.

Isotopes are a result of variations in the number of neutrons in the atomic nucleus of different elements. Some isotopes are unstable, and will spontaneously degrade over time through radioactive decay. Other isotopes are stable and persist in the environment. PELA (2005) measure the ratios of stable isotopes of hydrogen and oxygen in various water samples from the geologic/hydrologic study area. Deuterium (D), an isotope of hydrogen, has one additional neutron in comparison to hydrogen (H). Oxygen-18 (^{18}O) has two additional neutrons when compared with oxygen-16 (^{16}O).

The added neutrons make D and ^{18}O heavier and affect their behavior. In particular, water made up of the heavier isotopes does not evaporate as fast as water composed of the lighter isotopes. Therefore, when water evaporates from surface water bodies, it has less ^{18}O and D than the water it leaves behind. Consequently, rainfall, derived from evaporation, has low ^{18}O and D amounts compared to surface water. Surface water tends to have differing amounts of the heavier isotopes, dependent on elevation, temperature, and other environmental factors. However, once the water percolates to ground water, little evaporation is possible and the isotopic ratio thereafter generally remains relatively constant. Therefore, the amounts of heavy isotopes of hydrogen and oxygen in a ground water sample can be used to identify its surface water source.

At the quarry area, ground water from the Santa Margarita Sandstone and marble areas near the sandstone has lower ^{18}O and D ratios than stream water or water sampled from deep conduits in the marble aquifer. The stable isotope data combined with the specific conductance data have been used to group waters in the geologic/hydrologic study area into five source types. Figure 26, Interpretation of Isotopic and Specific Conductance Data, is a plot of hydrogen isotope ratio (δD) versus oxygen isotope ratio ($\delta^{18}O$) with the data points grouped according to specific conductance values. These data are discussed in more detail in Section 4.3.4 of the Geology and Hydrology Technical Appendix (Appendix F).

Dye Tracer Studies

A key component used in formulation of the surface/ground water model is the results of dye tracer tests conducted by P.E. Lamoreaux and Associates (PELA, 2005). The purpose of the dye tracer studies was to help define ground water flow paths around and through the quarry and to identify the sources of water surfacing at Liddell Spring. Tracer tests have been previously recognized to provide a potentially critical means for evaluating Liddell Spring's connectivity to recharge and quarry operations. Four tests were performed between 1959 and 1968, with only one positive tracer detection at Liddell Spring.

The earlier tests yielded little useful information. The more recent tests by PELA (2005) took place in three phases and included approximately a year of monitoring. In the dye tracer studies, trace amounts of florescent dyes were added where surface water enters the ground water system and ground water outlets were monitored to help determine where the dye turned up and how long it took to reach each location. In this way, the connection between various entry points into the ground water system and the springs could be determined.

Nolan Associates participated in the design and execution of the dye tracer studies. The results of the studies are summarized in PELA's final report (PELA, 2005) and in the Geology and Hydrology Technical Appendix, Section 4.4.2 (Appendix F).

The results of the dye tracer tests are summarized in diagrammatic form on Figure 27, Summary of 2004 Tracer Test Results. The physical locations of dye introduction and monitoring points are shown on Figure 24. In brief, the studies showed a strong connection between sinking stream reaches on Laguna and Reggiardo Creeks and flow at Plant and Liddell Springs. The studies also showed a connection between Liddell Spring and a sinkhole to the northeast of the quarry (SH-6) and a well drilled in the south central portion of the quarry (NZA, Figure 27).

Ground Water Flow Paths

The quarry and proposed Boundary Expansion Area are part of a ground water flow system that supplies water to Plant and Liddell Springs along two principal flow paths. These flow paths are identified based on information from the temperature, mineral content, specific conductance, isotopic composition, and dye tracer studies. One path (Path *A*) originates from ground water recharge into exposures of Santa Margarita Sandstone across both the Bonny Doon plateau north of the quarry and the sandy knolls immediately east and northeast of the quarry, also underlain by Santa Margarita Sandstone (Figure 24).

A second path (Path *B*) is fed by stream water entering swallow holes along Laguna and Reggiardo creeks (sinking stream reaches, Figure 24). Each of these primary flow paths is associated with specific ground water characteristics and each can be subdivided into more localized flow paths based on specific water chemistry signatures. Ground water flow paths are depicted on Figure 28, Conceptual Model for Ground water Flow Paths. Figure 28 shows each principal flow path divided into sub-paths (A1, A2, B1, B2, etc.) and it shows a few ancillary paths (C, D, & E). A full discussion of the various sub-paths and ancillary paths is contained in the Geology and Hydrology Technical Appendix, Section 4.2.2 (Appendix F).

Path *A* originates from precipitation recharge into about 800 acres of exposed Santa Margarita Sandstone in the Bonny Doon area north of the quarry. Ground water is mounded in the sandstone and generally occurs at shallow depths of 10 to 60 feet below ground surface. An estimated 5,000 ac-feet of ground water may be stored in this area of sandstone. The regional water table slopes gently southward through Bonny Doon, descending from about 1,700 ft msl near Ice Cream Grade to 1,100 ft msl just north of the quarry. Ground water table elevations are depicted on Figure 25. Ground water also flows to the southwest and southeast toward the surrounding creeks, with some shallow ground water discharging at small springs. This ground water is relatively cool and has very low dissolved mineral concentrations of a sodium-chloride type. Water tables also occur locally from ground water recharged into the sandy knolls immediately east and northeast of the quarry.

Path *A* shallow ground water encounters the marble aquifer immediately up stream of the quarry. The aquifer's highly permeable karst features cause the ground water level to drop 300 feet in elevation over a relatively short distance (Figure 25). The ground water in the transitional zone has a hydrogen and oxygen isotopic signature similar to that of water in the Santa Margarita Sandstone aquifer, but it has a dissolved mineral concentration of a strongly calcium-carbonate type and a moderately high mineral content as a result of contact with the marble.

Temporary and seasonal springs and seeps have occurred as quarrying exposed ground water zones transitional between the higher regional water table on the Bonny Doon plateau and the deeper ground water zone under the quarry. The lack of any permanent springs as a result of quarrying is indicative of the karst aquifer's overall interconnectivity. Some of the wells drilled in the area do not encounter perched ground water, indicating areas where vertical connectivity allows rapid, deep drainage.

Path *B* originates as stream flow in the upper Laguna and Reggiardo creek watersheds. This water has a very low dissolved mineral content and cool temperature during the wet season. Lower in the watershed, stream flow increases in mineral content and has a calcium-bicarbonate type, indicating some influence by the marble. Stream flows in Laguna and Reggiardo creeks that are available for capture by swallow holes are roughly 1,000 ac-feet/year. Flows of this magnitude are available for capture during most years.

Path *B* continues where stream flow is captured by swallow holes along Reggiardo and Laguna creeks. The ground water tracer tests (PELA, 2005) indicate a strong hydraulic connection between the sinking-stream reaches in Reggiardo and Laguna Creeks and Liddell and Plant springs. Travel times for dyes inserted at the Reggiardo Creek swallow hole to the springs were about one to two weeks, indicating an average flow velocity of about 300 to 500 feet/day (map distance). Ground water encountered in several monitoring wells between the swallow holes and the springs suggest that captured stream flow from swallow holes flows to the springs through relatively deep and conductive dissolution conduits in the marble, which at times may be under confined pressure. These wells are located along major fracture zones and have deep water levels relative to nearby shallower wells. The water from these wells has fairly low dissolved mineral concentrations and hydrogen and oxygen isotopic signatures similar to Reggiardo and Laguna creek stream flow. The relatively deep zones of saturation are consistent with the tendency for karst conduits to cut down to near “base level” (in this case, the level of Liddell Spring) given the low slope needed to move water through such highly conductive zones.

Ground water moving along paths *A* and *B* flows through the marble aquifer beneath the quarry floor and undergoes some mixing as it approaches Liddell Spring, as indicated by the mixed character of the water surfacing at the spring. Percolation of precipitation falling on the quarry watershed and adjacent basins and runoff collected within the quarry pit constitutes a substantial source of additional ground water recharge along this segment. Ranging up to 300 ac-feet/year, this recharge pulse descends through fractures and dissolution features with sufficient energy to transport sediment to ground water. Blasts of high explosives are used to fracture and loosen marble for quarrying. Quarry blasting and “ripping” of the blasted rock by heavy equipment augments surficial and subsurface sediment supplies.

Tracer tests (PELA, 2005) showed that a monitoring well located on the quarry floor (NZA, Figure 27) is hydraulically connected to sinkholes above the quarry and to Liddell Spring, below the quarry. The travel time from this well to Liddell Spring was approximately 7 hours, indicating an average ground water velocity of 2,600 ft/day, the fastest rate of travel observed during the recent tracer tests. Given its location, water chemistry characteristics, and the dye tracer results, Plant Spring appears to be fed by path *B* ground water uninfluenced by percolation from the quarry or much input from areas of Santa Margarita Sandstone.

Based on the water balance computed for the karst aquifer (Geology and Hydrology Technical Appendix, Section 4.5, Appendix F), Liddell Spring accounts for more than 80 percent of the marble aquifer’s total yield and appears to be a mixture of flow paths *A* and *B* based on isotopic signature and dissolved mineral content intermediate between the two flow paths. The seasonal and year-to-year consistency of Liddell Spring discharge is evidence of the spring’s connection to a large volume of ground water storage. If the spring were being fed mostly by stream flow entering the swallow holes, its flow would vary much more according to winter storms and year-to-year variations in rainfall amounts.

Although the fairly rapid ground water velocities documented by dye tracers between stream swallow holes and Liddell and Plant springs indicate that some ground water flows rapidly from the swallow holes to the springs, a significant portion of captured stream flow is diverted into pore spaces and cavities marginal to the high conductivity pathways in the marble. When the inferred deep conduits between the swallow holes and the springs become fully saturated and pressurized during periods of high stream flow, ground water is forced upward and outward into the unsaturated karst cavities and fissures. This water displaces more mineralized ground water, forcing it out into the springs. This process explains why the mineral content of the Liddell Spring water increases during high flow conditions, while the mineral content of surface streams diminishes under these conditions.

5.1.2.2 Water Quality

Nitrate

Potential sources of nitrate in the geologic/hydrologic study area include wastewater (sewage) disposal, fertilizers, agricultural wastes, and the explosives used in quarrying (ammonium nitrate and fuel oil [ANFO]). Nearly 400 septic systems occur within the potential source area for Liddell Spring that includes the Reggiardo and Laguna creek watersheds above the karst swallow holes and the Santa Margarita Sandstone recharge area. A turkey ranch operated immediately north of the quarry from about 1950 to the mid-1970s. Orchards that may be fertilized also occur north of the quarry.

Nitrate concentrations in quarry monitoring wells have averaged about 3 mg/L and ranged from below detection to 15 mg/L, with no clear spatial or temporal pattern (Geology and Hydrology Technical Appendix, Section 4.3.5, Appendix F). Nitrate concentrations over 45 mg/L are considered to be potentially hazardous in drinking water. Nitrate concentrations in Whitesell Spring up stream of the quarry ranged from 28 to 56 mg/L when sampled in 1992 and 1997. This suggests a concentrated source, possibly residual waste from the former turkey ranch. Because the spring flows at 10 gpm or less, the total amount of nitrogen is relatively small. Mill Creek, which drains a portion of the Santa Margarita Sandstone recharge area, had a nitrate concentration of 5 mg/L when sampled in September 1982. Previous studies have found that higher nitrate levels tend to persist in soils associated with the Santa Margarita Sandstone due to high percolation capacities. The nitrate concentrations of waters tested in the immediate quarry area include 2.3 mg/L in water ponded on the quarry floor, 4.2 mg/L in the discharge of Dump Spring, and 3.8 mg/L in the drainage channel leading to the quarry's detention basins.

Nitrate concentrations in the City's diversions from Liddell Spring were less than 2 mg/L prior to 1977 and have since typically ranged from about 1 to 5 mg/L, with a few spikes occurring up to 5 to 10 mg/L. The nitrate concentrations of the City's Laguna and Majors creek diversions have not experienced major trends or spikes since 1972 have been relatively stable at generally <2 mg/L.

The spring's nitrate concentration probably derives from a combination of sources, including ANFO, agriculture, and septic systems.

Turbidity and Sediment

Unlike other aquifers, karst ground water systems have the capacity to transport considerable amounts of both suspended and bedload sediment due to the relatively high velocity of ground water flow through solution channels. Furthermore, sinkholes, stream capture, and marble dissolution and collapse provide replenishable sources of sediment.

High turbidity can interfere with disinfection and provide a medium for microbial growth. As of January 2002, the Interim Enhanced Surface Water Treatment Rule requires that drinking water turbidity never exceed 1 NTU and not exceed 0.3 NTU in 95 percent of a month's daily samples.

Liddell Spring's potential sources of sediment include eroded material and channel sediment washed into sinkholes, stream sediment intercepted by swallow holes, sediment stored or in transport within the subsurface, erosion and collapse of rocks within the subsurface, broken rock and rock dust from quarry blasting, and material fallen and washed into open fractures. Clastic (coarse grained) sediment that accumulates in the spring box and suspended sediment (very fine grained particles) responsible for turbidity may have distinctly different sources. Sediment pulses may be released when sediment-filled karst voids become breached and exposed to ground water flow.

Mineralogical analysis of suspended sediment samples collected from Liddell Spring does not point to a single source and suggests that none of the local geologic formations can be ruled out as potential sources (Geology and Hydrology Technical Appendix, Section 4.3.6, Appendix F). The Technical Appendix study found that only a few cubic feet of sediment a day could be responsible for the all the turbidity measured at Liddell Spring, a small amount of soil given the large area of the aquifer feeding the spring (Section 4.3.6, Appendix F).

Records of turbidity at Liddell spring date from the late 1950s. Unfortunately, two factors affect the usefulness of the early data. First, the turbidity samples were relatively infrequent. Since turbidity can vary by a factor of 10 or 100 over several hours time, frequent sampling is necessary to obtain a true picture of turbidity levels. Second, much of the turbidity record at Liddell Spring is based on the measurements of turbidity in water diverted by the City of Santa Cruz for its use, and therefore did not include turbidity levels of water issuing from the spring when the City was not diverting water, a potential bias in the data. Beginning in 1997, continuous (hourly) turbidity data has been collected from the spring.

During the early 1970s (at the time the quarry was put into operation) the turbidity of Liddell Spring diversions commonly ranged from 1 to 100 NTU and peaked upwards to 500 NTU (Geology and Hydrology Technical Appendix, Section 4.3.6, Appendix F). From about 1980 through the mid-1990s, the turbidity of Liddell Spring diversions mostly ranged between about 0.05 and 10 NTU. Since the mid-1990s the overall turbidity trend has remained flat, however the incidence of turbidities between 10 and 100 NTU has increased and the minimum level is generally above 0.1 NTU. This recent trend may reflect the City's ability to accept and handle more turbid water since 1994 (that is, the data may indicate that the quality of water diverted by the City has changed, rather than the overall quality of the water coming from the spring). A similar trend has been noted for the City's diversion from Laguna Creek, which is not affected by the quarry.

Observers have documented a strong correlation between the start of quarry operations and the ensuing years of increased spring sedimentation and turbidity in the early 1970s (Geology and Hydrology Technical Appendix, Section 4.6.2, Appendix F). A data review by

Earth Sciences Associates and Creegan & D'Angelo (May 1979) found that spring turbidity under natural, pre-quarry conditions sometimes exceeded standards later used to evaluate whether the quarry was having an impact. As such, they found that pre-December 1969 data were inadequate for establishing pre-quarry turbidity conditions. Also, changes in turbidity sampling methods and measuring techniques had occurred, complicating the interpretation of the data.

Nevertheless, Earth Sciences Associates and Creegan & D'Angelo (May 1979) and other observers noted a significant increase in spring flow turbidity and spring box sedimentation for several years after the quarry overburden was first removed in 1969. They documented increased spring flow turbidity between December 1969 and March 1974 and deemed the coinciding startup of quarry activities as the probable cause. They stated that, "Careful field inspection did not reveal any specific source of contamination of Liddell Spring. However, there are locations at which recorded 'sink holes' have been excavated and/or covered, and drainage patterns have been changed; it is possible these could have been a source of contamination in the period 1969-1970." These observations indicate that both surface and subsurface pathways were responsible for the elevated spring turbidity and sedimentation. They concluded that the City of Santa Cruz's water production from Liddell Spring declined as a result of increased turbidity during that time, not because of any reduction in spring flow quantity. They provided quantitative estimates of the annual reduction in City water production from Liddell Spring for the years following the beginning of quarry operations.

The relatively continuous Liddell Spring turbidity record since 1997 includes spring flows too turbid for the City to divert, ranging up to 1,000 NTU. On average, mean daily turbidities exceeded 2 and 10 NTU about 15 and 4 percent of the time, respectively. Mean daily turbidity correlates poorly with mean daily flow. Turbidities greater than 10 NTU have occurred on days with mean daily flows anywhere between 900 and 3,000 gpm. The highest recorded turbidities have not occurred at the highest flows, but instead are most associated with flows between 900 and 2,000 gpm (Geology and Hydrology Technical Appendix, Section 4.3.6, Appendix F). In examining records of turbidity during winter storms, it is observed that peak turbidities tend to occur prior to peak storm flow.

5.1.2.3 Ground water Movement and Sediment Transport

Spring Flow Response to Precipitation

Nolan Associates analyzed Liddell Spring's response to 15 storm events from January 2004 through April 2005 (Geology and Hydrology Technical Appendix, Section 4.4.3, Appendix F). This time period is the most complete period of continuous monitoring record available. WY 2004 was the fourth in a series of generally dry years whereas WY 2005 had above average precipitation. The analyzed storms represent a wide range of antecedent moisture and precipitation conditions (antecedent moisture refers to how wet the ground is when the storm of interest begins and it has a marked affect on the amount of runoff generated by a storm). The analysis looked at variations in flow rate, turbidity, and specific conductance as each storm progressed. As with previous observations, the time it took for the spring to respond to rainfall ranged widely. However, the order in which the flow rate, turbidity, and specific conductance peaks occurred was very consistent between storms, as was the relative duration of each peak (Figure 29, Average Timing of Liddell Spring and Runoff Responses to Storm Precipitation, 2004-05).

Following peak precipitation, Liddell Spring turbidity peaked nearly as quickly as stream discharge (measured at Majors Creek) (Figure 29). Among all the responses evaluated, the timing of precipitation, peak stream discharge, and peak spring turbidity were the most closely and consistently linked. The peak stream discharge is a measure of how rapidly rainfall collects and flows into streams. The fact that peak turbidity occurs at more or less the same time and shows the same sharp peak as peak runoff in streams indicates that the turbidity peak is linked to the same surface runoff process. Dye tracer tests indicate that several days or more are needed for water to travel to Liddell Spring from the Reggiardo and Laguna creek swallow holes. In contrast, turbidity peaks about 15 hours after onset of precipitation. Therefore, the turbid runoff responsible for initial peaks in spring turbidity must be entering the ground water system closer to the spring.

Whereas plots of Liddell Spring turbidity and Majors Creek discharge had similar relatively steep rising and falling limbs, Liddell Spring discharge and specific conductance had more gradual rising and falling limbs. This observation suggests that, while elevated turbidity is most related to runoff processes, elevated specific conductance is related more to ground water pressure and flow.

The ability of water to transport sediment increases with the volume and velocity of the water flow. Therefore, the power to transport sediment should be greatest during peak spring flow, however spring turbidity typically peaked about 6 hours earlier (Figure 29). Relatively simultaneous peaks in spring discharge and turbidity would be expected if turbidity were caused primarily by ground water picking up and moving sediment through the saturated marble aquifer. Instead, as noted above, runoff-related processes appear significantly responsible for the occurrence of peak turbidity.

Liddell Spring’s specific conductance peaked on average 34 hours after storm precipitation began, exhibiting the longest and most gradual storm response (Figure 29). This observation suggests that as the aquifer becomes pressurized with captured stream flow and other recharge, a higher proportion of more mineralized ground water is temporarily discharged from the aquifer. This inferred pressurization is consistent with the observed timing of increased ground water levels measured in a monitoring well near Liddell Spring (Farallon, August 2001).

The most delayed storm responses were secondary turbidity peaks in Liddell Spring. These secondary peaks occurred an average of 2 days after the storm began, and as long as 3 days afterward. These tend to be sharp, short-duration peaks similar to the initial turbidity response. These late turbidity responses may be related to recharge flowing from stream swallow holes, given roughly similar travel times for the fastest tracers to reach the springs from the nearest swallow holes during non-storm conditions.

Water levels were monitored in ponded runoff in the quarry pit through several storm cycles. The pond water levels were observed to rise and fall relatively rapidly, similar to the Majors Creek discharge record, indicating that pond levels were responding to runoff processes, like the creek (Geology and Hydrology Technical Appendix, Section 4.4.3.2, Appendix F). 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 ground water tracer to reach the spring from the quarry area. Peak spring turbidity occurred about 6 to 9 hours after the beginning of the pond level rise, and about 2 to 5 hours after the peak pond water level. These results indicate that runoff infiltration in the quarry area has a direct effect on Liddell Spring turbidity.

5.1.2.4 Conceptual Ground water Model

This section synthesizes evidence presented in preceding sections regarding surface water and ground water flow in the context of an overall model of flow in the karst aquifer underlying the quarry and surrounding area. This conceptual model serves as the basis for discussing the ground water response to quarrying in the next section.

Several lines of evidence support the interpretation that Liddell Spring has roughly two primary sources of water. From both hydrologic and hydrogeologic standpoints, the Santa Margarita Sandstone aquifer on the Bonny Doon plateau north of the quarry represents one major source of water, whereas captured Reggiardo and Laguna creek stream flow represents another. In terms of water quality, Liddell Spring has values of water temperature, specific conductance, nitrate concentration, and stable isotope ratios that are intermediate between these two sources. Conversely, Plant Spring is more similar in character to captured stream flow from the creeks. A third major source of water to Liddell Spring is precipitation and runoff captured by the quarry and adjacent areas drained by sinkholes or swallow holes (drainages 1, 2, and 3, Figure 23)

The recent tracer tests were only successful at demonstrating the stream capture sources. However, the apparent pattern of tracer movement was consistent with the two-source model. The interpretation of the tracer test results by Nolan Associates suggests that ground water originating from the stream swallow holes follows high permeability pathways through fracture zones along the eastern and southern margins of the marble aquifer toward the springs, whereas ground water flowing into the marble aquifer from the north follows fractures toward and through the quarry area to Liddell Spring. During relatively wet periods, the transmission of captured stream flow dominates more of the entire fracture system and pressures large amounts of ground water into storage within voids higher in the marble (Figure 30, Conceptual Model of Seasonal Change in Flow Pattern).

Nolan Associates (2007) prepared a water balance for the aquifer based on:

- recorded diversions from Liddell and Plant springs and Laguna and Reggiardo creeks by the City of Santa Cruz;
- flow-gauge records for Laguna Creek and Liddell Spring; and
- estimates of drainage areas and average precipitation for watersheds contributing to the karst aquifer.

A previous study provided guidance for estimating the proportion of precipitation that becomes total stream flow (i.e., both seasonal runoff and baseflow from ground water discharge) versus evapotranspiration, that is, precipitation lost to evaporation and uptake by plants (Geomatrix, March 1999). With this information, an estimate was made of how much water is entering the geologic/hydrologic study area via precipitation and stream flow, and how much is leaving it and where it is leaving it via streams and springs. The estimates reflect enhanced recharge from stream capture by swallow holes and relatively low evapotranspiration in sandy-soil (Santa Margarita Sandstone areas) and quarried areas, due to rapid runoff or percolation and the relative lack of plant cover. The water balance is summarized in Section 4.5 of the Geology and Hydrology Technical Appendix (Appendix F).

Based on the water balance figures, it is estimated that a transfer of approximately 1,300 ac-ft/yr from the Laguna and Reggiardo watersheds is needed to supply the annual yields of Liddell and Plant springs. Some of the transferred water originates from areal ground water recharge (i.e., path *A*) and some from stream capture (i.e., path *B*). The balance of about 500 ac-ft/yr needed to match the annual combined discharge of Liddell and Plant springs, about 1,800 ac-ft/yr, comes from more local sources, such as recharge in the quarry. Constrained by known yields, this conceptual water balance contributes to an understanding of the overall hydrologic system.

Several previous investigators concluded that Liddell Spring has one or more nearby sources (within a few hundred feet of the spring) with some connection to the ground surface (e.g., Wisser & Cox, 1960; Creegan, 1972; Watkins-Johnson, 1992; Farallon, 2001). Such sources probably account for only a small portion of the spring's discharge, and could not account for the total sediment load or timing observed in response to a storm event.

Liddell Spring's unique and complex response to storm events probably results in part from its multiple sources of water. Furthermore, Liddell Spring has multiple potential sources of sediment, some of which may be relatively independent of the primary sources of water.

Several lines of evidence show that sediment is being introduced into the ground water system and/or entrained into the ground water flow as a result of runoff-related processes at locations intermediate between the spring and the spring's primary sources of ground water recharge (i.e., stream swallow holes on Reggiardo and Laguna Creeks and the Santa Margarita Sandstone north of the quarry). The earliest turbidity responses noted by this and previous studies generally range between 2 and 10 hours, and average about 5 to 7 hours. This timing is too slow for a source immediately nearby (e.g., a sinkhole or the landslide adjacent to the spring), and yet is too quick for travel from the Reggiardo and Laguna creek swallow holes. Tracers required at least several days to reach the springs from the swallow holes, which may be consistent with some of the later turbidity responses. Therefore, the timing of turbidity peaks is too early to be a result of turbid stream water reaching Liddell Spring from the Reggiardo or Laguna Creek swallow holes.

The tracer travel time to Liddell Spring from the quarry was 7 hours, and this was during a several-year period of average to below average precipitation, when it might be slower than during very wet time periods. The timing and character of Liddell Spring's turbidity response is similar to quarry-floor pond levels and to runoff relationships of local streams and dissimilar to peak spring discharge. If the turbidity observed at Liddell Spring was simply a result of increased flow velocities entraining sediment within the karst system, more continuous, pulsed, and/or random transport would occur up to the point of peak spring discharge.

The high ground water velocities demonstrated by tracer tests and water level and quality data clearly indicate the occurrence of high permeability pathways through the marble aquifer. These pathways occur preferentially along fracture zones and consist of interconnected voids formed by dissolution of the marble bedrock. Such conduits formed continuously while the area has undergone tectonic uplift, leaving a network of interconnected, older voids above those currently forming. This network of voids lying above the permanent saturated zone provides the flow system with a large surplus capacity. This high capacity is evidenced by the system's ability to absorb recharge throughout the wettest years without the emergence of additional springs or substantial lengthening of the springs' response to storm flow. This three-dimensional network of voids provides for both pressurized flow in fully saturated conduits at depth and turbulent, cascading flow above.

Aquifer storage exists in less dynamic zones of saturation surrounding the major fracture flow paths. Since the water in storage is held for some time, it is more mineralized than water flowing more directly to the springs through the major flow paths. Release of the stored water during storm conditions is shown by the substantial rise in specific conductance observed as a relatively late response to storm events (Figure 29). Because Liddell Spring's turbidity peaks well before specific-conductance and discharge, it is unlikely that release of stored ground water contributes substantially to sediment transport and turbidity.

Interconnected voids above the permanent zone of saturation are available for the capture and transport of runoff from locations other than the major stream swallow holes. A considerable amount of precipitation and runoff is captured by the quarry and adjacent terrain, possibly as much as one fifth of Liddell Spring's average annual flow. Percolation of this drainage entrains sediment at the surface and in the subsurface created through blasting, ripping, and the disturbance of overburden, as well as naturally occurring sediment deposited in subsurface voids. Highly permeable interconnected voids have the potential to transport this water and sediment in a turbulent and cascading flow down to the zone of saturation and laterally toward Liddell Spring.

Relatively late turbidity responses that occur days after a storm likely reflect pulses arriving from where water cascaded into swallow holes along Reggiardo and Laguna creeks and entrained sediment that could then be held in suspension all the way to Liddell Spring. The spring's primary and more immediate turbidity response, however, must be explained by sources of turbid water and/or sediment closer to the spring.

5.1.2.5 Ground Water Response to Quarrying

The Bonny Doon Limestone Quarry is a major activity within the ground water system contributing to Liddell Spring. Some quarry operations occur as near as 500 feet from the spring; the actively mined quarry is about 1,500 to 2,500 feet up gradient and occupies roughly 80 acres. Since 1970, the quarry has mined an estimated 34 million cubic yards of marble from the same body of rock that forms the Liddell Spring aquifer. Assuming a porosity of 5 percent, the volume mined to date represents nearly 1,200 ac-ft of pore space. The quarry has lowered the marble surface several hundred feet to within as little as 50 feet of the underlying ground water. Mining and removal of overburden have left the fractured rock exposed, and blasting disturbs the rock in the subsurface. The quarry pit and the hill slope drainage into it have no external drainage, so turbid runoff from the quarry collects in the pit. Tracer tests indicate that ground water flowing beneath the quarry floor reaches Liddell Spring in 7 hours.

The analysis provided by the Geology and Hydrology Technical Appendix does not indicate any significant division of the marble's macroporosity (the collection of cavities, fissures, and caverns) into separate, poorly connected or unconnected zones at different depths

(Appendix F). The quarry is surrounded by many sinkholes, while several former sinkholes and caverns have been excavated by mining. Major fracture zones are inferred to have a controlling influence on the distribution of high-permeability pathways through the marble, and several such fracture zones intersect the quarry and link it to Liddell Spring. Substantial volumes of runoff percolate into the quarry pit without evidence of discharge other than to Liddell and possibly Plant springs. Whatever hydraulic separation may have existed between the original ground surface and the water table, little remains now that mining has proceeded to within 50 feet of underlying ground water.

The removal of overburden from the quarry area began in 1969 and actual mining began in August 1970. Accounts from 1969-74 link documented instances of Liddell Spring sedimentation and elevated turbidity with the removal of overburden, the initiation of quarrying, and above-average precipitation. For the most part, these early quarry activities were separated from the underlying ground water by several hundred feet of as-yet unquarried marble. Thus, it must be concluded that there was hydrogeologic connectivity between quarry operations and Liddell Spring at that time. The connection can be no less now that several hundred feet of marble have been removed from above a ground water zone shown through tracer testing to contribute to Liddell Spring. More recent instances of overburden removal have been relatively minor compared to the initial clearing of the quarry site.

Because the total spring flow of Liddell Spring was not gauged regularly prior to 1997, the available data do not allow a definitive assessment of whether or not quarrying has affected spring yield. Nolan Associates' analysis does not show historical shifts in production other than what can be explained by climatic cycles. Quarrying may have exposed several springs over the years that did not become permanent or substantially affect Liddell Spring. The unsaturated void space of marble now quarried may have provided temporary storage for recharging ground water. Thus, the capacity of the subsurface to absorb large recharge events may have diminished such that potential recharge is now rejected. Rejected recharge may appear as increased runoff as well as discharge from minor springs. To the extent that rejected recharge collects in the quarry pit, most of this water will eventually percolate back into the marble aquifer.

Nitrate concentrations in diversions from Laguna and Majors creeks have been relatively stable, whereas the nitrate concentrations of Liddell Spring diversions have been more erratic with some upward trend. Liddell Spring derives a substantial portion of its yield by capturing stream flow from these creeks. Therefore, the spring's other sources of recharge must be responsible for its elevated or erratic nitrate concentrations. Blasting with ANFO represents one likely source. Other sources appear to be at least as important, however, given the occurrence of elevated nitrate concentrations in monitoring wells and springs up gradient of the quarry.

Previous investigators have acknowledged that some increase in turbidity occurs as a result of blast events (e.g., PELA, 2005). These responses are highly varied, however, similar to Liddell Spring's range of responses to storm events. Twenty-two blast events during 2004-05 were evaluated by Nolan Associates as part of the study for the Geology and Hydrology Technical Appendix (Section 4.6.5, Appendix F). No turbidity peak was apparent following three of these events. Among the other 19 events, peak turbidity levels ranged from 2 to 78 NTU and occurred 2 to 7 hours after the blast. Although weather conditions varied considerably among these events, it was inferred that most of these turbidity peaks were blast related. Although the inferred turbidity responses to blasting are relatively small compared to storm-related turbidity, any increase in turbidity is undesirable from a water supply standpoint. More importantly, blast events contribute to the generation and/or mobility of sediment responsible for turbidity. Blasting may effectively increase the supply of sediment available to percolating water and ground water flow during and following storm events.

Liddell Spring's turbidity response to precipitation occurs within hours to days. The turbidity response is complex, highly variable from storm to storm and year to year, and may include multiple turbidity peaks stretching out over several days. Because the City only measured the turbidity of spring flows it actually diverted (on a roughly bi-weekly schedule) prior to beginning continuous monitoring in 1997, the data record is insufficient to demonstrate a definitive causal, before-and-after relation between quarrying and spring flow turbidity. Furthermore, sampling and measurement methods have changed, as has the City's ability to divert slightly more turbid water. Thus, an assessment of whether or not quarrying is having an effect on spring flow turbidity must rely on an interpretation of the local ground water system. Aquifer connectivity and a subsurface source of sediment are demonstrated by the spring's turbidity response to blasting.

Under current conditions, interconnected voids above the permanent zone of saturation capture and transmit substantial volumes of incident precipitation and runoff that percolate from the quarry area into the marble. This water is generally turbid and may entrain additional sediment from the quarry surface and within the subsurface, such as that created through blasting, ripping, and the disturbance of overburden, as well as naturally occurring sediment deposited in subsurface voids. An average of only a few cubic feet of sediment per day could account for Liddell Spring's turbidity. Highly permeable interconnected voids have the potential to transport this water and sediment in a turbulent and cascading flow down to the zone of saturation and laterally toward Liddell Spring.

The average timing of Liddell Spring's initial and primary turbidity peak following peak storm precipitation is generally consistent with the observed time for tracers to reach the spring from ground water beneath the quarry and the turbidity response to blasting in the quarry. The consistent rise and decline of spring turbidity, quarry-floor pond depth, and nearby stream discharge prior to peak Liddell Spring discharge indicates that sediment is introduced, or at least entrained, by runoff-related processes affecting ground water in the quarry area. The timing of the main turbidity peaks appear too slow for sources immediately adjacent to the spring (e.g., the landslide or nearby sinkholes) and too fast for transport from the Reggiardo and Laguna creek swallow holes. This interpretation is consistent with the City's claim that turbidity peaks are larger and occur more quickly in response to precipitation since quarrying began. While other turbidity sources and delivery mechanisms likely exist, the available data and the characteristics of the local ground water system strongly indicate that the quarry operation has an important contributing influence to spring turbidity.

The record of Liddell spring box sedimentation events (the filling of the City's spring box with sand and silt) is mostly anecdotal. Several observers documented substantial increases in spring box sedimentation for several years following 1969 when the quarry overburden was first removed. A cause-and-effect relationship between quarrying and subsequent sedimentation events is less certain. Clastic sediment that accumulates in the spring box and suspended sediment responsible for turbidity may have distinctly different sources. While spring box sedimentation appears to have resulted directly from the quarry's initial overburden removal, direct evidence attributing subsequent sedimentation with quarry activities is generally incomplete or lacking.

5.2 REGULATORY SETTING

5.2.1 County General Plan/Local Coastal Program

The County of Santa Cruz regulates project impacts to water resources through General Plan/Local Coastal Program (GP/LCP) policies. Water related policies applicable to the proposed project include policies on Water Resources, Maintaining Adequate Streamflows, Maintaining Surface Water Quality, Overdrafted Groundwater Basins, and Erosion. These policies are listed in Section 3.2.1.

5.2.2 County Mining Regulations

The County Mining Regulations sets forth standards governing mining operations. Mining Regulations 16.54.050 identifies required conditions and standards for Water and Drainage and Drainage and Erosion. Mining Regulations 16.54.055 sets forth performance standards for Surface Drainage Controls for quarry reclamation. These policies are listed in Section 3.2.3 and 3.3.4.

5.2.3 California Water Code (Section 13000, et seq.)

The California Water Code establishes that the people of the state have a primary interest in the conservation, control, and utilization of the water resources of the state, and that the quality of all the waters of the state shall be protected for use and enjoyment by the people of the state. The California Water Code establishes the regulatory authority of the state over activities and factors that may affect the quality of the waters of the state. The California Water Code is intended to attain the highest water quality that is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible.

California Water Code declares that the health, safety and welfare of the people of the state requires that there be a statewide program for the control of the quality of all the waters of the state and that the statewide program for water quality control can be most effectively administered regionally, within a framework of statewide coordination and policy.

5.2.4 Porter-Cologne Water Quality Control Act (Porter-Cologne)

The Porter-Cologne Water Quality Act of 1969 (Porter-Cologne) established the State Water Resources Control Board (SWRCB) and the nine RWQCBs. Each RWQCB was charged with developing, adopting and implementing a Water Quality Control Plan for each region. The RWQCB is responsible for implementing the federal Clean Water Act (CWA) at the state level.

Under Porter-Cologne, the regional boards regulate the "discharge of waste" to "waters of the state". All parties proposing to discharge waste that could affect waters of the state must file a report of waste discharge with the appropriate RWQCB. The RWQCB will then respond to the report of waste discharge by issuing waste discharge requirements (WDRs) in a public hearing, or by waiving WDRs (with or without conditions) for that proposed discharge.

Both of the terms "discharge of waste" and "waters of the state" are broadly defined in Porter-Cologne, such that discharges of waste include fill, any material resulting from human activity, or any other "discharge" that may directly or indirectly impact "waters of the state". While all "waters of the United States" that are within the borders of California are also "waters of the state", the converse is not true - "waters of the United States" is a subset of "waters of the state."

5.2.5 Central Coast Basin Plan

Section 13241, Division 7 of the California Water Code specifies that each RWQCB shall establish water quality objectives, which are necessary for the protection of beneficial uses and the prevention of nuisance. Water quality objectives have been adopted by the state and when applicable extended as federal water quality standards. Water quality objectives in the Central Coast Basin Plan satisfy state and federal requirements to protect beneficial uses. Water quality objectives are primarily achieved through establishment of WDRs.

The beneficial uses of the East Branch of Liddell Creek identified in the Basin Plan include municipal and domestic supply, agricultural supply, industrial services supply, ground water recharge, water recreation, commercial and sport fishing, cold freshwater habitat, wildlife habitat, migration of aquatic organisms, and spawning. Additional beneficial uses further downstream in Liddell Creek include estuarine habitat, rare, threatened or endangered species, and freshwater replenishment. Objectives for all inland waters such as Liddell Creek include standards regarding color, taste and odor, floating material, settleable material, oil and grease, sediment, turbidity, pH, oxygen, temperature, toxicity, pesticides, chemical constituents, and organics among others.

The Central Coast Basin Plan includes an implementation plan to achieve water quality objectives. The discharge or threatened discharge of soil, silt, or other earthen materials into any stream in the basin is a violation of Best Management Practices and in quantities deleterious to fish, wildlife, and other beneficial uses is prohibited. Relevant to the Bonny Doon Quarries, the waste discharge program addresses storm water management by implementation of Best Management Practices through the NPDES permit described below.

5.2.6 National Pollutant Discharge Elimination System (NPDES)

The U.S. Environmental Protection Agency (EPA) administers the National Pollutant Discharge Elimination System (NPDES) Permit Application regulations for storm water discharges under the CWA. The CWA uses the NPDES permitting program to monitor and control pollutants in industrial process wastewater, municipal sewage, and industrial storm water runoff and runoff from construction sites.

In California, NPDES permits are issued by the SWRCB through the RWQCB. To meet Storm Water Pollution Prevention requirements, the SWRCB issued a statewide NPDES General Permit for Storm Industrial Discharges. Dischargers who wish to be covered by the General Permits are required to submit a Notice of Intent (NOI) to the SWRCB and to the Program.

Submittal of the NOI signifies that the discharger intends to comply with the conditions of the General Permits. A Storm Water Pollution Prevention Plan (SWPPP) must be developed prior to submitting an NOI and implemented prior to construction for discharges from construction sites.

The Bonny Doon Limestone Quarry has a SWPPP on file with the Central Coast RWQCB and operates under NPDES General Industrial Permit No. 344S010829. The SWPPP is to be considered a working document and kept at the job site. All employees are to be aware of and follow practices described in the SWPPP.

5.2.7 Federal Clean Water Act

The implementation of the CWA is the responsibility of the EPA. That agency depends on other agencies such as the individual states and the U.S. Army Corps of Engineers (USACE) to assist in implementing the Act. The objective of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters'. Sections 401 and 404 of the CWA apply to activities that would impact wetlands. Section 401 is implemented by the SWRCB/RWQCB. Section 404, which is implemented by the USACE, regulates the discharge of dredged of fill material into waters of the U.S. This can also include excavation and changes in drainage. The discharge of dredged or fill material into waters of the U.S. is prohibited except when it is in compliance with Section 404 of the Act.

The CWA, in Section 401, specifies that states must certify that any activity subject to a permit issued by a federal agency meets all state water quality standards. In California, the SWRCB and RWQCB are responsible for taking certification actions for activities subject to any permit issued by the USACE pursuant to Section 404 (or for any other USACE permit, such as permits issued pursuant to Section 10 of the Rivers and Harbors Act of 1899). Such certification actions, also known as 401 certification or water quality certification, include issuing a 401 certification that the activity subject to the federal permit complies with state water quality standards, issuing a 401 certification with conditions, denying 401 certification, or denying 401 certification without prejudice, should procedural matters preclude taking timely action on a 401 certification application.

5.3 PROJECT IMPACTS

The following project impact discussion and analysis applies to those portions of the Project that pertain to hydrology and hydrogeology. Those aspects include the Final Development Plan (Bowman and Williams, 2001a as shown in Figure 9), and the previously approved (1997) Final Drainage Plan (Bowman and Williams, 2001b as shown in Figure 10).

5.3.1 Threshold of Significance

Under the following Standards of Significance, based on Appendix G of the CEQA Guidelines, indicate that an impact would be significant if the project would:

- Substantially deplete ground water supplies or interfere substantially with ground water recharge such that there would be a net deficit in aquifer volume or a lowering of the local ground water table level (e.g., the production rate of pre-existing nearby wells would drop to a level that would not support existing land uses or planned uses for which permits have been granted);

- Affect the quality of ground water supply, or alter the direction or rate of flow to ground waters;
- Violate any water quality standards or WDRs;
- Substantially alter the existing drainage pattern of the site or area, including the alteration of the course of a stream or river in a manner that would modify the capacity or hydraulics of the stream or result in substantial erosion or siltation, on- or off-site;
- Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner that would result in flooding on- or off-site;
- Affect surface water quality (contaminants including silt, urban runoff, nutrient enrichment, pesticides, etc.);
- Create or contribute runoff water that would exceed the capacity of existing or planned storm water drainage systems or provide substantial additional sources of polluted runoff;
- Otherwise substantially degrade water quality;
- Place within a 100-year flood plain hazard area structures that would impede or redirect flood flows;
- Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam; or Inundation by seiche, tsunami, or mudflow;
- Affect a private or public water supply that results in any change in water quality or available water quantity;
- Result in inefficient or unnecessary water consumption;
- Change the amount of surface water in any water body.
- The proposed project would affect the quantity and quality of water to Liddell Spring, a municipal water supply. It will not alter drainage patterns, expose people or structures to flooding, or result in unnecessary water consumption. Mitigation measures are recommended to reduce all significant impacts to a less than significant level.

5.3.2 Hydrologic Impacts

5.3.2.1 On-Site Drainage and Sedimentation

The expansion of the Limestone Quarry onto 17.1 acres would increase the impervious surface area in the quarry by increasing the area of exposed rock. This change would increase storm runoff volumes, a potentially significant impact. Under present drainage conditions, the existing quarry pit has no outlet for surface drainage; runoff from the Boundary Expansion Area would collect on the quarry floor and percolate into the marble aquifer. According to the previously approved Final Drainage Plan for the quarry (Bowman and Williams, 2001), drainage from the quarry floor is to be directed to Settlement Basin 3 (Figure 10). This drainage is to be established by excavating a channel from the southern end of the quarry pit to an intake for Settlement Basin 3. CEMEX has submitted information to County Planning showing that Settlement Basin 3 has adequate capacity to accommodate the proposed expansion.

Percolation through the quarry floor has been historically adequate to remove collected runoff (and ground water from excavated perched zones) with little ponding or the need for external drainage. Sufficient subsurface drainage capacity would persist with expansion of the quarry into the Boundary Expansion Area; therefore runoff collected on the quarry floor under project conditions would continue to percolate without creating a drainage problem.

Subsurface drainage over areas of the quarry floor is potentially a source of turbidity and sedimentation at Liddell Spring. Runoff and sediment collected in the quarry pit migrates to ground water and contributes to Liddell Spring flow. Turbidity and sedimentation impacts during the time that runoff is being retained within the quarry may impact the public water supply at Liddell Spring and are therefore considered to be potentially significant. Implementing the Final Drainage Plan to drain the quarry floor requires lowering the ingress/egress ramp on the south side of the quarry by about 50 feet. This grade change would require blasting of rock and excavation of a drainage channel immediately upstream from Liddell Spring. Excavation and blasting in the vicinity of Liddell Spring may increase sedimentation and turbidity at the spring, a potentially significant impact with respect to a public water supply. Turbidity impacts are further discussed in Ground Water Quality (Section 5.3.3.3) below.

Once drainage of the quarry pit to Settlement Basin 3 is established, turbidity and sedimentation impacts are likely to be reduced. At the same time, this change in drainage may result in decreased spring flow quantities by removing water that would be percolating to ground water from the quarry. Spring flow quantity impacts after quarry drainage to Settlement Basin 3 is established may impact a public water supply at Liddell Spring and are therefore potentially significant. The potential water quantity impacts are further discussed in Ground Water Quantity (Section 5.3.3.2 below).

5.3.2.2 Off-Site Drainage and Sedimentation

The combined flow of Plant Spring and Liddell Spring is about 1800 acre-feet per year. The continued diversion by CEMEX of approximately 21 gpm (34 acre-feet/year) from Plant Spring for use in quarry operations represents a relatively minor loss (2 percent) of downstream flow and is not considered significant. In contrast, the diversion by the City of Santa Cruz of 1250 acre-feet per year from Liddell Spring represents 69% of the combined spring flow.

Mining of the Boundary Expansion Area would continue the existing impact of sediment from quarry activity entering Liddell Spring through percolating runoff (described above). By increasing the sediment entering Liddell Spring, the mining expansion project could indirectly increase the sediment loads discharged from the spring to downstream drainages of Liddell Creek. This impact would affect downstream water quality and increase siltation in the stream channel, a potentially significant impact. Mitigation Measure HYD-1 would reduce sedimentation impacts and protect the water quality of Liddell Spring and downstream drainages of Liddell Creek. With this measure, the project impacts to off site drainages are less than significant.

5.3.3 Hydrogeologic Impacts

This section addresses the potential impacts of the proposed quarry expansion on the quantity and quality of ground water feeding Liddell Spring. The analysis of these potential impacts has been complicated by uncertainties inherent in the complex karst hydrogeology. Furthermore, there has been a considerable difference of opinion expressed in the numerous technical studies performed to date, as well as in comments by County staff and others.

A recent study by PELA (2005) concluded that the proposed quarry expansion would have an insignificant effect on Liddell Spring because (a) the spring's primary ground water and sediment sources lie beyond the immediate area of the quarry and (b) the quarry operation is conducted in the unsaturated zone, which has poor hydraulic connectivity to the saturated zone.

As discussed above and in the Geology and Hydrology Technical Appendix (Appendix F), several lines of evidence indicate that there is good hydraulic connectivity between the shallow and deep karst zones in the quarry area. Furthermore, the quarry operation presents a substantial source of ground water recharge and sediment for the local ground water system. The potential impact of expanded quarry operations on ground water quality and quantity can be expected to continue or increase with the creation of additional quarry floor within 20 feet of ground water.

5.3.3.1 Intercepted Ground Water

Ground Water Separation from Quarry Floor

The Santa Cruz County Code defines an aquifer as a saturated permeable geologic unit that can transmit significant quantities of ground water under ordinary hydraulic gradients (Section 16.54.020). County mining regulations stipulate that the lowest elevation of any mining operation at any time shall be 20 feet above the peak ground water elevation unless the Planning Commission determines that a lower or higher elevation will ultimately benefit recharge of the aquifer (Section 16.54.050).

Relatively little data exist for characterizing ground water elevations beneath the quarry floor and the proposed Boundary Expansion Area. Among recently monitored wells, water levels in the proposed Boundary Expansion Area are generally below 750 ft msl, although some former wells now destroyed by quarrying had water levels exceeding 750 ft msl (Figure 31, Maximum Recorded Ground Water Surface Elevations). These higher water levels may have represented perched zones; alternatively, peak ground water levels may have been lowered by enhanced drainage resulting from the subsequent quarrying.

Because of the difficulty in pre-determining peak ground water elevations, given the complex hydrogeology of the quarry area, CEMEX proposes drilling shallow borings as the pit is lowered to test the depth to ground water. If ground water is encountered in a borehole, CEMEX proposes to pump ground water from the boring for 12 to 24 hours. A sustained yield of 50 gpm or more would suggest that the encountered zone is part of the "marble aquifer" (see RMC Lonestar, August 1999).

The drawback of this approach is that the minimum depth to ground water would not be known without additional, longer term monitoring. Ground water levels fluctuate seasonally and year-to-year based on the amount of precipitation. Without long term monitoring, the maximum ground water levels are not known with certainty and unless the ground water test proposed by CEMEX is conducted during a wet period of a wet year, it may not determine maximum ground water elevation. Other researchers have described ground water levels fluctuating as much as 63 feet in 20 days, and water level records (hydrographs) presented in previous reports have exhibited large fluctuations in ground water level, often with no obvious explanation (see Sections 4.2.3, 4.2.4, and 4.2.5, Appendix F, Geology and Hydrology Technical Appendix). In some cases these fluctuations may reflect the sudden draining of a perched zone and simultaneous filling of an underlying zone.

Perched Ground Water Zones

Substantial zones of perched ground water may be drained by quarrying down to 750 feet msl, as evidenced by several wells with maximum water levels ranging from 800 to more than 1,000 ft msl in and around the proposed Boundary Expansion Area (Figure 31). For example, one well (Appendix F, Geology and Hydrology Technical Appendix) beyond the northeast corner of the Boundary Expansion Area had a maximum water level of 996 ft msl during the recent PELA study and was described to have “a significant connection to the marble aquifer.”

The Santa Cruz County Code (Section 16.54.050) stipulating a 20-foot separation of mining elevation from peak ground water elevation has not been typically applied to perched zones. In the case of the proposed Boundary Expansion Area, the ground water surface is not well defined; there is little documentation of peak ground water elevations during periods of above-average precipitation; and quarrying may remove a considerable volume of perched zone (some of which may tap into the upstream regional aquifer and/or other sources of recharge). Perched zones also may represent pockets of water remaining after deeper zones fill and overflow during wet periods. Voids at or above the water table may fill and empty several times during the rainy season, increasing their volumetric significance within the overall karst system. If these perched zones do function as temporary storage sites for ground water entering the deeper karst aquifer, removing them may result in increased seepage into the pit from the unsaturated zone. To the extent that the quarry pit remains a closed depression with no external drainage, most of this water would eventually percolate into the aquifer. When the quarry is drained to Settlement Basin 3, any water flowing into the quarry from breached ground water conduits would be channeled out of the Liddell Spring drainage area.

Exposing perched zones, mining to within 20 feet or less of maximum ground water elevations, and flushing additional water through the quarry floor would potentially impact water quality and cause turbidity at Liddell Spring by exposing ground water to surface contamination and introducing additional natural and quarry-generated sediment into ground water. This opportunity for contamination of the water would affect both surface and ground water quality downstream and is therefore a potentially significant impact according to the thresholds of significance. Draining the quarry to Settlement Basin 3, as envisioned by the Final Drainage Plan (Figure 10), would lessen the potential water quality impact at Liddell Spring, but this plan would also increase the potential for the quarry to affect flow quantities at the spring.

If quarrying were to expose a significant, saturated karst water source, PELA (2005) recommended plugging, capping, or covering it, and surrounding it with a 50-foot buffer from further quarrying. The feasibility and efficacy of such measures within the active quarry is uncertain.

The water level data for the quarry area indicates the potential for large, relatively rapid fluctuations in water level. The quarterly water level monitoring proposed by CEMEX for the Boundary Expansion Area is inadequate to closely monitor the fluctuating water levels. Improved ground water level monitoring is needed in areas proposed for new and ongoing quarrying (e.g. the northeast corner of the Boundary Expansion Area) to prevent mining from intercepting the ground water table. More surveyed locations and a longer period of record are needed in order to determine a minimum mining surface at least 20 feet above maximum ground water levels. The three new wells proposed for water level monitoring by CEMEX should be augmented with at least one additional well drilled to coincide with the planned northeast corner of the floor of the Boundary Expansion Area (approximate California Coordinate System coordinates N1,519,3500 E198,000, per the Final Development Plan, (Figure 9). Continuously reading water level data loggers should be installed in all wells selected for water level monitoring. The data loggers should be programmed to record water levels at least twice daily. The monitoring at these wells should continue through the mining period, or at least until water levels during consecutive significantly higher than average rainfall seasons are recorded. This mitigation is specified in Measure HYD-2. The improved monitoring will help ensure that mining complies with County mining regulations stipulating that the lowest elevation of any mining operation at any time shall be 20 feet above the peak ground water elevation unless the Planning Commission determines that a lower or higher elevation will ultimately benefit recharge of the aquifer (Mining Regulations 16.54.050(3)(iii)).

5.3.3.2 Ground Water Quantity

Historic ground water levels are at or above the proposed depth of mining along the northern side of the Boundary Expansion Area (Cross Sections A-A' and D-D', Plates 3 and 4 of the Geology and Hydrology Technical Appendix, Appendix F). Several major fracture zones intersect the proposed Boundary Expansion Area and these fractures may be associated with important ground water pathways to Liddell Spring. Therefore, there is some potential for mining to intercept ground water flowing to Liddell Spring. As long as the quarry is a closed basin, most of any intercepted ground water eventually percolates into the aquifer from the quarry floor. Consequently, potential impacts on the quantity of ground water reaching the spring under the existing drainage conditions are considered to be less than significant.

Upon implementation of the previously approved Final Drainage Plan (July 1997), water draining to the quarry floor will be diverted to Settlement Basin 3. Surfacing ground water in the quarry would be diverted out of the drainage area for Liddell Spring, possibly resulting in a potentially adverse impact on spring flow quantities. Mining of the proposed 17.1 acre Boundary Expansion Area would increase the amount of water captured in the quarry floor and diverted to Settlement Basin 3 upon implementation of the previously approved drainage plan. Any change in ground water recharge is considered a potentially significant impact according to the thresholds of significance.

Quarrying of the Boundary Expansion Area could also result in some increase in ground water recharge. Overburden removal and exposure of fractured marble may allow for more rapid percolation in places where runoff concentrated in drainage ditches along roads or benches encounters open fractures or fissures. This potential increase in recharge would diminish as the final quarry benches and floor become covered in stockpiled overburden as part of reclamation. The potential increase in recharge is not expected to counterbalance potential impacts on recharge quantities due to draining of the quarry to Settlement Basin 3.

The project impact upon ground water quantity can be mitigated by modifying the Final Drainage Plan to retain surface drainage on the quarry floor and allow percolation for ground water recharge to Liddell Spring. This mitigation is specified in Measure HYD-1 and reduces the project impact on ground water quantities to less than significant.

5.3.3.3 Ground Water Quality

Nitrate

The existing quarry may have some ongoing influence on the concentration of nitrate and total dissolved minerals in ground water. However, substantial increases in the concentration of these compounds have not been clearly documented over time, and other sources appear to contribute as much or more than the quarry. Concentrations of nitrate and other dissolved minerals in Liddell Spring discharge are not exhibiting definite and/or significant upward trends. There is insufficient evidence to conclude that quarrying of the proposed Boundary Expansion Area would significantly worsen ground water nitrate and total dissolved minerals. Therefore, nitrate impacts are considered to be less than significant.

Turbidity

The analysis presented in the Geology and Hydrology Technical Appendix (Appendix F), summarized above, indicates that Liddell Spring's primary turbidity response to storm events is related to runoff capture and percolation at the quarry. Additionally, smaller turbidity events are related to quarry blasting (PELA, 2005). Turbidity also results from runoff capture by stream swallow holes and sinkholes, and mobilization of subsurface sediment during periods of peak ground water flow.

The hydrogeologic model and water balance estimates indicate that the quarry watershed contributes up to 13 percent of the 1,500 ac-ft/year flow from Liddell Spring (about 200 ac-ft/yr). However, the proposed Boundary Expansion Area's contribution to overall turbidity at Liddell Spring depends not only on how much water it is or would be contributing to spring flow, but how much sediment is entrained within that contribution. There are abundant sediment sources associated with the existing quarry and the proposed quarry expansion. Given the estimate that several cubic feet of sediment per day may account for all the turbidity observed at Liddell Spring, it is Nolan Associates' opinion that as much as half of Liddell Spring's overall turbidity may be directly or indirectly attributable to quarry operations.

Considerable interconnectivity exists between precipitation, runoff, and sediment collected in the quarry, ground water flow, and Liddell Spring discharge and turbidity, based on the following observations:

- Overburden removal prior to the inception of mining at the quarry resulted in elevated turbidity at Liddell Spring ((Earth Science Associates and Creegan and D'Angelo, May 1979; Geology and Hydrology Technical Appendix, Section 4.6.2, Appendix F).
- The removal of the overburden and mining of the marble reduces recharge filtering and exposes fractures and dissolution channels connected to the aquifer. Highly permeable, interconnected voids have the potential to transport water and entrained sediment from the quarry in a turbulent and cascading flow down to the zone of saturation, and then laterally toward Liddell Spring, resulting in spring turbidity (Geology and Hydrology Technical Appendix (Appendix F), Section 4.4.4).

- Observed quarry ponding and drainage into the subsurface zone, along with estimates of overall quarry recharge, indicate that the quarry represents a substantial source of ground water recharge during and following storm events relative to other sources (Geology and Hydrology Technical Appendix (Appendix F), Section 3.2).
- The timing and nature of Liddell Spring's response to precipitation, relative to a) the timing of runoff collected in the bottom of the quarry, and b) ground water travel times from the quarry to the spring, indicate that runoff captured by—and percolated into—the quarry pit, along with sediment generated by quarrying, substantially contribute to turbidity at the spring. (Geology and Hydrology Technical Appendix (Appendix F), Section 4.6.6).
- Spring box sedimentation likely resulted from the quarry's initial overburden removal (Geology and Hydrology Technical Appendix (Appendix F), Section 4.6.7).
- The bulk of the sediment needed to account for Liddell Spring's turbidity (roughly several cubic feet per day, on average) could conceivably be generated by quarry operations, including blasting, ripping, and the disturbance of overburden (Geology and Hydrology Technical Appendix (Appendix F), Section 4.3.6).
- Quarry blasting appears to mobilize and possibly generate subsurface sediment that contributes to spring flow turbidity, both as an immediate response to blasting and potentially during subsequent storm events (PELA, 2005).

Based on the above observations, the proposed quarry expansion could potentially have a significant impact on turbidity at Liddell Spring. The proposed expansion therefore has the potential to impact the City of Santa Cruz's water supply by affecting water quality at the spring. These impacts include: reduced production and increased operational costs as a result of halting diversions during periods of elevated turbidity and springbox sedimentation; increased reliance on other sources of water at such times, including the use of water intended for drought use; operational costs and lost production from purging pipelines and treating more highly turbid water at the Graham Hill Treatment Plant; and increased exposure to surface contamination in the event that ground water temporarily surfaces in mined areas. Based on the thresholds of significance given at the beginning of this section, any impact on a public water supply is considered a significant impact. Measures HYD-1 and HYD-3 would reduce or avoid water quality impacts from increased turbidity during quarry operations and following closure and reclamation. These measures reduce the water quality impact on Liddell Spring to a less than significant level.

5.3.3.4 Impact on Spring Flow Production

Spring flow production from Liddell Spring could be impacted by an outright decrease in flow from the spring or by an increase in turbidity and sedimentation. An increase in the turbidity or sedimentation at Liddell Spring has the potential to impact the City of Santa Cruz's water supply in several ways: reduced production and increased operational costs as a result of halting diversions during periods of elevated turbidity and spring box sedimentation; increased reliance on other sources of water at such times, including the use of water from Loch Lomond ordinarily reserved for use during droughts; and operational costs and lost production from purging the North Coast pipeline and treating more highly turbid water at the Graham Hill treatment plant. A quantitative estimate of the potential impacts to production, based on production records before and after quarrying began, is hindered by changes in the City's diversion procedures and ability to convey and treat turbid water. The City has not provided estimates of the potential impact of elevated turbidity on its production levels or operational costs.

The initial removal of overburden from the proposed Boundary Expansion Area may impact the City's spring diversion over a several-year period as a result of sedimentation events (the filling of the Liddell spring box with sediment), based on what reportedly occurred during the early 1970s. Because the proposed Boundary Expansion Area is smaller than the original quarry operation and there are now more effective standards and oversight regarding grading, erosion control, and runoff containment than were in effect during the initial quarry development, any impacts from developing the Boundary Expansion Area are expected to be less than those associated with the original quarry. Nevertheless, potentially significant impacts due to sedimentation are anticipated. Since sedimentation may impact the public water supply at Liddell Spring and may impact water quality downstream, sedimentation is considered a significant impact. The potential production losses and costs associated with such events have not been estimated.

Mining the proposed Boundary Expansion Area has the potential to impact flow volumes at Liddell Spring. Removal of overburden and quarrying would expose large areas of relatively low permeability rock, with the likely result of increasing runoff. The quarry is estimated to contribute as much as 200 ac-ft/yr of ground water recharge to the 1,500 ac-ft/yr flow at Liddell Spring. In addition, mining may encounter ground water sources, either perched or part of the deeper ground water flow system, allowing them to drain into the quarry. If the quarry is provided with an external drain, the runoff and any intercepted ground water may be drained from the quarry, decreasing recharge available to Liddell Spring. Any impact on water quantity available for diversion at Liddell Spring is considered a potentially significant impact.

In the event that quarrying impacts the flow to Liddell Spring, PELA recommended implementing one or more of the following four mitigation measures:

1. Supplement the City's water supply with a diversion from Plant Spring.
2. Construct a detention basin within the quarry to temporarily contain any ground water intercepted by quarrying, and divert this water to the City's intake at Liddell Spring.
3. Construct production wells that intercept karst conduits feeding Liddell Spring in the area between the quarry and the spring's recharge areas, and convey the pumped ground water to the City's existing spring intake.
4. Prevent Reggiardo and Laguna creek stream flows from recharging the karst, and instead pipe this water to the City's Liddell Spring intake.
5. Provide the City with a water treatment facility capable of mitigating increased Liddell Spring turbidity as a result of quarrying.

There are limitations associated with each of these recommendations. Plant Spring discharges at an approximate average rate of 180 gpm, of which the quarry diverts about 20 gpm. The remaining flow equals about one-fifth of the City's average annual diversion from Liddell Spring, and as such could only partially mitigate lost production as a result of quarrying. Furthermore, the partial transfer of Plant Spring water rights to the City would need to be addressed, along with potential impacts to downstream habitat as a result of diminished flows. The quarry's development of an alternative water supply to replace any reduced use of Plant Spring could have additional, separate impacts on Liddell Spring.

Constructing a detention basin in the quarry for intercepted ground water would essentially substitute a "new" surface water source for a spring flow source, and thus involve issues related to sustainability, exposure to surface contamination, and changes in water rights.

New production wells that successfully intercept significant karst conduits may be very difficult to locate and construct. The sediment load in these conduits might cause excessive wear on the wells' pumps. In light of California's water laws, there may be some inequity in exchanging a right to divert spring flow for a right to pump ground water from a well.

Diverting Reggiardo and Laguna creek stream flows would also be a substitution of surface water for spring flow. It would also result in reduced water-supply storage. Spring flow yields are more sustainable during the dry season and droughts, and are generally of better quality. If this measure were implemented, it would seem more reasonable to convey these flows to the City's downstream diversions on Reggiardo and Laguna Creeks rather than its Liddell Spring intake.

Providing the water treatment facility for Liddell Spring could effectively address water quality impacts, but would not address any water quantity impacts.

The quantity and quality of established municipal water supplies are managed very conservatively in California. Any impact on water quality or quantity for a public water supply is considered to be a significant impact. As such, there is reasonable uncertainty whether the City of Santa Cruz would find any of the above measures acceptable. In any event, potentially significant impacts to water production from Liddell Spring may be occur even with implementation of Measure HYD-1 and HYD-2 given the interconnectivity and complexity of the karst ground water system, the unavoidable generation of sediment by quarry operations, and the capture of significant precipitation and runoff within mined areas. A suitable package of relatively indirect or direct mitigation measures (e.g., treatment, water supply replacement) would require negotiation between CEMEX and the City. Measure HYD-3 requires that CEMEX enter into an agreement with the City of Santa Cruz regarding water treatment of Liddell Spring. This measure would reduce the water quality impact on the spring to a less than significant level.

5.3.3.5 Water Quality Impacts Vs. Water Quantity Impacts

As may be seen from the foregoing discussions, there is a trade-off between potential water quality impacts and water quantity impacts that is mediated by the type of drainage scheme instituted for the proposed Boundary Expansion Area. The mining of the proposed Boundary Expansion Area is expected to generate increased runoff and sediment that would result in turbidity and entrained sediment in the runoff. To the extent that runoff is detained within the quarry pit, these impacts are likely to lead to increased turbidity and sedimentation at Liddell Spring. If the quarry pit is breached and external drainage is established to downstream settlement basins, the impact may result in a decrease in recharge to Liddell Spring.

Therefore, although it has been concluded that the proposed Boundary Expansion Area mining would have impacts related to water quality and water quantity, the precise nature of those impacts is, to some extent, a function of the proposed quarry drainage scheme. For this reason, Measure HYD-1 identifies recommendations for developing an alternate drainage scheme so as to reduce impacts of mining the Boundary Expansion Area related to both water quality and water quantity. As specified in Measure HYD-1, overburden and spoils would initially be placed in the western portion of the quarry pit to a depth of approximately 15 feet and then extended eastward across in phases. As mining proceeds and pushes the east face of the quarry pit further eastward, the placement of overburden and spoils would also move eastward until the entire quarry floor area has been filled. In addition to reducing the potential impacts of the quarry expansion on Liddell Spring, this mitigation would eliminate or reduce the need for blasting a drainage channel from the quarry pit to Settlement Basin 3, as currently authorized by the previously approved drainage plan. This measure would thus further avoid or reduce ground-disturbing activities in close proximity to the spring. When incorporated into the Final Drainage Plan, these recommendations would also help restore pre-quarry hydrologic and hydrogeologic conditions over time.

The revegetation plan specified in the 1996 Reclamation Plan Amendment would establish early successional scrub/mixed evergreen forest in the mine pit upon closure. The modification to the drainage plan allowing retention of water on the quarry floor would potentially create wet conditions during winter months. Therefore, the modified revegetation plan would include species that can tolerate wet conditions for areas on the quarry floor receiving additional retention due to the modified drainage plan.

5.3.4 Cumulative Impacts

Cumulative hydrology and water quality impacts of the Bonny Doon Quarries Expansion Project are defined as the project impacts plus other activities occurring within the regional watershed that have a combined affect on water resources.

The proposed expansion of the Limestone Quarry expansion would potentially affect the quality of surface waters in the Liddell Creek watershed by increasing sediment to Liddell Creek either through discharges from Settlement Basin 3 or through Liddell Spring. Liddell Creek is also impacted by sediment from other adjacent land uses such as adjacent agriculture. Except for future mining in the 9.4 acres remaining within the Legal Mining Limit of the quarry, there are no new projects in the Bonny Doon Planning Area identified by the County that would directly contribute to or overlap with water quality project impacts to downstream sections of Liddell Creek (see Cumulative Impacts, Section 11.4). Future mining in the remaining 9.4-acre area would bring the mining operations closer to Liddell Spring and could result in increased water quality and water quantity impacts on the Spring.

Liddell Spring is one of four North Coast sources of water supply source for the City of Santa Cruz. The North Coast waters have excellent water quality and low production costs and are therefore used by the City to the greatest extent possible. North Coast sources combine to provide 32 percent of the City’s total annual water production (City of Santa Cruz Water Department, 2005). The City of Santa Cruz is undertaking a Section 10(a) Permit and Habitat Conservation Plan (HCP) with the USFWS and NOAA Fisheries regarding impacts to listed and other sensitive species from the City’s surface water diversion activities on the coastal streams. The conservation measures identified in the HCP may place limitations on the quantity of water that may be diverted from Liddell Spring or the other North Coast sources and could adversely impact the City’s existing water supply.

Project impacts to production levels of Liddell Spring are identified in Section 5.3.3.2 above. This Bonny Doon Limestone Quarry Boundary Expansion Project could add to other possible losses of water supply the City may be facing from the pending HCP and Section 10(a) Permit. Any loss of production to a municipal water supply is considered a significant impact based on the thresholds identified in Section 5.3.1. Implementation of Measures HYD-1, HYD-2, and HYD-3 would protect the quantity and quality of Liddell Spring waters and mitigate the cumulative effects of the project to a less than significant level.

5.4 MITIGATION MEASURES

The following measures would reduce the hydrology, water quantity, and water quality impacts of the mining expansion project to a less than significant level.

IMPACT: *Stripping of overburden material and mining the Boundary Expansion Area would result in an increase in turbidity and sedimentation at Liddell Spring. Any increase in turbidity and sediment load in the flow at Liddell Spring would also increase sedimentation and turbidity in downstream drainages. Implementation of the previously approved Final Drainage Plan would divert Boundary Expansion Area runoff from percolating through the quarry floor and reduce ground water flow to Liddell Spring. Mining in the Boundary Expansion Area may also intercept perched ground water zones, potentially affecting water quantity or quality at Liddell Spring. Liddell Spring is a municipal water source for the City of Santa Cruz. The Project would cause water quality or water quantity impacts to Liddell Spring resulting in the loss of water production levels for the City of Santa Cruz. Any loss of water production is a significant impact.*

Measure HYD-1: CEMEX shall prepare an engineered drainage plan for use during removal of overburden and mining of the Boundary Expansion Area. This plan shall be integrated with the Final Drainage Plan for the quarry. The plan shall specify disposal of no more than 4.6 million cubic yards of quarry overburden and spoils across the entire floor of the quarry pit as a filter for percolating surface water (rather than only the western half as proposed (see Figure 9). Overburden and spoils shall be placed in the western portion of the quarry pit to a depth of approximately 15 feet and extend eastward across the quarry floor as mining proceeds. The entire quarry floor area shall be filled with overburden and spoils to a depth of approximately 15 feet.

A detailed design shall be developed by CEMEX for approval by County Planning prior to public hearing of the project proposal. The following basic design features shall be considered and addressed:

1. A revised drainage plan shall be prepared that will supersede the 1996 Drainage Plan (Use Permit No. 3236-U). The intent of the redesigned drainage plan is to retain surface water in the quarry pit for ground water recharge and sediment removal.

2. An engineered graded filter or other sediment barrier shall be placed beneath any overburden and spoil material placed within the quarry pit to prevent sediment from reaching the karst aquifer through fractures and other pathways. The filter shall be designed to resist infiltration of sediment, piping, or collapse into underlying fissures or karst conduits, but to allow ponded water to percolate. This provision can be combined

with sloping of the working floor of the quarry towards the filter-lined portion of the quarry floor to prevent ponding in areas with no filter. The filter shall extend up the sides of the quarry to provide containment for the ponded water. Ponding of water above a specified design depth shall be prevented by pumping or by providing external drainage from the quarry. (Note: this measure will be necessary regardless of the design of overburden and spoil disposal. The barrier will also reduce the amount of sediment currently reaching Liddell Spring thereby complying with the intent of previous approvals to minimize water quality impacts to Liddell Spring).

3. The fill shall be designed to retain and slowly infiltrate drainage from the quarry pit into the karst aquifer. The permeability of the overburden and spoils cover shall be evaluated during placement. If the permeability of the cover is insufficient to permit percolation of surface waters into the aquifer, local placement of higher permeability cover should be instituted, combined with grading of surface contours to achieve flow towards the higher permeability zones.

4. Retention pond depths at the end of quarrying shall not be more than several feet deep to avoid detaining water year-round.

5. An overflow spillway shall be constructed to direct any unretained drainage to settlement basins. Development of the spillway shall include design and construction of a fail-safe drainage system in the crusher area to prevent any runoff from flowing down slopes above Liddell Spring or onto the Liddell Spring landslide, during quarrying or after quarry closure. The drainage system shall be designed so that plugging of ditches or inlets for the settlement basins does not result in water being diverted towards the spring.

6. Drainage provisions shall be developed to reduce erosion and runoff during removal of overburden in the Boundary Expansion Area. Drainage during removal of overburden shall include provisions to: a) capture or divert runoff flowing towards the quarry from upland areas; b) stage the overburden removal during the dry season to allow drainage provisions to be instituted in working areas prior to the onset of winter rains; c) use movable plastic membranes to form temporary lined drains along inactive benches or where runoff may be intercepted by open fissures; d) develop temporary down drains at regular intervals along the benches to convey runoff to the quarry floor; and e) identify any prominent fissures or sinks exposed within the quarry as mining progresses and install drainage provisions to prevent runoff from entering the fissures. Benches shall be contoured for positive drainage. Runoff in disturbed areas shall be directed away from surface drainages leading to Liddell Spring as well as any subsurface drains such as sinkholes and open fractures. Sinkholes, fractures, and dissolution cavities shall be identified, mapped, and maintained in such a way as to prevent any precipitation or runoff capture.

7. The revegetation plan specified in the 1996 Reclamation Plan Amendment shall include hydrophytic native plant species that can tolerate wet conditions for areas on the quarry floor receiving additional retention due to the modified drainage plan. The revised revegetation plan shall be developed by CEMEX in cooperation with a qualified revegetation specialist for approval by County Planning prior to public hearing of the project proposal.

Implementation: by CEMEX

Effectiveness: Implementation of the drainage plan provisions would control runoff in the expanded mining area, reduce runoff exposure to sediment sources, reduce exposure of rock fissures and voids to runoff containing sediment, and remove sediment from runoff entering the ground water through the quarry floor. These measures would reduce the turbidity impacts on Liddell Spring and sedimentation of downstream drainages.

Feasibility: Feasible. Movable plastic membranes can be used to line benches and collect runoff in areas not being actively mined. The runoff so collected can be conveyed to the quarry floor by temporary down-drains. The efficacy of placing a compacted fine-grained cover on the quarry floor was previously disputed (SECOR, December 1998; EMKO, August 1999). However, given proper engineering consideration, a suitable sediment filter could be designed and installed as a basal layer of the planned fill placement in the base of the quarry. The filter would have to prevent migration or collapse of fill into solution channels or voids, but should maintain some permeability to allow ponded runoff to percolate.

Monitoring: Drainage plan shall be submitted to County for review and approval prior to commencement of project.

IMPACT: *Because existing data is inadequate to define maximum water levels in the Boundary Expansion Area, there is a potential for mining to intercept ground water. Exposing significant perched ground water zones, mining to within 20 feet or less of maximum ground water elevations, and flushing additional water through the quarry floor would potentially impact water quality and cause turbidity at Liddell Spring by exposing ground water to surface contamination and by introducing additional natural and quarry-generated sediment into ground water. This opportunity for contamination of the water would affect both surface and ground water quality downstream and is therefore a potentially significant impact according to the thresholds of significance. Draining the quarry to Settlement Basin 3, as envisioned by the Final Drainage Plan, would lessen the potential water quality impact at Liddell Spring, but this plan would also increase the potential for the quarry to affect flow quantities at the spring, also a potentially significant impact.*

Measure HYD-2: Improved ground water level monitoring is needed in areas proposed for new and ongoing quarrying (e.g. the northeast corner of the Boundary Expansion Area) to prevent mining from intercepting the ground water table. In addition to the three new wells proposed for water level monitoring, CEMEX shall augment the water level monitoring program with at least one additional well drilled to coincide with the planned northeast corner of the floor of the Boundary Expansion Area (approximate California Coordinate System coordinates N1,519,3500 E198,000, per the project Final Development Plan). Continuously reading water level data loggers shall be installed in all wells selected for water level monitoring. The data loggers should be programmed to record water levels at least twice daily. The monitoring at these wells shall continue through the mining period, or at least until water levels during consecutive significantly higher than average rainfall seasons are recorded.

Implementation:	by CEMEX
Effectiveness:	Relatively shallow borings or blast holes that do not intercept ground water will not provide the needed long-term record of ground water-level variability. If 60-foot test holes are used, as has been proposed, then encountering saturation during a relatively dry time of year may indicate that that mining has already advanced too deep. Without the recommended additional data, mining may inadvertently proceed to depths later determined to be within 20 feet of maximum ground water elevations. Nevertheless, because of the possibility of encountering isolated ground water conduits, any water encountering in blast hole borings shall be evaluated.
Feasibility:	Feasible. Continuous read meters can be installed in monitoring wells. Some of the proposed wells are within the mining area. These wells may have to be re-drilled if destroyed by the mining operation. If the new wells are constructed with steel casing, it is possible that the well casing can be cut off below the new bench level and capped each time material is mined from around the well.
Monitoring:	New monitoring well shall be shown on project maps. Monitoring data from continuous read data loggers all monitoring wells shall be included in routine monitoring reports submitted by CEMEX to the County.

IMPACT: *Even with implementation of mitigation measures HYD-1 and HYD-2, impacts to water quality and/or water quantity at Liddell Spring by continued quarrying may be significant. Based on the results of the analysis contained in the Geology and Hydrology Technical Appendix (Appendix F), as summarized above, some impacts on Liddell Spring water quality are attributable to the quarrying operation, either due to the ponding and recharge of turbid water in the quarry pit or due to blasting. To the extent the proposed quarry expansion would extend the life of the quarry operation in time, it would prolong the impacts of the current quarry operation.*

Measure HYD-3: CEMEX shall enter into a written agreement with the City of Santa Cruz for the purposes of reducing project generated turbidity at Liddell Spring to acceptable levels set by the EPA. According to the EPA, systems that filter must ensure that turbidity (cloudiness of water) may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month (U.S. EPA 1999 & 2001). CEMEX shall implement the following measures to ensure that impacts to the City of Santa Cruz water supply at Liddell Spring are not significantly impacted by the proposed project:

1. Complete pilot test of centrifuge, media filtration and cartridge filtration at Liddell Spring to determine level of filtration required to achieve EPA standards cited above.

2. Determine if centrifuge, media filtration and cartridge filtration are feasible when scaled up to filter all flows.

3. Enter into a memorandum of agreement (MOA) with the City of Santa Cruz as a condition of approval of the Use Permit Amendment to include terms such as maintenance, target levels for NTU, etc.

Implementation: by CEMEX and the City of Santa Cruz

Effectiveness: Implementation of the MOA between CEMEX and the City of Santa Cruz will ensure that project impacts to Liddell Spring are fully mitigated prior to project implementation.

Feasibility: Feasible. A pilot program carried out by CEMEX and the City determined that 1,000 NTU water pulled from Liddell Spring could be reduced to 45 NTU through the use of a centrifuge and media filtration. The addition of a cartridge filter could reduce the 45 NTU water down to EPA required levels (0.3 NTU) if needed (Pers. Comm., October 10, 2007, Robert Walker CEMEX, Davenport CA).

Monitoring: A copy of the MOA shall be submitted to the County prior to the issuance of the Use Permit Amendment. In addition, a monthly monitoring report (or at an interval determined by the City of Santa Cruz) shall be submitted to the City of Santa Cruz and the County of Santa Cruz Planning Department. Specified water quality levels are to be maintained as specified in the MOA or quarry operation within the Boundary Expansion Area will cease until the specified level of treatment is achieved.