5 Proposed Quarry Expansion: Potential Hazards and Impacts

5.1 Introduction

This section discusses potential geologic, hydrologic, and hydrogeologic hazards and impacts related to the proposed quarry expansion. These potential hazards and impacts include the following:

- Seismic hazards, including seismic shaking, ground deformation, and ground surface rupture
- Landsliding and slope instability
- Erosion potential
- Hydrologic impacts, including runoff and sedimentation
- Hydrogeologic impacts on groundwater quantity, groundwater quality, and springflow.

For the purposes of evaluating the potential geologic, hydrologic, and hydrogeologic hazards and impacts for the proposed quarry expansion, our constraints evaluation has focused on the issues listed above. Other hazards could impact the existing quarry operation but are not germane to the proposed expansion.

5.2 Seismic Hazards

Seismic shaking at the subject site will be intense during the next major earthquake along one of the local fault systems. It is important that seismic shaking be considered in evaluating the project design.

Our seismic shaking evaluation for the quarry site included an estimate of expected seismic shaking intensities based on both deterministic and probabilistic methods. A deterministic assessment considers the effects of the largest ground motion that can be expected at a site, regardless of the likelihood of this event during the design life of the project. A probabilistic seismic analysis differs from a deterministic analysis in that it evaluates the probability for shaking of a certain intensity to occur at a particular site over a given span of time.

The intensity of seismic ground shaking can be characterized qualitatively, by its visible effects on people and structures, or quantitatively, as an instrumental measurement of the acceleration at a given point on the ground. The Modified Mercalli Scale (Table 3) is used in a qualitative way to characterize shaking intensity during an earthquake. Ground acceleration as determined by instrumental readings is measured in *g* (one *g* is equivalent to the acceleration of gravity).

It is important to note that the ground acceleration values given below are not directly equivalent to seismic or pseudo-static coefficients used in slope stability analyses (CGS, 1997). Use of these values in the development of stability coefficients (i.e., the seismic coefficient *k*) should be based on state and local jurisdictional regulations and on appropriate engineering standards of practice.

5.2.1 **Seismic Sources**

For the purpose of evaluating seismic shaking at the site, we have considered the San Andreas, Zayante-Vergeles, San Gregorio, and Monterey Bay-Tularcitos fault systems (Figure 5). These faults are considered active seismic sources by the State of California (Petersen et al., 1996; Cao et al., 2003). While other faults in this region may be active, their potential contribution to seismic hazards at the site is overshadowed by these four faults. The distances between these faults and the quarry site are listed in Table 44.

5.2.1.1 San Andreas Fault

The San Andreas fault is active and represents the major seismic hazard in northern California (Jennings, 1994). The main trace of the San Andreas fault trends northwest-southeast and extends over 700 miles from the Gulf of California through the Coast Ranges to Point Arena, where the fault passes offshore and merges with the Mendocino triple junction.

Geologic evidence suggests that the San Andreas fault has experienced right-lateral, strike-slip movement throughout the latter portion of Cenozoic time, with cumulative offset of hundreds of miles. Surface rupture during historical earthquakes, fault creep, and historical seismicity confirm that the San Andreas fault and its branches, the Hayward, Calaveras, and San Gregorio faults, are all active today.

Historical earthquakes along the San Andreas fault and its branches have caused substantial seismic shaking in Santa Cruz County. The two largest historical earthquakes on the San Andreas to affect the area were the moment magnitude (M_w) 7.9 San Francisco earthquake of 18 April 1906 and the M_w 6.9 Loma Prieta earthquake of 17 October 1989. The San Francisco earthquake caused severe seismic shaking and structural damage to many buildings in the Santa Cruz Mountains. The Loma Prieta earthquake may have caused more intense seismic shaking than the 1906 event in localized areas of the Santa Cruz Mountains, even though its regional effects were not as extensive. There were also major earthquakes in northern California along or near the San Andreas fault in 1838, 1865, and possibly 1890 (Sykes and Nishenko, 1984; WGONCEP, 1996).

Geologists have recognized that the San Andreas fault system can be divided into segments with “characteristic” earthquakes of different magnitudes and recurrence intervals (WGCEP, 1988 and 1990; WGONCEP, 1996). Two overlapping segments of the San Andreas fault system represent the greatest potential hazard to the subject property. The first segment is defined by the rupture that occurred from the Mendocino triple junction to San Juan Bautista along the San Andreas fault during the great M_w 7.9 San Francisco earthquake of 1906. The WGONCEP (1996) has hypothesized that this “1906 rupture” segment experiences earthquakes with comparable magnitudes about every 200 years.

The second segment is defined approximately by the rupture zone of the M_w 6.9 Loma Prieta earthquake. The WGONCEP (1996) has posited earthquakes of M_w 7.0 on this segment of the fault, with an independent segment recurrence interval of 138 years.

Modified Mercalli Intensities (see Table 3) of up to VII (7) are possible at the site, based on the intensities reported by Lawson et al. (1908) for the 1906 earthquake and by Stover et al. (1990) for the 1989 Loma Prieta earthquake.

5.2.1.2 Zayante-Vergeles Fault

The Zayante fault lies west of the San Andreas fault and trends about 50 miles northwest from the Watsonville lowlands into the Santa Cruz Mountains. The postulated southern extension of the Zayante fault, known as the Vergeles fault, merges with the San Andreas fault south of San Juan Bautista.

The Zayante-Vergeles fault has a long, well-documented history of vertical movement (Clark and Reitman, 1973), probably accompanied by some right-lateral, strike-slip movement (Hall et al., 1974; Ross and Brabb, 1973). Stratigraphic and geomorphic evidence indicates that the Zayante-Vergeles fault has undergone late Pleistocene and Holocene movement and is potentially active (Coppersmith, 1979).

Some historical seismicity may be related to the Zayante-Vergeles fault (Griggs, 1973). The Zayante-Vergeles fault may have undergone sympathetic fault movement during the 1906 earthquake centered on the San Andreas fault, although this evidence is equivocal (Coppersmith, 1979). Gallardo et al. (1999) concluded that a magnitude 4.0 earthquake in 1998 in the Santa Cruz Mountains occurred on the Zayante fault.

In summary, the Zayante-Vergeles fault should be considered active for design purposes. Cao et al. (2003) concluded that the Zayante-Vergeles fault is capable of generating a magnitude 6.8 earthquake, with a recurrence interval of almost 9,000 years.

5.2.1.3 San Gregorio Fault

The San Gregorio fault skirts Santa Cruz County seaward of Monterey Bay and intersects the coast at Point Año Nuevo. North of Año Nuevo it passes offshore, intersecting the coast again at Half Moon Bay (Figure 5). North of Half Moon Bay, the San Gregorio fault lies offshore until it connects with the San Andreas fault near Bolinas. Southward from Monterey Bay, the San Gregorio fault intersects the coast at Point Sur and eventually connects with the Hosgri fault in south-central California (Dickinson et al., 2005).

The onshore segments of the San Gregorio fault at Point Año Nuevo and at Half Moon Bay show evidence of late Pleistocene and Holocene displacement (Weber and Cotton, 1981; Weber et al., 1995; Simpson et al., 1997). In addition to Stratigraphic evidence for Holocene activity, the historical seismicity in the region is partially attributed to the San Gregorio fault. Due to inaccuracies of epicenter locations, the magnitude 6+ earthquakes of 1926, tentatively assigned to the Monterey Bay fault zone, may have actually occurred on the San Gregorio fault (Greene, 1977). Recent stratigraphic studies of the fault document 97 miles of horizontal offset on the fault (Dickinson et al., 2005).

Petersen et al. (1996) divided the San Gregorio fault into the “San Gregorio” and “San Gregorio, Sur Region” segments. The segmentation boundary is located west of Monterey Bay, where the fault appears to have a right step-over. Petersen et al. (1996) assigned the San Gregorio fault in the study area a recurrence interval of 400 years. Cao et al. (2003) consider the fault capable of a magnitude 7.2.

5.2.1.4 Monterey Bay-Tularcitos Fault Zone

The Monterey Bay-Tularcitos fault zone is based on a postulated connection between the Tularcitos fault, located on land near the Monterey Peninsula, and the offshore Monterey Bay fault zone. The Monterey Bay fault zone is 6 to 9 miles wide and about 25 miles long, consisting of many northwest-trending, en échelon faults identified during shipboard seismic reflection surveys (Greene, 1977). The fault zone projects towards the coastline in the vicinity of Seaside and Ford Ord. At this point, a principal offshore fault trace in the heart of the Monterey Bay fault zone is tentatively correlated by Greene (1977) with the Navy Fault, a postulated westward extension of the Tularcitos fault. It should be emphasized that this correlation between onshore and offshore portions of the Monterey Bay-Tularcitos fault zone are only tentative; no concrete geologic evidence for connecting the Navy and Tularcitos faults under the Carmel Valley alluvium has been observed, nor has a direct connection between these two faults and any offshore trace been found.

Outcrop evidence indicates a variety of strike-slip and dip-slip movements associated with the onshore and offshore traces. Earthquake studies suggest the Monterey Bay-Tularcitos fault zone is predominantly right-lateral, strike-slip in character (Greene, 1977). Stratigraphically, both offshore and onshore fault traces in this zone have displaced Quaternary beds and, therefore, are considered potentially active. One offshore trace, which aligns with the trend of the Navy fault, has displaced Holocene beds and is therefore considered active (Greene, 1977).

Seismically, the Monterey Bay-Tularcitos fault zone may be historically active. The largest historical earthquakes *tentatively* located in the Monterey Bay-Tularcitos fault zone are two events, estimated at 6.2 on the Richter Scale, in October 1926 (Greene, 1977). Because of possible inaccuracies in locating the epicenters of these earthquakes, it is possible that these earthquakes actually occurred on the nearby San Gregorio fault (Greene, 1977).

Another earthquake in April 1890 might be attributed to the Monterey Bay-Tularcitos fault zone (Burkland and Associates, 1975); this earthquake had an estimated Modified Mercalli Intensity of VII (Table 3) for northern Monterey County.

The WGONCEP (1996) has assigned an expected earthquake of M_w 7.1 to the Monterey Bay-Tularcitos fault zone, with an effective recurrence interval of 2,600 years, based on Holocene offshore offsets. Cao et al. (2003) chose a magnitude 7.3 expected earthquake magnitude, but with a recurrence interval of 2,841 years. Their expected earthquake is based on a composite slip rate of 0.5 millimeters per year (after Rosenberg and Clark, 1994).

5.2.2 **Seismic Shaking Evaluation**

5.2.2.1 Deterministic Seismic Shaking Analysis

Table 45 shows estimated magnitudes ($M_{W(MAX)}$) and rupture geometries for the maximum expected earthquakes on each of the above-listed fault systems (Petersen et al., 1996; Cao et al., 2003). Estimated mean peak horizontal ground acceleration (PGA) and mean peak plus one dispersion (PGA + ∂) horizontal ground acceleration values for the site are calculated using the estimated magnitudes and fault geometries shown on Table 45 and the fault distances shown on Table 44. The estimated accelerations are based on an attenuation relationship derived from the analysis of historical earthquakes (Sadigh et al., 1997) and are for sites founded on rock. We caution that the listed values are approximations, based on theoretical curves generated from a relatively small data set; actual measured accelerations may be larger. The PGA + ∂ value is a conservative design parameter intended to compensate for the uncertainty in the attenuation relationships.

The duration of strong seismic shaking shown in Table 45 is calculated from a magnitude-dependent formula proposed by Dobry et al. (1978). The expected recurrence interval (RI), after Petersen et al. (1996), is the expected time between major earthquakes on each fault. The UBC Seismic Source Type (CBSC, 2000; Cao et al., 2003) is also listed.

In summary, the San Gregorio fault, passing within 7.5 km of the site, is expected to generate the largest earthquake ground motion at the site. The characteristic earthquake on this fault ($M_{W(MAX)}$ = 7.2) is expected to generate estimated ground motions in the range of 0.46 to 0.67g. The duration of strong seismic shaking from this event would be about 19 seconds. The recurrence interval for this design earthquake is about 400 years.

5.2.2.2 Probabilistic Seismic Shaking Analysis

The U.S. Geological Survey and the California Geological Survey together produced a probabilistic seismic hazards assessment for the state of California (Petersen et al., 1996; revised in Cao et al., 2003). The study used a model that explicitly considered faults that are capable of generating moment magnitude 6.5 or greater earthquakes. The San Francisco Bay area, Monterey Bay area and Santa Cruz Mountains are traversed by numerous minor faults and splays, many of which may be capable of generating smaller earthquakes; to account for these seismic sources, a background source magnitude of 6.5 was also applied in the probabilistic model.

Probabilistic ground motions for the quarry based on this joint study are listed in Table 46. These estimated ground motions assume a soil profile type Sc (firm rock), per the 2001 California Building Code (CBSC, 2002). We caution that these values are not based on a site-specific probabilistic assessment, as is normally required for critical structures such as schools and hospitals.

The ground motion intensities shown in Table 46 are the seismic shaking intensities that have a 10% probability of being exceeded in 50 years or a 2% probability of being exceeded in 50 years. The ground motion with a 10% probability of being exceeded, 0.43g, is considered appropriate for residential and non-habitable structures. The ground motion with a 2% probability of being exceeded, 0.7g, is considered appropriate for critical structures such as hospitals or fire stations.

5.2.2.3 Ground Shaking Amplification

The ground motion values listed in Tables 47 and 48 are merely expected values based on uniform site conditions in firm bedrock; actual ground motions during an earthquake may vary due to unique site conditions (e.g., bedrock type or topography) or the way different portions of the earth's crust transmit seismic energy to the site. Ground motions at the crest of a very steep ridge can be several times as intense as in the adjacent valleys due to topographic amplification (Hartzell et al., 1994). Topographic amplification is therefore potentially important for steep, high slopes such as quarry faces. However, the influence of topography on seismic shaking is complex, sometimes leading to pronounced disagreements between theoretical predictions and observed effects (Geli, et al., 1988; Hartzell et al., 1994). Hartzell et al. (1994) found amplification factors on a steep-sided ridge crest to be as high as five times for aftershocks of the 1989 earthquake. Ashford and Sitar (2002) have provided a method for estimating seismic shaking amplification on steep slopes.

5.2.3 **Seismically Induced Ground Deformation**

Ground deformation associated with strong seismic shaking may manifest in several ways

1. Seismically induced differential settlement occurs when seismic shaking compacts loose soils.
2. Off-fault coseismic ground cracks or fissures may form in response to strong shaking, particularly along the crests of ridges.
3. Seismic shaking can trigger landslides on slopes that are already marginally stable.
4. Liquefaction occurs when generally loose, saturated, cohesionless soil (typically sand) loses strength due to seismic shaking, causing it to behave like a liquid. Ground deformations that accompany liquefaction include lurch cracking, fissuring, and lateral spreading (i.e., liquefied soils flowing laterally toward a free face, such as a stream bank).

In the quarry area, the principal hazards from seismically induced ground failure are coseismic ground cracking along the crests of quarry slopes, and seismically induced landsliding, rock falls, or topples on the quarry faces. Soil liquefaction and differential settlement are not considered to be hazards in the quarry. However, it is possible that liquefaction or differential settlement during a strong earthquake could impact the embankment dams (levees) that retain the sediment basins. Liquefaction and settlement hazards posed to the sediment basin levees are discussed below. The potential impacts of seismically induced landsliding are discussed in the landsliding section, to follow.

5.2.3.1 Liquefaction Hazard

Golder Associates (1991) evaluated the stability of the earth embankments (levees) used to construct sediment basins for the quarry operation. Their report identified specific stability concerns with these levees and made recommendations for remedial stabilization measures. Golder

Associates did not include a formal, quantitative analysis of the liquefaction hazard but did note that "liquefaction could result in localized levee instability or complete failure" (1991, p. 13). In their assessment, they considered Sediment Basin 2 to be marginally susceptible to liquefaction and Sediment Basin 4 to be susceptible to liquefaction. A liquefaction hazard would exist only while there was an impoundment of water behind the embankments.

The Golder Associates (1991) report made recommendations for increasing the stability of the levees, but they concluded that even after implementing these measures the levee at Sediment Basin 4 could still be susceptible to liquefaction-related failure. The stability analysis performed for the levee associated with Sediment Basin 3 indicated that the levee is not stable under expected seismic shaking conditions. Golder (1991) calculated permanent seismically induced deformations of up to 9 inches if their predicted peak seismic loading occurred while the levee was saturated. They did not state what form the deformation would take or what the consequences of that deformation would be. The impacts of levee failure could be significant, including the release of sediment-laden water into local stream drainages.

The levee analysis performed by Golder (1991) used seismic accelerations based on a magnitude 7.0 earthquake on the San Gregorio fault. More recent studies suggest that a larger maximum probable earthquake, M_w 7.2, is warranted for the fault (Cao, et al., 2003), which may lead to a higher estimated seismic acceleration for use in the analysis. Similarly, the method of choosing the appropriate seismic coefficient for slope stability analysis has changed since 1991. Goulder (1991) use the Repeatable High Ground Acceleration (RHGA). While there is currently no universally accepted means of selecting the seismic coefficient used in slope stability analysis, the RHGA is not now commonly employed. Selection of a seismic coefficient using current information on the San Gregorio fault and current selection criteria could result in a higher estimated ground motion and greater overall estimates of levee susceptibility to liquefaction.

5.2.3.2 Ground Surface Rupture Due to Faulting

Earthquakes are caused by slippage along faults in the earth's crust. Where the fault intersects the ground surface, this slippage causes displacement that will damage or destroy structures placed directly over the fault. We consider the faults mapped in the area of the quarry (see Plates 1 and 2) to be related to deformation accompanying metamorphism, igneous intrusion, and uplift of the basement rock, most of which took place in Late Cretaceous and early Tertiary time. These faults are not genetically related to the current active tectonic regime of central California. In our opinion, therefore, the potential for fault-related ground surface rupture within the proposed quarry amendment area is low.

5.3 Landsliding and Slope Instability

Broadly defined, landsliding includes any movement of earth materials outward or downward on a slope. The associated hazards depend to some extent on the type of landslide that occurs. There are several classifications of landslides, all generally based on type of movement, type of material, and, less often, rate of movement. The most generally applied classification scheme (Cruden and Varnes, 1996) divides landslides according to type of movement (fall, topple, slide, spread, or flow) and material type (rock, debris, or soil). These categories can be further subdivided based on lesser distinctions between types of movement and slide materials.

The principal factors controlling the distribution of landsliding are the underlying rock type, the steepness of the slopes, and the presence of older landslide masses susceptible to reactivation. In particular, the steepness of the terrain greatly promotes slope instability, all other factors being equal. Landslides are often triggered by ground saturation (due to intense precipitation or misdirected drainage), seismic shaking, or both.

We observed two types of landslide in the quarry area. The landslide complex adjacent to Liddell Spring was classified by Pacific Geotechnical Engineering (PGE, 2000) as the combination of an earth flow and several debris flows. The debris flow component is considered to have been caused in part by stockpiled spoils from the quarry. As discussed earlier, this landslide complex poses some hazard to the springbox at Liddell Spring and to the water quality of the spring.

A second landslide was observed in the quarry itself. This landslide occurred on a quarry face as a rock and debris slide. As discussed earlier, this failure appears to have been facilitated by an existing fracture surface on the quarry wall.

Both of these landslides illustrate the potential impact of quarry operations on slope stability. Additional landsliding around Liddell Spring could impact operation of the Santa Cruz City diversion and the water quality of the spring. Landsliding within the quarry could threaten quarry workers or impact adjacent lands and increase the risk of erosion, downstream sedimentation, and turbidity. There is a small risk that a large slope failure on the north slope of the quarry could impact the transition zone from shallow groundwater to deep groundwater within the karst aquifer, potentially affecting water quantity and quality at Liddell Spring.

An evaluation of slope stability for the proposed finished quarry configuration (including the expansion) was performed by Jo Crosby and Associates (JCA, 1997; 1998; 1999). The following sections discuss the stability of the existing and proposed finished quarry slopes and the Liddell Spring landslide.

5.3.1 **Stability Evaluation of Proposed Quarry Expansion**

Our geotechnical evaluation of the proposed quarry expansion is limited to (a) slope stability within the expansion area, and (b) possible impacts of continued quarry operations on Liddell Spring. Slope stability within the expansion area is considered here; the Liddell Spring landslide is addressed in the next section.

Geotechnical evaluations have been conducted for the sediment basins and for planned fill embankments (e.g., Golder Associates, 1991; Jo Crosby and Associates, 1991, 1995a, and 1995b). These studies were part of an earlier CEQA analysis of the quarry (see Engineering Science, Inc., 1990; Thomas Reid and Associates, 1996).

5.3.1.1 Stability of Quarry Slopes

During our reconnaissance we noted a few minor rock falls or topples and one relatively large rock and debris slide in the quarry. The rock falls or topples generally involved several cubic yards to a few tens of cubic yards of fractured rock, usually derived from the crest of freshly worked benches. The large rock and debris slide has been described above.

- Proposed Slopes

The planned development of the quarry calls for the final side slopes in the quarry pit to be benched with an overall inclination of 60 degrees. Individual benches are planned to be 16 feet wide and 40 feet high, with the steps between benches having an inclination of 80 degrees (Bowman and Williams, 2000). Working slopes are to be slightly less steep. The finished benches will be gently sloped to the inboard side, with inboard ditches used to collect runoff from the benches and channel it to the floor of the quarry, via down-drains.

Overburden slopes around the quarry, consisting of loose soil and Santa Margarita Sandstone, are to be cut back to an inclination of 1½:1 (H:V). Overburden removed from the expansion area, along with quarry waste, will be placed and compacted along the western wall of the quarry. The fill will be finished with a 2:1 (H:V) slope and benched every 40 feet vertically.

- Review of Existing Stability Analysis

A geotechnical evaluation of the finished grading for the quarry was performed by Jo Crosby and Associates (JCA, 1997; 1998; 1999). Jointed rock slopes within the quarry excavation were analyzed using a fracture mechanics approach. Rotational failure models were applied to overburden and sandstone cut slopes around the top of the quarry. Double-wedge and rotational failure models were applied to the proposed fill slopes around the west side of the quarry.

The stability analysis for both the jointed quarry faces and the sandstone slopes assumed seismic accelerations of 0.2g. This value was considered appropriate by many researchers at the time the JCA reports were prepared. Recent research, however, has prompted most current practitioners to employ seismic design coefficients based more on specific site location and site characteristics. Ashford and Sitar (2002) have developed a method for estimating appropriate seismic coefficients for analyzing the stability of very steep slopes. Their method indicates that substantially larger seismic coefficients would be would be applicable in the analysis of the planned quarry slopes.

JCA concluded that the planned quarry slopes would be stable. A peer review of the JCA reports was provided by a registered geotechnical engineer, attached as Appendix D. We performed our own peer review of the geologic portion of these reports. The following comments summarize the results of both the geologic and geotechnical reviews.

- Fracture Mechanics Analysis for Jointed Rock

JCA performed kinematic and limit equilibrium analysis of plane and wedge failures, using stereographic projection techniques, for the metamorphic and granitic rock slopes. Forty-five fracture attitudes and their intersection lineations, taken from different rock types throughout the quarry, were plotted on four equal-area stereonets (one for each of the four proposed quarry faces). No identifiable structural trends or groups exist in the JCA data, indicating that the sampled fractures represent multiple structural domains.

A great-circle representation of the average strike and dip of each of the four proposed finished quarry faces was plotted on a stereonet with the fracture and fracture intersection data. Fracture and intersection attitudes plotted on both sides of the great circle for each of these proposed quarry faces, indicating that many of the fractures and intersections observed by JCA are kinematically potentially unstable, and that limit equilibrium analyses are needed to resolve their stability. The material strengths required for stability were then back-calculated from an assumed potential failure surface. The JCA reports concluded that the back-calculated material strengths were reasonable, given the rock and soils types observed in the field, and that the proposed slopes are therefore likely to be stable.

In our opinion, fracture mechanics theory was employed incorrectly in JCA's analysis for the jointed quarry slopes. This opinion is based on the following findings:

- As discussed earlier, each structural domain requires a separate analysis. Individual structural domains were not identified, and the number of discontinuities sampled was too small to provide an adequate representation of fracture conditions at the site.
- JCA's structural data and slope-face orientations were plotted on equal-area stereonets. Analysis of angular relationships using stereographic techniques, such as a fracture stability analysis, should be performed using equal-angle stereonet projections.
- JCA concluded that rock slopes were probably stable if a majority of fractures or intersections did not daylight within the slopes. In fact, a slope is kinematically unstable if only one daylighting fracture or intersection is present.
- JCA performed a back-calculation for an assumed 70-degree failure surface and concluded that the rock slopes were stable. No documentation was provided as to why this failure surface was selected, or if this failure surface represents the critical surface.
- No field or laboratory tests were used to determine material strength properties. The material strengths required for stability were back-calculated from assumed failures, and these calculated strengths were assumed to be present in the rock.
- JCA did not consider fracture strength independently of rock strength. Strength differences between clean joints and infilled or cemented joints were not considered. Sampling and laboratory testing of fractured rock, both with and without infill, is required to perform this analysis.

- Water pressures (i.e., open fractures filled with water during storm events) were not considered as part of JCA's analysis.
- JCA considered the satisfactory past performance of the quarry slopes, as of the publication dates of their reports, as evidence that the planned slopes of 80 degrees could be justified. The landslide observed during the winter of 2005-2006 calls this evidence into question.

5.3.1.2 Stability of Proposed Overburden Cut Slopes

JCA employed Bishop's Method of Slices to analyze the potential for rotational failures in the planned 1½:1 (H:V) overburden and sandstone cut slopes. No laboratory testing was performed on representative samples of overburden or sandstone material to determine in-situ strength parameters. Instead, JCA back-calculated strength parameters from an assumed failure surface to obtain a factor of safety of 1.2 under seismic loading, using a seismic coefficient of 0.2. Because the back-calculated strength parameters were considered to be representative of the sandstone, JCA concluded that the cut slopes were stable.

The rotational stability analysis for the proposed overburden and sandstone cut slopes was found to be in general conformance with the local engineering standard of practice at the time of publication (PCEI, 2004; see Appendix C). However, we are of the opinion that revisions would be required to meet the current standard of care, specifically:

- Field and/or laboratory testing should be used to determine overburden and sandstone strength parameters, and a forward stability analysis should be performed.
- Updated seismic coefficients (e.g., Ashford and Sitar, 2002) should be employed. A new stability assessment based on current information and procedures for seismic coefficient selection may produce results differing from the stability assessment by JCA.

5.3.1.3 Engineered Fill Slopes

JCA employed laboratory triaxial test results on remolded, laboratory-compacted, screened rock fines from the quarry to represent the material that will be used as fill on the west side of the quarry. Strength parameters from these tests were applied to double-wedge and rotational failure models.

The stability analysis for the fill slopes was found to be in general conformance with the local engineering standard of practice at the time of publication (PCEI, 2004; see Appendix C). In our opinion, the following revision would be required to meet the current standard of practice:

Updated seismic coefficients should be employed.

5.3.1.4 Summary of Slope Stability Evaluation

Until updated stability analyses are completed as recommended, the stability of existing and proposed quarry slopes cannot be readily validated. The recent landsliding within the quarry, however, highlight the potential hazards. At the same time, the amended grading plan for the quarry calls for placing spoil from the amendment area along the western side of the quarry. The placement of these soils in compacted form will reduce the landslide hazard in that portion of the quarry.

5.3.2 Liddell Spring Landslide

The Liddell Spring landslide complex has been extensively characterized by PGE (2001). Potential impacts due to quarry expansion include the following:

- Additional instability could be induced by blasting.

Placement of additional spoils from the quarry near the head of the landslide complex could further destabilize the area.

- Changes in runoff patterns could result in increased saturation of the landslide mass.

The landslide complex appears to have been stable since monitoring began in 2000 (Reid Fisher, personal communication, 2006). The PGE (2001) geotechnical report presents their stability analysis and makes recommendations for stabilizing the landslide mass, should that become necessary. The landslide complex includes an earthflow that PGE (2001) interprets as having occurred under natural conditions, prior to quarrying, and more recent debris flows exacerbated (if not triggered) by quarry spoils placed on the slopes above. The landslide abuts the City's springbox at Liddell Spring. Tompkins (January 2002) discussed the potential for the landslide to damage or destroy the springbox.

The PGE (2001) report provides recommendations for reducing the landslide hazard at Liddell Spring, including drainage control, continued monitoring, and dewatering the landslide mass. They concluded that blasting would be unlikely to induce new landslide movement at the spring site. Provided that no more quarry waste is placed on the slopes surrounding Liddell Spring and that the PGE (2001) recommendations are followed, the proposed quarry expansion will not increase the risk of renewed landsliding in the vicinity of the spring.

5.4 Erosion Potential

Erosion results in the gradual lowering of the ground surface due to the action of wind and water. Erosion by water begins with the loosening of individual soil particles by rain drop impact and by mechanical transport of soil particles by surface flow. Runoff starts as sheet flow that collects into tiny rills guided by small irregularities in the ground surface. Rills merge into streams and streams into rivers. Erosion rates are proportional to the volume and velocity of the water flow. Consequently, the larger streams and rivers cut down more rapidly, leading to ridge and valley terrain. Vegetation plays a key role in determining natural erosion rates.

In areas where the slope aspect and rock type promote redwood forests, the redwood canopy intercepts rainfall and helps protect the soil from raindrop impact. At the same time, the buildup of tree litter under the canopy creates a thick layer of duff that protects the ground surface from erosion. Erosion rates in these areas can be relatively low. In contrast, areas of poor soils with sparse vegetation are exposed to direct impact by raindrops and have little protection from erosion caused by runoff. Wind erosion tends to be a more important erosion factor in arid climates, where surface runoff is minimal and sparse vegetation leaves soils exposed to the action of wind.

Cultural activities such as road building, logging, and (in some instances) wildfires can result in an increase in erosion rates, usually referred to as "accelerated" erosion. The degree to which cultural activities will impact erosion rates depends on the nature of the activity, the manner in which the activity is conducted, and the natural susceptibility of the local earth materials to erosion.

Erosion can and does occur in natural settings undisturbed by human activity. However, human activities such as agriculture, timber harvesting, road building, and quarrying have the potential to increase erosion impacts by orders of magnitude over natural conditions. Removal of vegetative cover, grading, and changes in drainage courses or redirection of surface waters can cause accelerated erosion. This accelerated erosion results in loss of soil cover, which limits opportunities for the plant growth upon which natural ecosystems depend, and redeposition of the eroded material can destroy aquatic habitats in downstream areas.

Quarry expansion will increase the amount of runoff from the quarry by creating a larger area of exposed rock. The proposed quarry expansion therefore has the potential to cause erosion by increasing runoff volumes and velocities, possibly resulting in sedimentation of downstream areas and increased turbidity at Liddell Spring.

The amendment area is partially overlain by as much as 150 ft of Santa Margarita Sandstone, a poorly consolidated and weakly cemented sandstone. The mechanical removal of this material will create loose sand and silt that will likely infiltrate buried karst sinks and open fractures, thus gaining entry to the karst aquifer system. This sediment will also be entrained in runoff.

The removal of overburden from the original quarry area in 1969-70 is closely linked to instances of sedimentation and turbidity in Liddell Spring. Additional removal of overburden has reportedly occurred since then, presumably on a smaller scale. We did not identify any reports or evidence of major sedimentation or turbidity as a direct result of more recent clearing. We are not aware if the more recent clearing activities were done differently in order to avoid a repeat of past problems.

The final drainage plan for the quarry (Bowman and Williams, 2001) shows all runoff being captured and conducted to the quarry floor, where it will concentrate and flow to Sediment Basin 3. This drainage scheme is to be implemented at some point during mining of the expansion area. Prior to that time, runoff will be impounded within the quarry, as is presently the case. Potential impacts due to the expansion of mining will be different during the time period where runoff is being impounded within the quarry and the time where the quarry is graded to drain to Sediment Basin 3. Potential impacts are expected to diminish after implementation of the reclamation measures at the end of mining.

Under the present drainage scheme, mining of the amendment area will result in increased runoff and sediment volumes being impounded on the quarry floor. To the extent that this runoff and sediment enters voids and fractures in the quarry floor and walls, this process has the potential to impact turbidity at Liddell Spring, but is unlikely to affect flow quantities at the spring. Turbidity and sedimentation at Liddell Spring could result sedimentation of downstream areas.

Under the final drainage plan, runoff will be collected on inboard-sloped benches and flow to down-drains leading to the quarry floor. From the quarry floor, the runoff will flow to Sediment

Basin 3. No provision is shown on the plan to slope the benches toward the down-drains. Sediment-laden runoff flowing along the benches may enter the subsurface where the bench drains cross open fractures or conduits, possibly contributing to turbidity and sedimentation at Liddell Spring, but this impact should be less than that related to the impounding runoff within the quarry. However, the final drainage plan will greatly increase flow to the sediment basins, increasing the potential for project impacts should the sediment basin levees fail.

At the end of active mining, the reclamation plan will result in revegetation of the quarry and other remedial measures that will reduce the supply of loose sediment over time. Provided the reclamation plan is successfully implemented, the potential hazard due to erosion and sedimentation will diminish over time.

Under any drainage condition, the principal erosion and sedimentation impacts due to mining of the amendment area will be related to removal and disposal of overburden. We have not reviewed any drainage plan for controlling runoff and erosion during the actual process of removing overburden from the amendment area. The removal of this overburden will have significant impacts on erosion and sedimentation, unless appropriate mitigation measures are implemented over the short term.

5.5 Hydrologic Impacts

5.5.1 On-Site Drainage and Sedimentation

The existing quarry pit has no outlet for surface drainage. Thus, runoff from approximately 125 acres of quarry and the surrounding swales and hillslopes collects in the quarry and percolates into the marble aquifer. In Section 4.6 we identified this process as a potentially major source of Liddell Spring turbidity.

The County Senior Civil Engineer has stated that the existing drainage controls and sediment retention basins are adequately sized to handle the amendment area under the final drainage plan, where runoff from the quarry will be directed to Sediment Basin 3. Under the present drainage conditions, which will pertain for at least the initial mining of the amendment area, most of the runoff and sediment from the amendment area will never reach these basins, but will instead collect in the quarry pit and percolate to groundwater.

A loss of subsurface drainage capacity could also result from collapse or disruption of the karst system beneath the quarry. However, percolation through the quarry floor has been historically adequate to remove collected runoff (and groundwater from excavated perched zones) with little ponding or the need for external drainage. We infer that sufficient subsurface drainage capacity will persist with expansion of the quarry into the amendment area. However, subsurface drainage over areas of quarry floor (as planned) may cause increased turbidity at Liddell Spring.

5.5.2 Off-Site Flow and Sedimentation

The sediment discharged from Liddell Spring due to quarry activities represents an additional sediment load for the natural drainage system downstream of the spring. Sedimentation of the downstream channel could adversely impact listed-species habitat.

The continued diversion of approximately 30 gpm from Plant Spring for use in quarry operations represents a relatively minor loss of flow downstream from the spring. In contrast, ongoing studies and/or rulings by regulators (e.g., California Department of Fish and Game) may determine that the City of Santa Cruz is adversely impacting downstream habitats as a result of its much larger diversions from Liddell Spring. The CEMEX diversions from Plant Spring should have a correspondingly smaller impact.

5.6 Hydrogeologic Impacts

This section addresses the potential impacts of the proposed quarry expansion on the quantity and quality of groundwater 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 (May 2005) concluded that the proposed quarry expansion will have an insignificant effect on Liddell Spring because (a) the spring's primary groundwater 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 in Section 4, 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 both water and sediment for the local groundwater system. The potential impact of quarry operations on groundwater quality will therefore continue or increase with the creation of additional quarry floor within 20 ft of groundwater.

5.6.1 Groundwater Separation from Quarry Floor

The Santa Cruz County Code defines an aquifer as a saturated permeable geologic unit that can transmit significant quantities of groundwater 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 ft above the peak groundwater 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 groundwater elevations beneath the quarry floor and the proposed amendment area. Among recently monitored wells, water levels are generally below 750 ft msl, although some former wells now destroyed by quarrying had water levels exceeding 750 ft msl (Figure 32). These higher water levels may have represented perched zones; alternatively, peak groundwater levels may have been moderated by enhanced drainage resulting from the subsequent quarrying.

5.6.1.1 Previous Assessments

- Wisser and Cox (April 1959) concluded that a quarry floor with an elevation of 700 ft msl might fall a little below the top of the zone of saturation and thus have undesirable effects on Liddell Spring.

- SECOR (November 1997) estimated that the proposed final quarry floor (750 ft msl minimum) would fall below peak water levels recorded in well DDH-38 by 150 ft, BD-44 by 167 ft, DDH-26 by about 60 ft, DDH-32 by 34 ft, BD-36 by a small amount, and BD-43 by about 10 ft. Peak water levels recorded for DDH-37 would be within 20 ft of the proposed final quarry floor. Also, the quarry floor would be 200 to 300 ft below water levels observed in BD-40, -41, and -42, located near but outside the proposed amendment area. SECOR concluded that most of these wells encountered perched zones and noted that no new springs had occurred as a result of past quarrying.
- EMKO (August 1999) proposed a modified program for drilling blast holes in order to help determine depths to groundwater as mining proceeded. EMKO suggested that mining could proceed below peak groundwater levels, because the groundwater occurs under confined conditions. EMKO also suggested that quarrying to within 20 ft or less of the groundwater surface would enhance recharge and thus provide an overall benefit to the aquifer.
- Cloud (February 2000) strongly disagreed with EMKO's suggestion to allow mining within 20 feet of groundwater because of the possibility of encountering fractures and conduits with a direct connection to the aquifer. To the extent that confined (artesian) conditions exist, breaching the confining layer by exposing these fractures could flood portions of the quarry floor. Cloud (March 2000) also pointed out that peak water levels in well DDH-25 were 50 ft above the proposed depth of mining.
- Brown and Caldwell (October 2000) concluded that a final quarry floor of 750 ft msl would be at or above deep-zone water levels, and thus acceptable. This determination did not account for the required 20-ft separation from groundwater. They stated that because perched zones were incapable of producing much water, there would be no significant impact on the water supply if they were mined.
- Cloud (October 2000) stated that in order to properly evaluate a final quarry floor at 750 ft msl, quarry monitoring wells should be grouted for their entire depth above a single screened interval at 730 ft msl. He noted that this was not the case. Cloud estimated that there was a potential for continued mining to intercept the saturated zone at the northern end of the proposed amendment area, in which case a 20-ft separation to groundwater would not be maintained for most of the northern half of the amendment area.

5.6.1.2 Potential Impacts

Because of the difficulty in pre-determining peak groundwater elevations, given the complex hydrogeology of the quarry area, CEMEX proposes drilling shallow borings as the pit is lowered to test the depth to groundwater. If groundwater is encountered in a borehole, CEMEX proposes to pump groundwater 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 groundwater would not be known without additional monitoring (i.e., during a year of above-average precipitation). Lindsey

(April 1967) describes groundwater levels fluctuating as much as 63 ft in 20 days. Hydrographs presented in previous reports have exhibited large fluctuations in groundwater level, often with "no reasonable explanation" (Watkins-Johnson Environmental, November 1992). In some cases these fluctuations may reflect the sudden draining of a perched zone and simultaneous filling of an underlying zone (e.g., the hydrographs for wells BD-42 and BD-41 during late 1992; Figure 26).

Substantial zones of perched groundwater may be drained by quarrying down to 750 ft 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 expansion area (Figure 32). For example, well BD-42 beyond the northeast corner of the expansion area had a maximum water level of 996 ft msl during the recent PELA study (May 2005) and was described to have "a significant connection to the marble aquifer."

Santa Cruz County Code stipulates that "the lowest elevation of any mining operation at any time shall be 20 ft above the peak groundwater elevation" (Section 16.54.050). Typically, this has not been applied to perched zones. In the case of the proposed expansion area, the groundwater surface is not well defined; there is little documentation of peak groundwater elevations during periods of above-average precipitation; and quarrying may remove a considerable volume of perched zone (some of which may tap into the upgradient 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 groundwater entering the deeper karst aquifer, removing them may result in increased seepage into the pit from the unsaturated zone. To the extent that that the quarry pit remains a closed depression with no external drainage, most of this water will eventually percolate into the aquifer. Such percolation appears to result in turbidity at Liddell Spring. When the quarry is drained to Sediment Basin 3, any water flowing into the quarry from breached groundwater conduits will be channeled out of the drainage area for Liddell Spring.

Given these uncertainties, the potential exists for the quarry expansion to intercept volumetrically substantial zones of perched groundwater and come within 20 ft or less of the fully saturated zone. The proposed tests for determining depth to groundwater as quarrying proceeds will not necessarily coincide with times of peak groundwater elevation. Assuming the quarry pit remains a closed depression with no outlet, most unsaturated-zone seepage and rejected recharge is expected to percolate eventually into the aquifer. The potential effect of exposing perched zones, mining to within 20 ft or less of maximum groundwater elevations, and flushing additional water through the quarry floor will be to expose groundwater to surface contamination and introduce additional natural and quarry-generated sediment into groundwater, causing turbidity at Liddell Spring. The potential impact of draining the quarry to Sediment Basin 3, as envisioned by the final drainage plan (Bowman and Williams, 2001), will be to lessen the potential for the quarry to impact water quality at Liddell Spring, but to increase the potential for the quarry to affect flow quantities at the spring.

5.6.2 **Groundwater Quantity**

5.6.2.1 Previous Assessments

- Engineering-Science (1991) expected quarrying to have no impact on the quantity of groundwater flow because none had been reported to date. Rather, in their opinion, groundwater recharge might be enhanced by quarrying.
- SECOR (November 1997) concluded that mining could impact the hydrogeologic system by modifying groundwater flow pathways. The significance of this would depend on the amount of groundwater flow affected and the relation of these pathways to the overall system.
- Cloud (March 2000) said that nearby wells with shallow water levels could be affected by the interception of perched zones during quarrying.
- PELA (May 2005) concluded that the overall range of Liddell Spring annual discharge had not and would not substantially change as a result of quarrying.

5.6.2.2 Potential Impacts

There is a lack of evidence demonstrating long-term changes to the quantity of groundwater and/or springflow as a result of past or ongoing quarrying. The quarry's continued diversion of water from Plant Spring will not impact the quantity of groundwater. It also appears that few if any water-supply wells are sufficiently near the quarry to be impacted.

Several major fracture zones intersect the proposed amendment area, and because these fractures may be associated with important groundwater pathways to Liddell Spring, expanding the quarry as planned could disrupt this groundwater flow to the spring. As long as most of any intercepted groundwater eventually percolates into the aquifer from the quarry pit, no significant impacts are expected with regard to the quantity of groundwater reaching the spring. On the other hand, if the quarry pit is provided with external drainage (e.g., to mitigate impacts to groundwater quality), a significant net loss of groundwater yield and storage could occur. Similarly, quarry reclamation has the potential to reduce recharge by redirecting surface drainage out of the quarry.

Quarrying of the expansion area may result in some increased groundwater recharge. Overburden removal and exposure of fractured marble and collection of runoff in the quarry pit may allow for more rapid percolation and thus reduced evapotranspiration of soil water. This potential increase in recharge would diminish as the final quarry walls and floor become covered in stockpiled overburden as part of reclamation.

5.6.3 **Groundwater Quality**

The existing quarry may have some ongoing influence on the concentration of nitrate and total dissolved minerals in groundwater. However, substantial increases in the concentration of these compounds have not been clearly documented over time, and other sources may contribute as much or more than the quarry. Thus, there is insufficient evidence to conclude that quarrying of the proposed amendment area will significantly worsen groundwater nitrate and total dissolved minerals.

The remainder of this section addresses potential increases in groundwater and springflow turbidity.

5.6.3.1 Previous Assessments

- Tompkins (April 1991) asserted that Liddell Spring peak turbidities were greater and occurred more quickly after rainfall since quarrying began.
- Watkins-Johnson (November 1992) recognized that solution cavities exposed by quarrying provided a pathway for turbid water on the quarry floor to enter the aquifer.
- SECOR (November 1997) recognized that the quarry's removal of sandy overburden that filters recharge and exposure of fractures and conduits in the quarry walls and floor could potentially affect springflow turbidity.
- Farallon (March 2000) concluded that a cover placed over a portion of the quarry floor had no dramatic effect on springflow turbidity, thus ruling out the quarry floor as a source of turbidity.
- Brown and Caldwell (October 2000) held that groundwater flowing through the marble aquifer would be sufficiently filtered to maintain ambient turbidity conditions.
- Cloud (October 2000) commented that Brown and Caldwell's conclusions about turbidity and aquifer filtering were unsubstantiated.
- PELA (May 2005) stated that the turbidity at Liddell Spring could be affected by logging, construction, and clearing. PELA also recognized that the quarry could contribute to springflow turbidity if open fractures allowed sediment-laden runoff to drain into the subsurface. However, because of a poor hydraulic connectivity between the unsaturated and saturated zones, PELA concluded that the quarry's potential contribution to the turbidity of groundwater and Liddell Spring was limited.

5.6.3.2 Potential Impacts

The turbidity of Liddell Spring responds to precipitation in a complex and highly variable manner. The data record cannot, by itself, be used to demonstrate a definitive cause-and-effect relationship between quarrying and springflow turbidity because the City of Santa Cruz (a) historically measured only the turbidity of its actual diversions, (b) implemented various changes in sampling and measurement methods, (c) increased its ability to divert slightly more turbid water since 1994, and (d) did not initiate more complete turbidity monitoring until 1997. However, as listed below, several lines of evidence suggest that past and ongoing quarry activities have contributed to Liddell Spring turbidity, and it is reasonable to conclude that such impacts will continue with the proposed mining expansion.

- A cause-and-effect relationship between quarry activities, springflow, turbidity, and sedimentation has been demonstrated by the documented impacts of overburden removal at the start of quarry operations.
- 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. Quarry blasting appears to mobilize and possibly generate subsurface sediment that contributes to springflow turbidity, if not immediately then following subsequent storm events.
- Observed quarry ponding and drainage into the subsurface, along with estimates of overall quarry recharge, indicate that the quarry represents a substantial source of groundwater recharge during and following storm events.
- The removal of the overburden and mining of the marble reduce recharge filtering and expose 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.
- The poor correlation between the discharge and turbidity of Liddell Spring suggests that the cause of turbidity is partially independent of the principal sources of groundwater recharge.
- The primary turbidity response at Liddell Spring typically is too slow for sediment sources near the spring (e.g., the landslide complex or possible sinkholes), and too fast for sediment transport from the Reggiardo and Laguna creek swallow holes (based on tracer times of several days or more).
- The timing and nature of Liddell Spring's turbidity response to precipitation, runoff, and quarry ponding indicate that runoff captured by the quarry pit and percolated through the quarry floor -- along with sediment generated by quarrying -- are significantly responsible for turbidity at the spring.

While other turbidity sources and delivery mechanisms exist, these lines of evidence, along with our understanding of the groundwater system, indicate that the existing quarry operation has had -- and will continue to have during quarrying of the expansion area -- a significant impact on Liddell Spring turbidity.

Quantitative estimates of the potential impact of quarry expansion on springflow turbidity are hindered by the lack of fully representative turbidity data for the period before and immediately after quarrying began (prior to the initial use of data loggers in 1997). However, based on inferred relationships between precipitation, runoff, quarry ponding, generation of sediment, and spring turbidity, we conclude that the potential impact will be significant.

The analysis presented in this report indicates that Liddell Spring's primary turbidity response to storm events is largely related to runoff capture and percolation at the quarry. Additionally, smaller turbidity events are related to quarry blasting. Turbidity also results from runoff capture by stream swallow holes and sinkholes, and mobilization of subsurface sediment during periods of peak groundwater flow. On balance, it is reasonable to conclude that roughly half or more of Liddell Spring's overall turbidity may be directly or indirectly attributable to quarry operations.

5.6.4 Impact on Springflow Production

An increase in the turbidity of Liddell Spring has the potential to impact the City of Santa Cruz's water supply. These potential impacts include: reduced production and increased operational costs whenever diversions are halted because of elevated turbidity; increased reliance on other sources of water at such times, including water from Loch Lomond ordinarily reserved for use during droughts; operational costs and lost production from purging the North Coast pipeline and treating highly turbid water at the Graham Hill treatment plant; and increased exposure of the water supply to surface contamination in the event that groundwater temporarily daylights in mined areas. 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 amendment area may impact the City's spring diversion over a several-year period as a result of considerable and repeated sedimentation events, based on what reportedly occurred during the early 1970s. The potential production losses and costs associated with such events have not been estimated.

5.7 Data Gaps

Data gaps associated with this analysis of potential geologic, hydrologic, and hydrogeologic impacts from the proposed quarry expansion include the following:

- Sufficiently detailed turbidity data for comparing conditions before and after quarrying began are unavailable.
- Long-term water-level data representative of groundwater conditions beneath the existing quarry and proposed amendment area. This data gap reflects the difficulty of maintaining monitoring wells in an area being actively mined. Fulfilling this data need may require repeated construction and surveying of replacement monitoring wells.
- The collection and analysis of groundwater turbidity data from monitoring wells has been discouraged in the past due to uncertainties associated with monitoring-well construction and sampling techniques (e.g., Farallon, March 2000). However, such data, if reliable, would be useful for evaluating potential groundwater impacts from quarrying at locations other than Liddell Spring. The potential for employing improved sampling methods should be evaluated.

5.8 Conclusions

We draw the following conclusions regarding potential geologic impacts of the proposed expansion of the mining area:

- Very strong seismic shaking may occur during the project lifetime. Seismic shaking could damage buildings and other structures associated with the quarry operation. Because no new structures or any increase in the size of the quarry operation is planned, the existing level of hazard due to seismic shaking is not expected to increase due to the quarry expansion.
- The principal seismically induced ground failure hazards that are likely to affect the quarry area are co-seismic ground cracking along crests of quarry slopes, seismically induced landsliding, rock falls and rock topples along the quarry faces. These events could pose a hazard to quarry workers. There is a potential for large, seismically induced landslides to impact the landscape adjacent to the quarry, elevating erosion and sedimentation hazards. There is a small potential for landsliding on the north wall of the quarry to impact pathways for migrating groundwater. Although we consider additional analysis to be necessary for validation of previous slope stability evaluations, the expansion of the mining to the amendment area will result in impacts only to the extent that the amendment area exposes additional workers to a hazard or creates additional quarry wall area subject to landsliding. To our knowledge, the mining operation in the amendment area will only be a continuation of the existing operation, and will therefore not result in exposure of additional persons to a slope stability hazard. The quarry wall length for the existing mining area and the amendment area combined is about 12% longer than that of the existing mining area by itself (measured as the circumference of the existing and proposed mining areas), with only a very little increase in length of the north wall of the quarry. Balanced against this increase in exposure, the amended mining plan calls for placement of compacted spoils from the amendment area against the western wall of the quarry, which will reduce the hazard posed by landsliding in that area.
- It is possible that liquefaction or differential settlement during an earthquake could impact the embankment dams that retain the sediment basins, damaging drainage works and releasing sediment laden water into local stream drainages. In a worst case event, rapid failure of a levee while the sediment basin is full could result in flooding of downstream areas. This potential impact is considered significant. To the extent that runoff from the proposed amendment area and existing quarry will be greater than that of the existing quarry alone, the amendment area may result in a significant increase in potential impacts.
- Landsliding within the quarry under static (non-seismic) conditions is possible, as indicated by the recent landslide within the quarry. The hazards associated with non-seismic landsliding are comparable to those associated with seismically induced landsliding, discussed above. Such landsliding could threaten quarry workers during the quarry operation or damage land adjacent to the quarry after the end of active quarrying, increasing the risk of erosion. There is a small potential for a large slope failure on north slope of the quarry could impact the transition zone from high groundwater to deep groundwater in the karst aquifer, potentially affecting water quantity and quality and

Liddell Spring. Potential impacts due to slope stability issues cannot be assessed without updated stability analysis of the proposed amendment area slopes.

- The proposed quarry expansion has the potential to cause increased erosion and sedimentation. Where runoff from the quarrying operation is detained within the quarry, the increased erosion and sedimentation may significantly impact turbidity at Liddell Spring, as discussed below. Since it has previously been established that Sediment Basin 3 is adequately sized to handle runoff from the amendment area, the impact is judged to be less than significant for the proposed final drainage scheme (drainage of the quarry to the sediment basin).

Conclusions regarding potential hydrologic impacts include:

- Existing runoff and sediment retention basins have been deemed adequate to handle the proposed quarry expansion.
- Runoff and sediment collected in the quarry pit migrates to groundwater and contributes to Liddell Spring flow and turbidity. It is not possible to directly quantify the contribution of the quarry operation to the overall turbidity at Liddell Spring. However, based on consideration of the geologic and hydrogeologic data, it is our opinion that roughly half of Liddell Spring's turbidity is directly or indirectly attributable to quarry operations. This impact will be on-going during mining of the amendment area.
- When drainage of the quarry pit to Sediment Basin 3 is established, impacts on turbidity are likely to be reduced. At the same time, this change in drainage may increase impacts on spring flow quantities.
- Tubidity impacts during the time that runoff is being retained within the quarry are considered to be potentially significant.
- Spring flow quantity impacts after quarry drainage to Sediment Basin 3 is established are potentially significant.

We draw the following conclusions regarding the response of groundwater and springflow to quarry operations and potential impacts of the proposed quarry expansion:

- Considerable interconnectivity exists between precipitation, runoff, and sediment collected in the quarry, groundwater 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
  - The removal of overburden and mining reduces recharge filtering and exposes fractures and dissolution channels that interconnect with groundwater. These have the potential to transport water and sediment from the quarry in a turbulent and cascading flow down to the zone of saturation and laterally toward Liddell Spring, resulting in spring turbidity.

- Observed quarry ponding and estimates of overall quarry recharge indicate that the quarry represents an important contribution to the groundwater system and Liddell Spring discharge during storm events relative to other sources.
- The timing and nature of Liddell Spring's turbidity response to precipitation, relative to (a) the timing of runoff collected in the bottom of the quarry and (b) groundwater 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, contribute significantly to turbidity at the spring. Springbox sedimentation likely resulted from the quarry's initial overburden removal.
- The bulk volume of sediment needed to account for Liddell Spring's turbidity (roughly several cubic feet per day, on average) could be generated by quarry operations.
- Quarry blasting appears to mobilize and possibly generate subsurface sources of sediment that contribute to spring turbidity, both as an immediate response to blasting and potentially during subsequent storm events.

Based on these observations, we conclude that the proposed quarry expansion could have a significant impact on turbidity at Liddell Spring. This, in turn, has the potential to impact the City of Santa Cruz's water supply. 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 groundwater temporarily surfaces in mined areas. The City has not provided estimates of potential production or cost impacts associated with elevated turbidity.

- Quarry activities probably contribute to groundwater nitrate. However, other sources appear to be as or more important. Concentrations of nitrate and other dissolved minerals in Liddell Spring discharge are not exhibiting definite and/or significant upward trends. Therefore, nitrate impacts are considered to be less than significant.
- There has been no apparent decline in the quantity of Liddell Spring discharge as a result of quarrying.
- Historic groundwater levels are at or above the proposed depth of mining along the northern side of the amendment area. There is some potential for mining to intercept groundwater flowing to Liddell Spring. Surfacing of groundwater in the quarry will have different impacts depending on whether the water is retained within the quarry or if it is conducted out of the quarry to Sediment Basin 3. When the quarry is a closed basin, such water is likely to percolate back to the groundwater system. Consequently, potential impacts on springflow quantity are considered to be less than significant, although water surfacing in the quarry could be exposed to contaminants, affecting groundwater quality when it percolates into the quarry floor. When drainage of the quarry to Sediment Basin 3 is established as part of the

final drainage plan, surfacing of groundwater flow in the quarry could result in that flow being diverted out of the drainage area for Liddell Spring, possibly resulting in some potentially significant impact on spring flow quantities.

- The final drainage plan for the quarry requires lowering of the ingress/egress ramp on the south side of the quarry by about 50 feet. This lowering will require blasting of rock immediately upstream from Liddell Spring, which will likely result in an increase in turbidity at the spring. This impact is potentially significant.