5.3 GEOLOGIC HAZARDS AND RESOURCES

This section of the application presents information on the geologic hazards and resources of the area surrounding the ESGS, in accordance with CEC requirements. The geologic and tectonic setting of the region and the study area are described, followed by an evaluation of geologic hazards including surface fault-rupture, strong ground shaking, liquefaction, mass wasting/slope stability, subsidence, and collapsible and expansive soils, and coastal hazards. Potential environmental impacts of the proposed project on the geologic resources at the site are addressed, as are potential mitigation measures.

The final portion of this section describes laws, ordinances, regulations, and standards relevant to geologic impacts of the project as well as providing contacts in respective regulatory agencies. Required permits are also discussed.

5.3.1 Affected Environment

The ESGS and ancillary facilities are located along the shoreline of Santa Monica Bay on the Pacific Coast (Figures 5.3-1 and 5.3-2). The project site is situated between Palos Verdes Peninsula on the south and the Santa Monica Mountains on the north. This location is in the western portion of the Los Angeles Structural Basin, which forms the transition between the northern portion of the Peninsular Ranges Physiographic Province and the southern portion of the Transverse Ranges Physiographic Province of California (Figure 5.3-3).

5.3.1.1 Power Plant Site

The ESGS is underlain by marine and non-marine Tertiary sediments, which overlie Franciscan age bedrock. The plant’s elevation ranges from 18 to 22 feet above mean lower low water (MLLW), increasing away from the ocean.

5.3.1.1.1 Regional Geology. As previously mentioned, the site is located at the transition between the northern portion of the Peninsular Ranges Physiographic Province and the southern portion of the Transverse Ranges Physiographic Provinces. The Peninsular Ranges Province is characterized by northwest-trending mountains and valleys formed largely by a system of active right-lateral, strike-slip faults with a similar trend. The Transverse Range Province is characterized by east-west trending mountains and intervening valleys that were formed by a series of east-west trending fold belts and active right-lateral reverse and thrust faults. The geomorphic character of the region is predominantly controlled by the structural grain of the Peninsular Range and Transverse Range Provinces, but has been influenced by marine and non-marine erosional and depositional processes.

The stratigraphy beneath the site, from oldest to youngest, comprises Jurassic metamorphic basement rocks, Miocene and Pliocene sedimentary rocks, and Quaternary strata.

5.3.1.1.2 <u>Local Geology- Stratigraphy and Structure</u>. There are no bedrock outcrops at the site or in the project vicinity. The site and surrounding area is underlain by a thick, interbedded sequence of Quaternary clays, silts, sands, and gravels. The underlying Pliocene and Miocene sedimentary rocks include claystones, siltstones, and sandstones. Jurassic Catalina schist basement rocks lie beneath the sedimentary rocks at depths of about 6,700 feet. The Catalina Schist, Miocene Monterey Formation Strata, and Quaternary sediments have been uplifted and exposed on the Palos Verdes Peninsula, located approximately 10 miles south of the site (Figure 5.3-1).

The youngest and uppermost deposits within the Quaternary sequence consist of late Pleistocene and Holocene sand dunes (Figures 5.3-1 and 5.3-2). These deposits are likely remnants of nearshore marine and beach deposits that have been reworked as aolian sand dunes. The aolian strata are part of a coastal belt of sand dunes that parallels the coast and extends half a mile to several miles inland (Figure 5.3-2). The steep slopes immediately to the west of the ESGS is part of this sand dune complex. Structurally, these upper stratigraphic units are essentially flat lying to shallow dipping.

The underlying strata consist of Cenozoic marine and continental formations, which were originally deposited in the subsiding Los Angeles Basin. These strata have been complexly folded and locally faulted, resulting in the formation of traps for the extensive oil reserves underlying many parts of the Los Angeles Basin.

Available boring data from previous site investigations (Dames & Moore, 1953; 1962; Woodward-Clyde, 1997; 1998) indicates that the foundation-related subsurface conditions are characterized by a sequence of interbedded Pleistocene sand and gravel, and clay deposits. The underlying stratigraphy of these deposits has been divided on the basis of hydrogeologic units. The site vicinity is underlain by three relatively shallow aquifers separated by aquitards/aquicludes within a depth of approximately 100 feet below ground surface. The stratigraphic units, in descending order, consist of the Old Dune sand, Manhattan Beach clay, the Gage sand, El Segundo clay and the Silverado sand (Woodward Clyde, 1998). The Manhattan Beach clay which separates the Old Dune sand from the Gage sand is absent beneath the site under existing Units 1 and 2 (Black & Veatch, 2000, Appendix G). The following provides a description of the stratigraphic units, in descending order, underlying the power block for Units 1 and 2 (Black & Veatch, 2000, Appendix G):

- <u>Old Dune/Gage Sand:</u> consists of generally light brown to brown, medium dense to dense, slightly silty fine to medium grained sand, poorly graded (SP), with some lenses of sandy gravel (GP) and occasional cobbles. Based on the description of boring logs, the soils underlying the existing foundation for the Units 1 and 2 power block appear to be more gravelly. The Old Dune/Gage Sand extends to about Elevation –30 to –37 feet (MLLW). Corrected SPT blow counts (N_{60}) for this layer average 32 blows per foot (bpf).

- El Segundo Aquitard: consists of generally dark gray, very stiff, wet, low to high plasticity silty clay (CL to CH), containing minor amounts of shell fragments and interbeds of generally brown, dense, wet, fine grained silty sand (SM), poorly graded. The El Segundo aquitard soils underlie the Old Dune/Gage Sand and vary in thickness throughout the site, from 5 to 15 feet. The base of this layer ranges from Elevation –35 to Elevation –55 feet (MLLW). Corrected SPT blow counts (N_{60}) in this layer average 21 bpf, although some clay areas with blowcounts ranging from 6 to 9 bpf are also encountered. The fines contents of the sand layers above and below this aquitard layer increases within 5 to 10 feet of the aquitard, as the sand grades into and out of the clay layer.

- Silverado Sand: consists of generally brown, dense, wet, fine to medium grained, silty to clean sand, poorly to well graded (SP to SW), with gravel. This layer underlies the El Segundo aquitard, extending to the maximum depth explored, at elevation –168 feet (MLLW). The total thickness of the aquifer on the site is unknown. Corrected SPT blow counts (N_{60}) in this layer range from 9 to 118 bpf, with an average of about 40 bpf. Only four out of the thirty-one samples obtained in this layer had blowcounts less than 10 bpf.

5.3.1.1.3 Groundwater. The project site is underlain by three relatively shallow aquifers found in the first 100 feet below ground surface. The aquifers include the Old Dune Aquifer, the Gage Aquifer, and the Silverado Aquifer. These aquifers are separated by aquicludes/ aquitards primarily consisting of clays. The Manhattan Beach Aquitard that separates the Old Dune Sand and Gage Sand Aquifers is not present under the site, so that the Old Dune and Gage aquifers are in direct connection with each other.

Shallow groundwater was encountered in the Old Dune/Gage Sand Aquifer generally at approximately 12 feet below ground surface (bgs) under unconfined conditions in 1998 (Woodward-Clyde, 1998). This groundwater was measured at an elevation of approximately 8.0 feet above MLLW. Groundwater elevations monitored in the Old Dune/Gage Sand Aquifer suggest that the water levels are tidally influenced. Differences in elevation indicated changes of approximately 0.3 foot on the western side of the site. As measured on December 15, 1997, the direction of groundwater flow in the Old Dune/Gage Aquifer was generally to the northwest at a gradient of 0.0015 feet/foot.

The El Segundo aquitard underlies the Old Dune/Gage Aquifer and consists of clay with interbedded sands. Monitoring wells MW-3D and MW-3S (Woodward Clyde, 1998) screened in the El Segundo Aquitard and Old Dune/Gage Sand Aquifer, respectively, have shown little or no difference in groundwater elevation indicating the aquifers are connected in the area of Units 1 and 2. However, based on groundwater measurements on January 21, 1998, groundwater flow in the sand layers within the El Segundo Aquitard was to the southeast at a gradient of 0.0007 feet/foot. The ground water levels are estimated to be about 7 to 8 feet below the proposed bottom of any new plant structures.

5.3.1.1.4 Plate Tectonic Setting. The Los Angeles region is located within the active boundary zone between the Pacific and North American Plates (Figure 5.3-3). In this region, the width of the plate boundary extends more than 350 km from the offshore San Clemente fault zone to the Mojave shear zone east of the San Andreas Fault zone. At the latitude of Los Angeles the relative right-lateral motion between the Pacific and North American Plates is 48 mm/yr (DeMets et al. 1994). The simple model of strike-slip faulting along the California coast is complicated in the Los Angeles region. As shown on Figure 5.3-3, deformation along the plate boundary involves both northwest directed right-lateral strike-slip faulting of the San Andreas system, east-trending left-lateral strike-slip and oblique-slip faulting of the southern boundary of the Transverse Ranges zone, and west-northwest trending thrust and reverse faults of the Transverse Ranges. The complexity of deformation in this region is related to the combination of transcurrent and contractional deformation along the 'Big Bend' in the San Andreas fault zone, and changes in regional tectonics over the last 4 to 5 million years (M_a).

The tectonic setting has changed dramatically over a period of several million years. During the Miocene and the early part of the Pliocene the Los Angeles area was characterized by development of deep sedimentary basins within normal fault-bound grabens; the Ventura Basin contains one of the thickest Plio-Pleistocene sedimentary successions in the world. During the middle Pliocene the tectonic setting changed from an extensional to a compressional regime, and sedimentary basins such as the Ventura Basin were structurally inverted forming mountain ranges out of what were basins. The Santa Susana Mountains at the northern edge of the Ventura Basin are an example this type of structural reversal. These former normal faults now play an important role on the location and style of deformation in the Los Angeles region (Huftile and Yeats, 1995).

The high rate of relative motion between these two plates is accommodated along eight major fault zones and numerous smaller zones. As shown on Figure 5.3-4, these include from west to east the San Clemente, Santa Cruz-Santa Catalina Ridge fault zone, Palos Verdes, Newport Inglewood, Elsinore, San Jacinto, San Andreas, and Mojave shear zone faults. The first three of these faults are located partly or entirely offshore of Los Angeles and extend from Baja California to the area offshore of Los Angeles. Each of these major faults display evidence of Quaternary and Holocene deformation and accommodate a significant proportion of the overall strain across the boundary zone (Jennings, 1994; CDMG/USGS, 1996).

The Elsinore, San Jacinto, and San Andreas faults to the east of the site are among the most active faults in California. Each of these faults has high slip rates and has had moderate to large magnitude historical earthquakes. The seismic moment release along these three faults accounts for more than 70 percent of the available seismic moment from the overall plate rate of 48mm/yr (DeMets et al. 1994). Frequent large magnitude earthquakes characterize the major faults described above with recurrence intervals on the order of several hundreds of years. These faults, however, also serve to bound large portions of the region (tectonic provinces) that are characterized by lower rates of seismicity and smaller maximum earthquake magnitudes.

Three major tectonic provinces defined in the region are the Peninsular Ranges, Continental Borderlands East, and the Transverse Ranges. These provinces are large areas characterized by consistent tectonic framework and, with the exception of the Transverse Ranges, low rates of seismicity. The Peninsular Ranges Province is bound on the east and west by the Elsinore and Newport-Inglewood faults. The Continental Borderlands East is bound by the Newport-Inglewood and Palos Verdes faults. For this study, we define the Transverse Ranges to extend from the San Andreas Fault on the east to San Miguel Island on the west.

The Transverse Ranges, which now form the northern boundary of the Los Angeles Basin, are controlled by a series of generally east-trending active reverse and oblique faults. These faults have formed along the prominent change in strike of the San Andreas Fault that is referred to as the "Big Bend". As the San Andreas changes strike to a more westerly direction contractional deformation occurs along the restraining bend and folds and reverse faults are produced. There is currently estimated to be approximately 7 to 11 mm/yr of north-south compressional strain occurring across the Los Angeles Basin because of this north-directed contraction adjacent to the Big Bend (Donellan, 1993).

Earthquakes along major active faults, together with the smaller earthquakes in the tectonic provinces, comprise the seismic hazard of the region. Each of the major tectonic features that contribute to the ground-motion hazard at the site is described in more detail below.

5.3.1.1.5 Seismicity and Seismotectonics. Figure 5.3-5 shows the approximate locations of the larger earthquakes (M~6) occurring in Southern California between the years 1769 and 1998. This figure shows that the San Jacinto and Imperial fault zones have been the most seismically active faults in Southern California in historical time. Since 1890, these two fault zones have experienced as many as 14 earthquakes with magnitudes between 6 and 7. In this century the largest of these earthquakes on the San Jacinto fault was the 1918 event (moment magnitude, M_w6.8), while the largest earthquake on the Imperial fault was the 1940 event (M_w7.0).

Few large events are known to have occurred on the southern San Andreas Fault zone in historical time. The largest event known with certainty occurred in 1857 (Ft. Tejon earthquake) and its magnitude was estimated as M_w7.9.

Other significant historical earthquakes near the El Segundo Power Redevelopment Project (ESPR) site include:

- The 1933 Long Beach earthquake (M_w6.4) that ruptured a segment of the Newport-Inglewood fault from Newport Beach through Long Beach

- The 1971 San Fernando earthquake (M_w6.6) on the San Fernando fault

- The 1987 Whittier earthquake (M_w6.0), and

- The 1994 Northridge earthquake (M_w6.7).

The ESPR site is located within Zone 4 of the Uniform Building Code (UBC, 1997). The site is situated between the Newport-Inglewood fault to the east and the Palos Verdes fault to the southwest (Figure 5.3-6). DMG Open-File Report 96-08, Probabilistic Seismic Hazard Assessment for the State of California (CDMG, 1996), both faults have a right lateral - strike-slip geometry. Estimated peak ground acceleration for medium dense to dense alluvial deposits at the site is 0.46g with 10 percent probability of exceedance in 50 years (CDMG, 1998). No active (Holocene) or potentially active (Quaternary) faults were found to cross the site in this review. The hazard for ground rupture is negligible. The earthquake history and earthquake potential of each seismic source in the site region are discussed in more detail in Section 5.3.1.1.6.

5.3.1.1.6 <u>Significant Seismic Sources</u>. Southern California is a tectonically complex region comprised of many potential seismic sources. The level of information for these sources varies in amount and reliability, and for many sources is incomplete for the purposes of hazard characterization. For this reason, a number of techniques must be used to model the sources for the computation of seismic hazard at the ESPR. This study has relied on existing available information to develop the input parameters, i.e. maximum earthquake magnitude, slip-rate, and recurrence interval, for the probabilistic seismic hazard assessment. Data have been drawn from a number of different sources to characterize the major seismic sources in the region. Where sufficient data were not available to model a fault for the hazard assessment, tectonic provinces were defined and treated as areal source zones.

Faults that were treated as individual seismic sources in the seismic hazard model are shown on Figure 5.3-6. The relevant estimated seismic source parameters are summarized in Table 5.3-1. Only those sources potentially having a significant contribution to the ground-motion hazard at the site are described below.

TABLE 5.3-1

SUMMARY OF FAULT PARAMETERS

Fault Name	Abbreviation	Type	UBE (Mw)	Distance (km)
Raymond	Raymond	LL-RO	6.5	32.5
Hollywood	Hollywd	LL-RO	6.6	21.5
Elysian Park Thrust	EPT	R	6.8	30
Verdugo	Verdugo	R	6.7	33
Newport-Inglewood	NIF	RL	7.0	9
Sierra Madre	SierraMa	R	7.4	44.5
Santa Monica	SantaMon	LL-RO	6.6	16
San Fernando	SanFern	R	6.7	41.5
Northridge	Northrdg	R	6.9	34.5
Palos Verdes-Santa Monica Bay	PVF-SMB	RL	6.6	4.5
Palos Verdes	PVF	RL	7.0	13.5
Whittier-Elsinore-Whittier segment	WEWhittier	RL	6.9	38.5
Santa Susana	SantaSus	R	6.8	45.5
Cucamonga	Cucamong	R	7.0	71
San Andreas-Mojave segment	SAMojave	RL	7.5	79
Whittier-Elsinore-Glen Ivy segment	WEGlenIvy	RL	6.9	84.5
San Jacinto-San Bernardino segment	SJSanBer	RL	6.75	104
San Andreas-San Bernardino segment	SASanBer	RL	7.25	111
San Jacinto-San Jacinto segment	SJ SanJac	RL	7.0	124.5
Whittier-Elsinore-Temecula segment	WETemecula	RL	7.0	119
San Jacinto-Anza segment	SJAnza	RL	7.4	146
San Andreas-Coachella Valley segment	SACoache	RL	7.5	210
San Andreas-Carrizo segment	SACarriz	RL	7.75	157

Notes:
LL-RO = Left lateral reverse oblique
R = Reverse
RL = Right-lateral

5.3.1.1.6.1 **<u>Elysian Park Thrust.</u>** The Elysian Park Thrust forms a 38-km long, northwest-trending anticlinorium that passes underneath the site and deforms miocene through recent strata. a series of south vergent parasitic folds and flexures are interpreted to result from contractional deformation above the north-dipping blind thrust fault (Oskin and Sieh, 1998). The Elysian Park anticlinorium is interpreted to be a southward migrating fault-propagation fold linked to the elysian park fault.

Instrumentally recorded seismicity indicates that the Elysian Park anticlinorium is underlain by a seismogenic blind thrust fault, the source of the 1987 Whittier Narrows earthquake (Hauksson and Jones, 1989). Active seismicity and clear evidence of Quaternary deformation indicates that the Elysian Park Thrust may be the source of future moderate magnitude earthquakes.

The October 1987 Whittier Narrows earthquake (M_w6.0) occurred near the northern termination of the Whittier fault near the intersection with the Montebello Hills, a fault bend fold above the Elysian Park Thrust. Geodetic measurements indicate uplift of the Elysian Park anticlinorium during or immediately following the earthquake (Lin and Stein, 1989). The east-trending orientation of the nodal plane for the focal mechanism solution of this event is consistent with the east-trending Elysian Park Thrust and the structural axis of the Montebello Hills (Hauksson and Jones, 1989; Bullard and Lettis, 1993). This orientation is also consistent with the dominant trend of structures within the Transverse Ranges Southern Boundary fault system (described below).

The subsurface geometry of the Elysian Park anticlinorium has been modeled by Davis et al., (1989), and Shaw and Suppe (1996). The southwestern margin of the trend is interpreted by Shaw and Suppe (1996) to contain at least two distinct zones of faults and folds. Shallow structures, including symmetric folds, kink bands, and south-dipping monoclinal flexures are interpreted as fault-bend folds above the Coyote and Cienegas blind-thrust ramps. These thrust ramps are predicted to lie at depths of approximately 5 km, which may limit their seismogenic potential. The deeper structure along the Elysian Park anticlinorium consists of gently-dipping (15-30 degree) monoclinal flexures that are separated from near horizontal strata by axial surfaces. These monoclinal structures are interpreted as kink-bands, or deep rooted folds above an active blind-thrust ramp that are the front limb of a fault-bend fold. Based on the geometry of the fault-bend fold, a dip of 14 to 24 degrees is predicted for the Elysian Park ramp. This structure is inferred to lie between 10 and 17 km depth. Approximately 4 km of long-term slip is inferred to have occurred across the thrust ramp (Shaw and Suppe, 1996).

Based on the strike and geometry of the fault-bend folds, and the presence of shallow cross-faults, the Elysian Park Thrust may be either a continuous fault ramp or a series of fault segments. Shaw and Suppe (1996) present both segmented and unsegmented models for the Elysian Park Thrust. The unsegmented model is assigned an area of approximately 680 km^2. Their segmented model assigns areas of 360 km^2 for the northern (Los Angeles) segment and 320 km^2 for the southern (Whittier) segment. The segmentation point is based on an apparent offset of the deeper fault-bend fold near the San Gabriel River. Though permissive, this interpretation is non-unique, and specific data on the behavioral characteristics of each fault segment are not available. CDMG/USGS (1996) treat the Elysian Park trend as a single segment in development of the recent seismic hazard model for the State of California.

Based on the available data, the Elysian Park Thrust is treated as a single segment for this seismic hazard assessment. A length of 39 km and a width of 16 km are assigned to the Elysian Park thrust ramp. The source geometry is slightly modified from CDMG/USGS (1996) and Shaw and Suppe (1996). The northern termination of the Elysian Park trend is defined in this report as the intersection with the Raymond-Hollywood fault trend. In the previous models, the Elysian Park trend continued north approximately 10 km beyond this Raymond-Hollywood fault trend. We interpret this system of east-trending structures to form a logical termination point for the northwest trending Elysian Park Thrust. Based on the area/length relationship of Wells and Coppersmith (1994), we assign an Upper Bound Earthquake (UBE) of M_w 6.8 to the Elysian Park thrust ramp.

The fault slip rate for the Elysian Park Thrust has been assessed through use of both balanced cross-section techniques (Davis et al., 1989; Shaw and Suppe, 1996) and quantitative morphometric techniques (Bullard and Lettis, 1993; Oskin and Sieh, 1998). The slip rates reported through the balanced cross-section techniques range from 1.3 to 4.6 mm/yr. The slip rates obtained through quantitative morphometric techniques range from 0.3 to 0.9 mm/yr. Although the lower bound of the rates derived from balanced cross-section techniques approaches the upper rates derived from morphometric techniques, there exists a disparity among the slip rate results. The rates predicted from the balanced cross-section method are considered to over-estimate the slip rate on the fault. This assessment is based on several factors:

- Slip rates above 1 mm/yr would be expected to produce significant vertical crustal deformation. The geomorphic expression of the Elysian Park Thrust is much less pronounced than other dip-slip faults in southern California with slip rates of greater than 1 mm/yr, such as the Sierra Madre or Sierra Nevada Range Front.

- The balanced cross-section estimates base slip rates on the length of kink bands in Plio-Pleistocene strata. The uncertainties in the age of deposits modeled and amount of deformation adds considerable uncertainty to the slip rate estimates. Plio-Pleistocene deposits are much older than the period of concern for seismic hazard assessments in southern California. The relative plate motion rates, directions of motion, fault interactions, and other kinematic factors may have changed considerably over the past 4 million years.;

- Balanced cross-sections rely on the assumption that no material moves into, or out of, the plane of the section. In southern California, this assumption may not be valid, as there may be a considerable component of oblique slip along many of the thrust fault systems and,

- Balanced cross-sections are non-unique solutions. The available data can be interpreted in a variety of ways leading to considerable variability in the predicted geometry and fault slip rates.

Quantitative morphometric techniques are considered to provide estimates of deformation rates that are more realistic over the period of concern for seismic hazard assessment. The results of Bullard and Lettis (1993) and Oskin and Sieh (1998) provide estimates of late

Quaternary deformation rates that are based on verifiable geomorphic data. The results provided by these studies are also more consistent with the qualitative comparison of the Elysian Park trend to other dip-slip, or oblique-slip faults. The earthquake recurrence interval for the UBE is estimated between 1000 and 4000 years (Oskin and Sieh, 1998) based on the average displacement for the UBE, range of potential fault dips and range of morphometrically derived slip rate values. Based on this range of values, we have assigned a best estimate recurrence interval of 2500 years for the Elysian Park thrust.

5.3.1.1.6.2 Whittier-Elsinore Fault. The Elsinore fault is one of the major tectonic elements of the San Andreas Fault System in southern California. The fault extends approximately 280 km from the Los Angeles Basin to northern Baja California. The fault zone comprises six major segments including from north to south: the Whittier, Glen Ivy, Temecula, Julian, Coyote Mountain, and Laguna Salada segments. As shown on Table 5.3-1, these fault segments vary from 37 to 67 km in length [California Department of Minerals and Geology/United States Geological Survey 1996] and are capable of earthquake magnitudes up to M_w7.1.

Paleoseismic investigations along the Elsinore fault demonstrate repeated Holocene surface rupturing events. Four to five prehistorical events have been documented along the Glen Ivy segment of the fault, with a recurrence interval for large magnitude earthquakes of approximately 250 years.

The geological and seismological characteristics of the fault zone change at approximately 33.5^{o}N latitude. North of this point on the fault zone, the Elsinore consists of relatively simple fault strands that occupy the narrow Elsinore Trough (Hull and Nicholson, 1992). South of 33.5^{o}N the zone comprises a number of fault traces parallel to and east of the main fault trace. The distribution of earthquakes similarly occupies a narrow zone to the north and a wider zone to the southeast (Magistrale and Rockwell, 1996).

The Whittier segment of the Elsinore fault is the closest segment to the ESPR site. This segment extends approximately 45 km (28 miles) to its junction with the Chino fault and Glen Ivy segment of the Elsinore fault. The north end of the fault is located approximately 18 km (11 miles) southeast of the site. Holocene age right-lateral displacement along the fault zone has been identified through exploratory trenching and is supported by right-lateral deflections of stream channels across strands of the fault (Leighton and Associates, Inc., 1987). The Whittier fault has a Holocene slip rate of 1.7 to 2.5 mm/yr (Rockwell, 1988).

Although the Whittier-Elsinore fault is interpreted to have a high slip rate, the rate of historical earthquakes along the fault is low. The 1910 M6.0 event near Lake Elsinore is the largest earthquake reported for the entire zone. Although the historical record does not provide any examples of large magnitude earthquakes on the Whittier-Elsinore fault zone, the segment lengths and slip rate suggests that large frequent events are possible. The parameters used to characterize the various fault segments for the hazard analysis are summarized in Table 5-3.

5.3.1.1.6.3 San Jacinto. The San Jacinto Fault zone consists of several northwest-striking, strike-slip faults that extend from the San Gabriel Mountains on the northwest to the imperial fault on the southeast (Figure 5.3-4). The working group on California earthquake probabilities (USGS, 1988) subdivided the zone into five segments based on varying fault-slip rates and historic earthquakes. For the site, the three northernmost segments (San Bernardino Valley, San Jacinto Valley, and Anza) are the most important ones and these were considered in the analysis.

During historical times, the San Jacinto fault system has produced more earthquakes than any other fault system in Southern California. Since 1890, as many as 11 earthquakes in the magnitude 6 to 7 range have occurred (Figure 5.3-5). The largest earthquake appears to have been the 1918 event (M_w6.8) on the San Jacinto Valley segment. The maximum earthquake capable of occurring in this province is estimated to be a magnitude 7.5 event if more than one segment ruptures. Individual segments are capable of generating smaller maximum earthquakes of about 7 or 7.25, depending on the segment length (Table 5.3-1).

5.3.1.1.6.4 San Andreas. The San Andreas Fault forms a relatively linear narrow zone extending from Cape Mendocino in northern California to the Salton Sea in southern California, a distance of about 1,100 km (Figure 5.3-4). Based on varying slip rates, earthquake recurrence intervals, and maximum earthquakes, the system can be divided into several segments. The working group on California earthquake probabilities (USGS, 1988) subdivided the southern half of the San Andreas fault into seven segments. For the site, the three southernmost segments (Mojave, San Bernardino Mountain, and Coachella Valley) are the most important ones, and these were considered in the analysis.

Seismic activity is low along the southern San Andreas fault. Since 1932, when earthquakes began to be systematically recorded in southern California, only a few small-magnitude events have been recorded near this fault (Figure 5.3-5). Two moderate events, the 1986 Palm Springs (M_L 5.9) and the 1948 Desert Hot Springs (M_L6.5) earthquakes, were probably associated with the Banning fault (Nicholson, 1987), a splay of the San Andreas fault near the north end of the Coachella Valley segment. The latest known great earthquake on the southern San Andreas fault system was the 1857 event, which ruptured the Carrizo and Mojave segments from just north of the Carrizo Plain to Cajon Pass near San Bernardino, a distance of about 300 km. The magnitude of this event is believed to have been about 7.9 (M_W). This is the largest earthquake known to have occurred in southern California. The epicenter of this event is believed to have been at the northern portion of the surface rupture, about 150 to 250 km from the Los Angeles area.

Since the Working Group study (USGS, 1988), more information has become available on slip rates, recurrence intervals and maximum earthquakes for the San Bernardino Mountain segment. Work by Jacoby et al., (1988) and Sieh et al., (1989) suggests an event in 1812 occurred in the Wrightwood area (which includes the northwestern end of the San Bernardino Mountain segment). New data show that six surface-faulting events have occurred at Wrightwood since 1192 A.D., which corresponds to an average recurrence interval of about 140 years (SCEC, 1995). Geologic data on the Coachella Valley segment indicate three large earthquakes between the years 1000 A.D. and 1700 A.D. The average recurrence interval for these events is about 220 years.

In contrast, the northern segments of the southern half of the San Andreas fault are relatively well studied. Geologic data indicate that slip during prehistoric earthquakes along the Carrizo segment has been as much as 12 m per event. Geologic data on the Mojave segment indicate slip ranging from about 20 cm to 4.5 m per event. The geologic data also indicate that the slip rate is about 30 to 35 mm/yr on the Carrizo and Mojave segments and about 25 mm/yr on the San Bernardino Mountain and Coachella Valley segments.

The recurrence intervals between ground-rupture events on the Mojave segment range from 44 years to about 332 years, with an average of about 131 years. Sieh et al. (1989) suggest these events and their associated earthquakes occur in clusters. Recurrence intervals within clusters are less than 100 years, but between clusters they are about 200 to 300 years.

5.3.1.1.6.5 Newport-Inglewood. The fault nearest the site is the Newport-Inglewood fault zone, which comprises a closely spaced system of northwest-trending, potentially active, strike-slip and/or oblique-slip faults. These faults form the boundary between the non-tectonic, structurally coherent, crustal block of the Peninsular Ranges province and the offshore, tectonically active Southern California Continental Borderland province. The northern end of the Newport-Inglewood fault zone extends through the Los Angeles Basin from the Santa Monica Mountains to Newport Beach, where it trends offshore (Figure 5.3-4). This segment is characteristically a series of aligned, low-relief hills and mesas and en echelon buried faults that are a result of compressional folding and uplift along the fault zone. The Newport-Inglewood fault zone is terminated on the north by the southern frontal fault system of the Santa Monica Mountains in the Transverse Ranges province.

Offshore, the surface trace of the fault zone is primarily along the margin of the mainland shelf, generally around the 100-m depth. Southward, the fault zone extends onshore again at Rose Canyon in the San Diego area, and trends southerly into Mexico. The southern extent of this zone of deformation is poorly defined, but appears to merge with or be transected by the northwest trending active faults in Mexico, such as the San Miguel, Vallecitos, or Aqua Blanca faults, which terminate the Peninsular Ranges province.

Earthquakes have been most abundant at the northern end of the fault zone. Most of these events were aftershocks of the 1933 Long Beach earthquake. The 1933 event, (M_w6.4), was the largest historical earthquake in the fault zone. Based on the length of the longest faults in the zone and the tectonic relationships, a UBE of 7 is estimated for the zone.

The slip rate of the Newport-Inglewood zone cannot be precisely estimated from available surface data because of the many uncertainties regarding interpreted offsets and ages of geomorphic features. Calculated slip rates vary by an order of magnitude from 0.1 mm/yr to about 1.5 mm/yr (Peterson and Wesnousky, 1994; SCEC, 1995). A slip rate of 1 mm/yr was assumed for the onshore segment (Santa Monica to Newport Beach) and offshore segment (Newport Beach to Oceanside).

5.3.1.1.6.6 Palos Verdes. The Palos Verdes fault is a northwest-trending right-lateral strike-slip fault zone. The fault extends from the southern boundary of the Transverse Ranges across the Santa Monica Bay and offshore of the Los Angeles Basin. It then crosses the northeastern base of the Palos Verdes Hills of the onshore Palos Verdes Peninsula, and extends across the San Pedro Shelf (Fischer et al. 1987; Darrow and Fischer, 1982). The fault continues south and possibly connects with the offshore Coronado Bank fault within the Continental Borderlands Province.

Deformation along the Palos Verdes fault has resulted in uplift of the Palos Verdes Peninsula and preservation of a series of marine terraces. Correlation of these terraces with global eustatic sea-level fluctuations provides an estimate of uplift rates of the peninsula, and thus this portion of the fault zone. Although there remains some disagreement as to the ages of all the terraces, most studies yield uplift rates of approximately 0.3 to 0.4 mm/yr. The fault is considered to be dominated by a strike-slip style of deformation with a minor component of oblique slip near the peninsula. Recent structural modeling of faults in the LA Basin area suggest that the Palos Verdes fault is a blind-thrust fault with essentially no strike-slip motion (Davis et al., 1989; Shaw and Suppe, 1996). These models, however, predict higher uplift rates than are resolvable from the height and age of the marine terraces on the peninsula.

The amount of horizontal slip vs. vertical slip has been addressed by several previous studies. Darrow and Fischer (1983) suggested that the sense of slip is partitioned roughly equally between the horizontal and vertical components. Ward and Valensise (1994) conclude that the fault is dominated by horizontal slip with a rate of 3 mm/yr. Stephenson et al. (1995) suggests the fault is largely strike-slip with a rate of 2.5 to 3.8 mm/yr. McNeilan et al. (1996), in a recent investigation of the Los Angeles Harbor and surrounding areas, conclude that the fault is dominated by horizontal slip with a horizontal slip rate of about 2.7 to 3.0 mm/yr. The resultant vertical slip rate is estimated to be 0.35 mm/yr, which is consistent with the uplift rates determined from the marine terrace record. A horizontal slip rate of approximately 3 mm/yr is assigned to the Palos Verdes fault for this study.

The potential maximum earthquake magnitude, or upper bound earthquake for the Palos Verdes fault is based on analysis of segmentation models along the fault zone (McNeilan et al., 1996). We consider the most likely fault rupture scenario to include two rupture segments: (1) Santa Monica Bay; and (2) combined onshore and San Pedro Shelf segments. The Santa Monica Bay segment extends from the Redondo Canyon fault on the south to the southern margin of the Transverse Ranges. This segment is defined based on dissimilar strike of the fault north and south of the Palos Verdes Peninsula, distribution and width of faulting in Santa Monica Bay (Clarke et al., 1987) compared to the San Pedro Shelf, and intersection with the east-trending Redondo Canyon fault. Rupture of this segment (approximately 30 km) would be expected to produce an earthquake of M_W 6.6 based on the empirical relationships of Wells and Coppersmith (1994).

The second rupture scenario includes the onshore portion of the fault combined with the offshore extension across the San Pedro shelf. This rupture segment is approximately 64 km in length. The estimated rupture length is based on the lack of any significant cross structures or other geometric irregularities, such as the Redondo Canyon fault to the north, and the lack of evidence for the onland portion of the fault to act as an independent segment. If this onland segment were independent, it would require a high rate of seismic activity to accommodate the 3 mm/yr slip rate. There is currently no significant seismicity along this portion of the fault, and there is no evidence for short recurrence intervals. A UBE of M_W7 is assigned to this southern segment of the Palos Verdes fault zone based on the empirical relationships of Wells and Coppersmith (1994). Rupture of the entire length of the fault in a single event is not anticipated due to the presence of the apparent asperity at the peninsula (fault bend and increased vertical slip rates), and the intersection with the Redondo Canyon fault. These geometric changes are anticipated to form a barrier to rupture of the entire fault.

5.3.1.1.6.7 Transverse Ranges Southern Boundary Fault System: Raymond-Hollywood-Santa Monica Faults. The southern boundary of the Transverse Ranges province is bounded by a system of east-trending reverse, oblique slip, and left-lateral strike slip faults that extend for more than 200 km. This system accommodates the westward translation of the Transverse Ranges block, relative to the Los Angeles basin. This motion occurs along the Raymond (Jones et al., 1990), Hollywood (Dolan et al. 1997), Santa Monica (Dolan and Sieh, 1992), Anacapa-Dume (Ellsworth 1990), Malibu Coast (Treiman, 1994), Santa Cruz Island (Pinter and Sorlien, 1991), and Santa Rosa Island (Colson et al., 1995) faults. Paleomagnetic studies of upper Pliocene strata (1 to 3 Ma) indicate that parts of the Transverse Ranges have undergone more than 20 degrees of clockwise rotation (Liddicoat, 1992). This observation suggests that the left-lateral deformation along the southern boundary system be accompanied by active clockwise rotation of the Transverse Ranges.

5.3.1.1.6.7.1 Raymond Fault. The Raymond fault splays from the Sierra Madre fault in Monrovia and extends westward approximately 21 km (15 miles) to its western termination south of the Hollywood fault (Dibblee, 1989). However, there is no consensus on the location and continuity of the fault in the Repetto Hills (Lamar, 1970; Hill et al., 1979; Weber et al., 1980; Dibblee, 1989). The Raymond fault exhibits reverse and left-lateral displacement of Holocene deposits and its geomorphic expression is consistent with the left-lateral focal mechanisms and aftershock patterns from the 1988 M_L4.9 Pasadena Earthquake.

The fault shows well-defined evidence of repeated fault movements in late Quaternary time (Crook et al., 1987). Based on alluvial fan stratigraphy five periods of activity are estimated to have occurred at approximately 36,000, 25,000, 10,000, 2,200, and 2,200 to 1,500 years before present (ybp). Evidence for three additional events were reported but no data on the timing of these events was available (Crook et al., 1987). A recurrence interval of approximately 3,000 years was inferred by (Crook et al., 1987). Based on a fault length of 21 km, the Raymond fault is estimated to be capable of producing a UBE of M_w6.5.

5.3.1.1.6.7.2 <u>Hollywood Fault</u>. The Hollywood fault extends east-northeast along the southern edge of the Santa Monica Mountains. The range is interpreted as a south vergent, asymmetric anticline above a gently north-dipping blind thrust structure (Davis and Namson, 1994). The Hollywood fault is a steeply north-dipping fault that juxtaposes Cretaceous quartz diorite and Miocene volcanic and sedimentary rocks of the Santa Monica Mountains against Quaternary and Tertiary sedimentary rocks to the south. The fault is marked by a narrow, steeply southward sloping gravity gradient (Dolan et al., 1997; Chapman and Chase, 1979). The fault has had at least one surface fault rupturing event since the latest Pleistocene to middle Holocene time, and has an estimated fault slip rate of 0.35 mm/yr (Dolan et al., 1997). On-going studies of the Hollywood fault suggest that the fault slip rate of 0.35 mm/yr may approximate the vertical slip rate, but that the left-lateral rate along the fault may be closer to 1 mm/yr (Lindvall, pers. comm). Walls et al. (1998) '*predict*' a fault slip rate of 2.7 ± 1.0 mm/yr, based on evaluation of geodetic strain rates across the Los Angeles basin, and an apparent discrepancy between the geodetic and geologic rates. Based on a length of 17 km, the Hollywood fault is estimated to be capable of producing a UBE of M_w6.6. A slip-rate of 1.0 mm/yr is assigned to the fault, which is consistent with CDMG/USGS (1996).

5.3.1.1.6.7.3 <u>Santa Monica Fault</u>. The Santa Monica fault forms a portion of the Transverse Ranges Southern Boundary fault zone (Dolan et al., 1997). The fault extends approximately 28 km from the Hollywood fault on the east to the offshore, Anacapa-Dume fault on the west. The Santa Monica fault and the other associated faults within the system accommodate clockwise rotation of the western Transverse Ranges.

The fault is interpreted as a left-lateral reverse-oblique structure. Left-lateral slip along the Hollywood fault steps southward along the western Beverly Hills to the Santa Monica fault. Although now extensively developed, geomorphic features indicative of Holocene activity are reported from historical photographs of the area. Features observed include well-defined linear scarps and ridges, closed depressions, sag ponds, and springs (Real, 1987). A well-defined groundwater barrier exists along the fault zone (Hill et al., 1979).

Based on the evidence for activity, the fault is considered active and capable of moderate magnitude earthquakes. Using the empirical relationship of Wells and Coppersmith (1994) and a fault length of 28 km, we estimate a maximum earthquake magnitude of M_w6.6 for the Santa Monica fault. A slip rate of 1 mm/yr is assigned to the Santa Monica fault in CDMG (1996) based on general geomorphic criteria, and comparison with other structures of the Transverse Ranges Southern Boundary zone. This value is slightly higher than the dip-slip rate of 0.5-0.6 mm/yr reported by Dolan and Pratt (1997).

5.3.1.1.6.8 <u>Transverse Ranges</u>. The Transverse Ranges province comprises a series of closely-spaced, east-west trending mountain ranges that transect the predominantly north-northwest trend of the California geologic structure and physiography. The Channel Islands are the exposed tops of mountains that are offshore extensions of the Santa Monica Mountains. The major mountain ranges are the Santa Ynez, Santa Susana, Topatopa, and Santa Monica Mountains. A major portion of the province consists of the Santa Barbara Channel that is a major geologic downwarp between the mountain ranges that form the northern and southern portions of the province. The downwarp extends onshore as the Ventura Trough and narrows easterly into the Santa Clara River Valley, which extends nearly to the San Andreas Fault zone.

The mountain ranges in the Western Transverse Ranges province consist largely of folded and faulted sedimentary strata with most major structures aligned east-west. The east-west trending physiography and geologic structure in this province is a result of north-south to north-northeast crustal compression. Most of the faults are reverse or thrust faults with the north side upthrown. The reverse faults commonly have left-lateral components of displacement.

Numerous faults in this province have had late-Quaternary movement, and late-Quaternary uplift rates in the Ventura region are among the highest in the world. Some of the major Quaternary faults are the Big Pine, Santa Ynez, Arroyo Parida, Oakridge, Santa Cruz Island, Malibu Coast, Sierra Madre, Cucamonga, and Santa Susana faults (Figure 5-4). This tectonic regime is probably related to geometrical constrictions of the plate motion along the plate boundary. This is supported by the presence of the San Gabriel fault in this province. The San Gabriel fault is thought by many geoscientists to be an ancestral trace of the plate boundary.

A high level of historical seismicity characterizes the Transverse Ranges province. The earthquake epicenters are most dense in a belt trending westerly from the San Gabriel and Santa Susana faults, near San Fernando, through the Ventura and Santa Barbara regions. This belt generally coincides with the area of most-abundant late-Quaternary faulting, but few events have been correlated directly to specific faults because the faults dip both northerly and southerly in the subsurface. Earthquake focal-mechanism solutions indicate a dominant north northeasterly to south southwesterly compressional tectonic regime.

The Transverse Ranges province has experienced several moderate-magnitude events in recent decades, notably the 1971 San Fernando (M_w6.6), 1973 Pt. Mugu (M_L5.9), 1979 Malibu (M_L5.0), 1987 Whittier (M_w6.0), 1994 Northridge (M_w6.7), and several events in the Santa Barbara Channel. Based on focal-mechanism determinations, all of these events had a reverse sense of displacement. The only event with a documented surface displacement was the San Fernando earthquake, but many of the other earthquakes occurred offshore and it is not certain that they did not rupture the seafloor surface.

The largest historical event in the province is believed to have been the December 21, 1812, earthquake which is thought to have occurred in the Santa Barbara Channel region. The 1812 event had a maximum Modified Mercalli Intensity of x and an estimated magnitude of about 7.1 (Ellsworth, 1990). Based on these seismic data and on the presence of numerous long faults, the UBE within the province is estimated to be a M_w7.25 event.

Recent investigations of specific faults within the Transverse Ranges have lead to important revisions to the perceived hazard within the province. The major faults in the province that are most important for the ESGS site are described below.

5.3.1.1.6.8.1 ***<u>Santa Susana</u>.*** The Santa Susana fault extends along the southern edge of the Santa Susana Mountains, approximately 27 km from its intersection with the Oak Ridge fault on the west to the San Fernando segment of the Sierra Madre fault on the east. The Santa Susana fault is a north dipping structure that dips gently near the surface and steepens with depth (Yeats, 1987). The fault separates two different stratigraphic sequences. The Santa Susana Mountains on the north side of the fault comprise a folded and uplifted sequence of middle Miocene to Pliocene age sediments. The sequence on the south side of the fault consists of discontinuous late Cretaceous and Tertiary age sediments that are offset by both north-dipping and south-dipping thrust faults. The faulted sequence on the south side of the fault is unconformably overlain by Pleistocene age Saugus formation. The Saugus formation and Quaternary age alluvial fan deposits are overthrust by the Santa Susana fault (Yeats, 1987). The fault occurs along an older depositional hingeline that marked the southern edge of the Ventura Basin in Miocene and Pliocene time (Yeats et al, 1994).

Displacement varies along strike of the Santa Susana fault. No displacement is measured at the west-end of the fault near the Oak Ridge oil field, while more than 4 km of displacement is measured near the Aliso Canyon oil field. Structural relations along the fault, and older faults within the system (i.e., Frew fault) suggest that fault slip rates have accelerated from ~5 to 8 mm/yr between 975 to 500 ka, to around 10 to 14 mm/yr since 500 ka (Huftile and Yeats, 1995). No slip-rate, or recurrence data from paleoseismic investigations of the Santa Susana fault are available (Lung and Weick, 1987). CDMG/USGS (1996) have adopted a fault slip rate of 5 mm/yr for the Santa Susana fault.

Several significant changes in fault strike may form segmentation points along the fault. At Gillibrand Canyon and at the west edge of Sylmar Basin the fault steps left, steepens in dip, and forms a lateral ramp. Aftershocks occurred along the left-step near Sylmar following the 1971 San Fernando earthquake.

Based on empirical relationships among fault length/fault area and magnitude (Wells and Coppersmith, 1994) the Santa Susana fault is estimated to be capable of generating a UBE of between M_w 6.6 and M_w 6.8. For this study we have assigned a UBE of M_w 6.8 for the Santa Susana fault. The upper bound of the magnitude range is taken because the fault has a greater length than the San Fernando segment of the Sierra Madre fault, which generated the M_w6.6 earthquake in 1971. Based on the length and prominent geomorphic expression of the fault, we have assigned a slightly larger UBE for the Santa Susana than the historical maximum on the San Fernando fault.

5.3.1.1.6.8.2 ***Sierra Madre Fault.*** The Sierra Madre fault is a Holocene active reverse fault that extends approximately 57 km along the south flank of the San Gabriel Mountains. The fault dips to the north and has a down-dip seismogenic width of 18 km. Crook et al. (1987) conclude that there is a lack of demonstrable evidence for Holocene activity along the fault. However, recent paleoseismic investigations of the fault show that it has ruptured in large magnitude earthquakes of M_w 7.2 to 7.6 at least twice in the past 15,000 years (Rubin et al., 1998). Although displacement parameters for the most recent event are well constrained and support an earthquake of M_w 7.2, the amount of displacement for the penultimate event is equivocal, but may be as large as 6 meters.

The slip rate on the Sierra Madre fault is based on the paleoseismic displacements observed in a trench. Rubin et al. (1998) report 10.5m slip in 15,000 years, or a fault slip rate of 0.6 mm/yr. They also suggest there exists a strong slip gradient along the fault with higher slip rates to the east on the Cucamonga fault and lower slip rates to the west, where some slip may be accommodated along the Verdugo fault.

Using the Wells and Coppersmith empirical relationship between rupture area and moment magnitude yields an upper bound earthquake magnitude of M_w 7.0, consistent with the M_{max} assigned to the Sierra Madre in the CDMG/USGS (1996) seismic hazard model for California. However, the recent paleoseismic results support the occurrence of less frequent large magnitude events on the Sierra Madre. A UBE of M_w7.4 and a slip rate of 0.6 mm/yr is assigned to the Sierra Madre fault, based on the paleoseismic results of Rubin et al. (1998).

5.3.1.1.6.8.3 ***San Fernando.*** The San Fernando fault is a steeply north-dipping reverse fault, and is the western-most segment of the Sierra Madre fault zone. The San Fernando fault ruptured causing the M_w 6.6 San Fernando earthquake in 1971. The surface trace of the closest segment of the fault zone is located approximately 17 km (11miles) north of the site. This segment is the most active of the Sierra Madre fault zone based on the available geological information (Crook et al., 1987) and was also the likely source of the 1991 M_L5.8 Sierra Madre earthquake.

The zone of surface rupture along the San Fernando fault was about 15 km long, extending from the western side of San Fernando to Big Tujunga Canyon. Displacements of up to 2.1 meters were observed along the fault zone and showed a predominantly left-oblique sense of deformation. The zone of surface faulting coincided with a groundwater barrier in Quaternary alluvium formed by pre-1971 faulting. The previous event, before the 1971 earthquake, is dated between 100 and 300 ybp (Bonilla, 1973). A UBE of M_w6.7 is assigned to the San Fernando fault based on rupture area, and historical precedence.

5.3.1.1.6.8.4 Northridge Blind Thrust. The Northridge blind thrust is located near the northern edge of the San Fernando Valley. The fault dips 35 degrees to the south and has a length of approximately 31 km. Unlike other blind thrusts in the Los Angeles basin the Northridge blind thrust is not obviously associated with surface geological structures (Hudnut et al., 1996).

The Northridge blind thrust produced the January 17, 1994 Northridge earthquake of M_w6.7. The mainshock hypocenter was located at a depth of 19km in the lower crust. Aftershock distributions define a fault plane that extends from a depth of 7 to 10 km near the upper termination of the rupture to a depth of 23 km. The west side of the aftershock zone is characterized by a north-northeast striking and steeply dipping planar cluster of aftershocks with mostly thrust-type focal mechanism solutions. This cluster coincides with the Gillibrand lateral ramp described by Yeats (1987) along the Santa Susana fault. The eastern edge of the rupture area is also characterized by thrust faulting focal mechanism solutions (Hauksson et al., 1995).

Both the 1971 San Fernando earthquake and the 1994 Northridge earthquake accommodated contractional deformation of the Transverse Ranges. The San Fernando earthquake ruptured a north-dipping thrust fault from a depth of approximately 10 to 12 km to the ground surface. The Northridge earthquake ruptured a south-dipping thrust fault from a depth of 19 km to approximately 7 km, where it partially abutted the rupture surface of the San Fernando fault at a depth of ~3 to 5 km (Hauksson et al., 1995). However, the relationship of the Northridge fault to other structures of the Transverse Ranges remains ambiguous. Based on the inferred area of the Northridge thrust fault, a UBE of M_w6.9 was assigned.

5.3.1.1.6.8.5 Cucamonga. The Cucamonga fault is the eastern-most segment of the Transverse Ranges frontal fault zone. The structure extends approximately 28 km along the southern flank of the San Gabriel Mountains, initiating near the San Jacinto fault and continuing westward to the eastern end of the Sierra Madre fault. Morton and Matti (1987) found the height and age distribution of fault scarps along the Cucamonga fault to be consistent with an average repeat time for 2-meter displacements every 684 years. The slip-rate for the fault is estimated, based on cumulative offset of alluvial fans, between 4.5 and 5.5 mm/yr during the last 13,000 years.

The fault length of 28 km results in an estimated magnitude of M_w6.7. However, the empirical estimate of displacement for a M_w6.7 event is less than the >2m displacement reported by Morton and Matti (1987). To account for the observed >2m displacements along the Cucamonga fault, we assign a UBE of M_w 7.0.

5.3.1.1.6.9 <u>Peninsular Ranges Province</u>. The Peninsular Ranges Province is a northwest trending mountain belt that includes the Santa Ana, Laguna, Jacumba, and Sierra Juarez mountains. Except for a relatively narrow strip of Cenozoic and Mesozoic sedimentary rocks along the western flank of the ranges, the Peninsular Ranges is primarily a massive granitic batholith of Cretaceous age.

The province boundaries are based on the internal geological and seismological characteristics as well as the location of major active faults. The Peninsular Ranges province has only a very limited number of Quaternary faults (e.g. La Nacion fault near San Diego; Jennings, 1994) and a very low rate of seismic activity. These factors suggest the province is a relatively stable structural block. This province is bounded by the Elsinore fault on the northeast and the Newport-Inglewood-Rose Canyon and Vallecitos-San Miguel faults on the southwest. The eastern boundary in northern Baja coincides with a north-south trending structure that also delineates a change in the regional rate of seismicity.

The UBE for the Peninsular Ranges province is estimated to be M_w6.5. This is considered to be the maximum background earthquake that is likely to occur without developing recognizable geomorphic features related to repeated surface fault rupturing events. This maximum magnitude also encompasses the potential UBE for earthquakes on the few Quaternary faults in the region, based on empirical length-magnitude relationships of Wells and Coppersmith (1994).

5.3.1.1.6.10 <u>Catalina Province.</u> The offshore area between the San Clemente and Palos Verdes fault zones, north of San Clemente Island, is included in the Catalina province. This offshore area includes several major structures including the Catalina Escarpment, San Clemente, and Santa Cruz-Santa Catalina Ridge fault zones. These faults generally coincide with prominent seafloor escarpments. This zone is similar to the Continental borderlands province, but is treated separately based on the more westerly strike of fault segments and a change in the level of seismic activity. This zone is interpreted as a transition zone between the offshore faults of the borderland and the faults of the Channel Islands. A number of historical small to moderate magnitude earthquakes have occurred in this region.

The major faults within the province appear to be similar in size and tectonic style to the Palos Verdes fault. They are associated with major uplift along some part of their length, and consist of complex anastamozing splays with alternating Holocene and late-Quaternary displacements (Clarke et al. 1987). Based on the length of the major fault segments, this province is assigned a UBE of M_w 7.

5.3.1.1.7 Potential Geologic Hazards. Geologic hazards that are known to be present in portions of California that could possibly affect the project are described in the following sections. The potential for geologic hazards are evaluated in general terms and discussed in relation to overall site conditions. These geologic hazards include:

- Ground rupture
- Ground shaking
- Liquefaction potential and related effects
- Slope instability
- Ground Subsidence
- Expansive and collapsible soils
- Shoreline erosion
- Coastal flooding and tsunami.

5.3.1.1.7.1 Surface Fault-Rupture. Surface fault-rupture is defined as ground breakage along a trace of a fault during an earthquake. Other forms of ground failure, such as liquefaction, lateral spreading, slope failure are discussed in separate sections herein.

The closest fault zones to the site zoned under the Alquist-Priolo Special Studies Zone Act are the Palos Verdes and Newport-Inglewood fault zones, at distances of approximately 5 km and 9 km, respectively. No active (Holocene) or potentially active (Quaternary) faults were found to cross either the plant area or any of the linear facility corridors in this review (Jennings, 1994). Thus the hazard from surface fault-rupture is considered low.

5.3.1.1.7.2 Earthquake Ground Shaking. Strong earthquake ground shaking is a significant seismic hazard in the project area. The site has experienced strong ground motions in the past, and will do so in the future. Therefore, strong ground shaking will directly affect the design of the planned project features. Possibly the strongest shaking that has been observed at the site occurred during the 1994 Northridge Earthquake, when minor damage to the wall adjacent to the beach bike path on the westside of the facility was noted.

Preliminary determination of ground shaking parameters for the project will be based on the general requirements of the Uniform Building Code (UBC) [ICBO, 1997] that take into account regional seismicity, near-source active faulting, and site specific subsurface conditions. In general, based on the UBC methodology, the site may be considered stiff and to behave as Soil Profile Type S_D as long as soil liquefaction does not occur. In this respect, the estimated peak ground acceleration for the site may be on the order of 0.46g. This level of peak ground acceleration may be assumed to have a 10 percent probability of exceedance in 50 years. However, since the site subsurface has potentially liquifinole zones the UBC would require that the site be categorized as Soil Profile Type S_F. By implementing liquefaction mitigation measures the site will be categorized as UBC soil profile type $S_{D.}$

5.3.1.1.7.3 **<u>Liquefaction Potential.</u>** The geologic hazard of soil liquefaction is a process by which loose, saturated, granular deposits develop high porewater pressure due to strong earthquake-induced ground vibrations and then suddenly lose a significant portion of their shear strength. Soil liquefaction can lead to sand boiling, ground subsidence, differential settlement, heave of buried structures, lateral spreading, slope toe failure, and foundation bearing failure.

Based on regional, planning level studies, the general liquefaction susceptibility of the aolian, alluvial and marine deposits of the Venice Quadrangle having a dense consistency is considered to be low (CDMG, 1999). The soil profile below the existing facility consists of generally medium dense to dense sands of the Old Dune/Gage Aquifers (above and below the water table); firm to stiff silty clay of the El Segundo Aquitard (below the water table), and the dense to very dense sand with some gravel of the Silverado Aquifer. A shallow tidally-influenced groundwater table is located below the project site. Within the sand layers of the Old Dune/Gage Aquifers and the Silverado Aquifer, zones of loose to medium sand have been encountered during previous subsurface investigations conducted at the project. These loose to medium dense sand zones have been encountered throughout the stratigraphic section in the site area but are most often encountered between elevations of +8 to -30 feet MLLW. If this zone were to liquefy, ground surface settlements on the order of 1 to 6 inches could occur.

Lateral ground displacement occurring as a result of liquefaction is referred to as lateral spreading. Potential lateral spreading could occur anywhere within or adjacent to the site area between the beach free face and the slopes east of the plant site. Depending upon the location of the zone of failure, the geometry of the failures and the relative location within the site area, the lateral ground displacements could range from inches to several feet.

Impacts to the proposed project resulting from liquefaction induced ground deformation are potentially significant. Without mitigation, impacts could include foundation failures, pipe failures and disruption of existing utilities, and slope failures.

Based on studies performed by California state agencies, the liquefaction susceptibility of the alluvial, and marine deposits (Qe, Qoe and Qoa) of the Venice Quadrangle generally having a dense consistency is considered to be low (DMG, 1999). However, loose to medium dense deposits may have a susceptibility of moderate to high. Seismically-induced liquefaction at the site may result in ground surface settlements on the order of 1 to 6 inches.

5.3.1.1.7.4 Slope Stability. Slope stability is a significant geologic hazard at the project site. The slope along the east side of the site between the existing facilities and Vista Del Mar Boulevard is identified as an area of high landslide susceptibility and where some ground movement has occurred previously (DMG, 1999). This man-made cut slope is approximately 70 feet high (without benching), has an overall 1.75:1 (horizontal to vertical) inclination, and consists of medium dense to very dense cohesionless dune sand. At the toe of the slope is a low reinforced concrete cantilever retaining wall that supports numerous pipelines (above and below the top of the wall). The slope supports existing transmission towers, wood poles, fencing, and heavy vegetation. Beyond the crest of the slope to the east are Vista Del Mar Boulevard and the elevated Chevron storage tank farm. The slope encompasses the entire east side of the site.

Observed conditions of the slope indicate that relatively minor surficial sloughing, unraveling, and erosion have occurred in the past during periods of heavy precipitation. However, in general, the slope has performed well since its original construction. Preliminary deep-seated slope stability analyses indicate stable static conditions. The recently released Seismic Hazard Zone Map of the Venice Quadrangle maps the slope area as having a potential for permanent ground displacement due to an earthquake (DMG, 1999). Preliminary evaluations of the susceptibility of the slope to seismically induced landslides suggests a low to moderate hazard potential exists. The susceptibility may increase to moderate to high if subsurface soils below the slope toe were to liquefy. In this respect, the high slope condition may influence the potential for liquefaction-induced lateral spreading toward the ocean.

Impacts to the project resulting from slope instability range from minor to significant depending upon the extent of slope failure. A large scale failure could have significant impact on the project site and adjacent facilities. The structures on and adjacent to the slopes are at risk and include the various pipelines that run along the toe of the slope, the transmission line towers on the slope and the roadway at the crest of the slope. Additionally, structures near the toe of the slope could be impacted.

5.3.1.1.7.5 Ground Subsidence. Ground subsidence is not considered a significant geologic hazard in the project area. The project area is not located in an area that has historically been subject to high levels of ground subsidence due to fluid withdrawal (i.e., petroleum or groundwater). No significant impacts to the project are anticipated as a result of ground subsidence.

5.3.1.1.7.6 Expansive and Collapsible Soil Characteristics. Expansive and collapsible soil conditions at the site are not considered significant geologic hazards at the project site. Near surface soils at the site consist of fine to medium cohesionless dune sand. These soils are considered non-expansive and non-shrinking due to changes in moisture content. Clayey soils underlying the site are represented by the Manhattan Beach, El Segundo, and Redondo Beach aquitards separating the aquifers in the first 100 feet below the project site.

These layers are below the water table and saturated. It is very unlikely that these soils would ever experience a significant change in moisture content. The lower aquifer consists of non-expansive fine to medium dense sands with lenses of gravel with some silt content. Consequently, the potential for soil expansion or shrinkage of the soils underlying the site is considered remote.

Soil collapse (hydrocompaction) is a phenomenon that results in relatively rapid settlement of relatively dry, loose to medium dense soil deposits due to the addition of water. This generally occurs in soils having a loose particle structure cemented together with soluble minerals or with small quantities of clay. Water infiltration into such soils can break down the interparticle cementation, resulting in collapse of the soil structure. Collapsible soils are sometimes found in Holocene alluvial fan deposits. Natural soils above the water table at the site are older aolian deposits and do not have a significant potential for collapse. Therefore, the potential for collapsible soils at the site is negligible.

No significant impacts to the project are anticipated as a result of expansive or collapsible soils.

5.3.1.1.7.7 Coastal Conditions. It is anticipated that the combination of future high tides, local wave setup, rising sea level, extreme storm waves and atmospheric anomalies could result in erosive forces acting along the shoreline. The site is located adjacent to the Pacific Ocean, and the possibility of continued shoreline erosion, wave runup, protective device overtopping, and flooding by storm waves and storm surges is significant south of the existing rock groin. The groin was constructed in the late 1980s to protect an oil pipeline owned by Chevron, which is used to serve the offshore loading terminal. Due to the presence of a significantly narrower beach south of the groin, the likelihood of wave runup to the property may be considered moderate to high. For example, storm waves in the last 20 years have undermined and eroded the bike path adjacent to the project site during past El Niño storm events. These events have moved large rip-rap rock and caused flooding of the back-beach areas. Shoreline protection consisting of rip-rap placed on the beach adjacent to the bike path was constructed to prevent undermining and erosion of the bike path and project site.

Evaluation of the coastal environment involved an understanding of the following elements of the coastal setting:

- Santa Monica littoral cell
- Offshore bathymetry
- Tides and sea level
- El Niño Southern Oscillation
- Winds
- Nearshore currents
- Wave climate
- Storm surge and wave setup
- Tsunamis
- Shoreline erosion
- Existing coastal structures
- Wave runup and overtopping.

These elements are described briefly below. The coastal engineering design procedures used for the project should be in general accordance with the methodologies prescribed by in the U.S. Army Corps of Engineers based on an assumed 100-year storm wave condition coinciding with severe erosional shoreline retreat and amplified high tide conditions.

5.3.1.1.7.7.1 ***<u>Santa Monica Littoral Cell</u>***. El Segundo is part of the Santa Monica littoral cell. The Santa Monica littoral cell extends over a length of approximately 35 miles, from Point Dume to Palos Verdes Point (CDBW, 1977). The predominate net sand transport by shoreline currents in this region is south, which results in accretion and erosion of the shoreline north and south of the existing groin, respectively. Sand in the El Segundo area has mainly been brought into the littoral cell during previous phases of construction of the Hyperion wastewater treatment plant, the Los Angeles airport, other construction projects, and river watershed depositions from the north.

5.3.1.1.7.7.2 ***<u>Offshore Bathymetry.</u>*** Historical beach profiles for the El Segundo area may have been performed in the past by others. Foreshore beach slopes may be expected to be on the order of 10:1 to 20:1 and tidal beach slopes range from 50:1 to 100:1. Offshore slopes seaward of El Segundo may range from 100:1 to 200:1. Despite beach nourishment efforts, the El Segundo shoreline may be assumed to have a nominal rate of shoreline retreat. However, during severe high tide and storm wave conditions the rate of shoreline retreat may be on the order of tens of feet per event. The offshore bathymetry naturally adjusts to these conditions and seeks a dynamic equilibrium.

5.3.1.1.7.7.3 ***<u>Tides and Sea Level.</u>*** The tides along the Pacific Ocean coast have a semidiurnal inequality (roughly twice each day). The lowest annual predicted tide is about -2 feet MLLW; the highest annual tide is about + 8 feet MLLW. The average daily tide ranges from about 0 to +6 feet MLLW. Mean Sea Level for the region is +3 feet MLLW. Relative sea levels on the coast of California are projected to be increasing at a rate of 0.7 feet per century (Flick and Cayan, 1984). However, this value does not include the effects of global warming which is believed by some researchers to be contributing to sea level rise. Definitive rates of sea level rise due to global warming have not been evaluated for the project area. Other factors that effect apparent sea level are storm surge, wind and wave setup, and sustained atmospheric low pressure. A preliminary design still water level (DSWL) on the order of +9 feet MLLW may be considered appropriate for the site area. The DSWL should take into account an astronomical high tide, estimated sea level rise, wave setup, storm surge, and atmospheric low pressure due to an El Niño Southern Oscillation (ENSO) event.

5.3.1.1.7.7.4 ***<u>El Nino Southern Oscillation.</u>*** Positive departures from astronomical high tides and normal seasonal wind patterns can occur during strong El Niño Southern Oscillation (ENSO) events. Research scientists using numerical evaluations of anomalous sea surface temperatures and winds around the world have characterized ENSO events. These meteorological anomalies include sustained low atmospheric pressures and persistent onshore winds that can combine to create devastating tidal and wave conditions. Heavy precipitation and flooding are also possible. However, reciprocal high pressure systems may also develop during an ENSO event causing abnormally low tides, weak winds, heat waves, and drought.

During ENSO events, average sea levels in Southern California can rise 0.5 feet or more above normal tide conditions. Abnormal deepwater swell heights due to interaction with persistent winter storm conditions may also occur during ENSO events. Hence, sustained elevated sea level and high wave conditions from an event can accelerate landward retreat of beach areas.

5.3.1.1.7.7.5 ***<u>Winds.</u>*** Sea breezes attaining velocities of 5 to 10 mph blow landward across the shoreline nearly every afternoon. Reciprocal land breezes at night have much lower velocities. Coastal storms bring stronger winds to the shoreline area but their durations are relatively short. Wind velocities in excess of 30 to 40 mph occur on rare occasions. Hurricanes and tropical depressions with strong winds from the south are even more rare. In order of predominance, winds along the coastline come from the west, northwest, and southwest.

5.3.1.1.7.7.6 ***<u>Nearshore Currents.</u>*** Nearshore currents in the project area are mainly driven by waves acting on the shoreline at oblique angles and are responsible for the majority of shoreline erosion. The presence of the Channel Islands causes diffraction and sheltering of high waves and strong currents coming from the northern Pacific Ocean. Therefore, the net current in the El Segundo area is to the south. Complex cross-shore and rip currents exist throughout the El Segundo shoreline area. High wave conditions and currents can create irregularities in the circulation of seawater in the area. The presence of a rock groin in the area promotes beach deflation locally and can contribute to more complex and less predictable nearshore currents.

5.3.1.1.7.7.7 ***<u>Wave Climate.</u>*** Waves provide nearly all of the energy that drives shoreline processes in southern California. Determining the wave potential at a given coastal location requires a number of critical assumptions including the budget of deep water waves and the refraction of waves in water of variable depth. Typical high waves that break along the El Segundo shoreline may be in excess of 5 to 10 feet in height. Such waves can be expected to arrive at almost any time during the year, especially during the winter months, and continue for 3 to 4 days at a time. These high-wave episodes are frequently accompanied by strong winds. Extreme waves with estimated heights of 20 to 30 feet have been observed further off the coastline and may be expected every 20 to 200 years, respectively.

Limited historical data for coastal conditions along the El Segundo shoreline indicate that the project site may be subjected to extreme storm swell and sea conditions in conjunction with astronomical high tides. In particular, relatively recent coastal storms during the winter of 1982-83, January 1988, and February 1998 caused extensive damage to coastal structures. Atmospheric anomalies such as the ENSO contributed to the 1982-83 and 1998 events.

Nearshore conditions are such that large height, longer period waves tend to break further offshore in deeper water. These broken waves may reform and break again closer to the shoreline with much less energy. Usually, winter waves have shorter periods and greater heights than summer waves. The general shore-normal direction is from the west along the El Segundo coastline. The direction of final wave approach along the shoreline varies usually within a few degrees (0 to 15 degrees) of shore-normal during all seasons.

The shoreline of El Segundo is exposed to wave action, through one relatively well-defined wedge-shaped corridor of onshore wave approach from the west. The wave interference patterns caused by the offshore Channel Islands are difficult to evaluate and may vary widely event to event. The sheltering effects of these coastal features may reduce the overall wave exposure mainly from the southwest and northwest. However, there is a narrow window of vulnerability and long fetch corridor that approaches El Segundo from the southwest between Santa Barbara Island and Santa Catalina Island. Probabilistic recurrence intervals for significant wave heights may be available from the either the U.S. Army Corps of Engineers or NOAA.

A depth limited significant wave height of 15 to 20 feet with a period of 12 to 18 seconds may be considered within the applicable range of design waves for the project area. However, due to depth limited constraints for breaking waves in the area, this wave will break early and reform into another smaller wave. Therefore, a breaking wave height of about 5 to 8 feet may be directly impacting the exposed shoreline protection fronted by a water depth of about 6 to 10 feet.

It should be noted that breaking waves of 5 to 8 feet in height could occur any time during the year. Nevertheless, the combination of erosion, water depth, and breaking wave conditions assumed for design may be considered a relatively low probability event. However, if the shoreline is provided with a well-maintained sandy beach of at least 100 to 200 feet wide, the probability of the design wave breaking on the structure is greatly reduced.

5.3.1.1.7.7.8 Storm Surge and Wave Setup. Storm surge is relatively minor along the southern California coast when compared with tidal fluctuations. Excluding the effect of waves, storm surges in southern California rarely exceed several feet in amplitude, with average heights less than one foot for several days. Due to the presence of a narrow continental shelf offshore of El Segundo, wave setup is most likely limited to approximately 0.5 to 1 foot. Wave setup from impinging waves varies along the beach profile from a minimum near the wave breaker to a maximum at the shoreline. Wave setup for the project area may be considered to be less than 1.5 feet.

5.3.1.1.7.7.9 Tsunamis. Given the exposed coastal site location, it is possible that the facility could be affected by tsunamis. Tsunamis are seismically induced free-surface gravity ocean waves with very long periods. Statistical probabilities of tsunamis along the Southern California coast indicate that large seismic seawave events are extremely rare (Houston, 1974; Joy 1968). Tsunami waves in the area may be manifested in the form of wave bores or a gradual upwelling of sea level. Tsunamis forming breaking waves have not been reported in southern California. Historical records for southern California, since about 1800, denote a maximum observed tsunami sea level rise of about 5 to 10 feet which occurred in May 22, 1960.

The greatest danger is from a local, seismically-induced tsunami generated by a submarine landslide. Collapse of the steep slopes offshore Malibu, Palos Verdes Peninsula, or Redondo Submarine Canyon could produce a local tsunami, possibly on the order of 6 to 10 feet in amplitude (personal communication Phil Watts, Applied Fluids, 2000).

Houston and Garcia (1974) have also made tsunami predictions. For the subject area, the predicted tsunami upwelling would be 5.5 and 9.4 feet for the 100 and 500 years return periods, respectively. Assuming high tide and non-storm conditions (small waves), the tsunami runup could be as high as about +12 to +16 feet MLLW (or slightly higher). This amount of runup could be greater given an eroded beach condition and moderate to large storm wave conditions. Normal shoreline protection devices in Southern California have top elevations on the order of +15 to +20 feet MLLW. The site is located approximately 19 feet above MLLW. Based on these evaluations, and conditions, there are no significant impacts to the project as a result of predicted tsunami upwelling.

5.3.1.1.7.7.10 Shoreline Erosion. Based on our site observations and topographic information, the shoreline adjacent to the project site (south of the existing rock groin) may be affected by high tides and wave run-up. Shoreline processes in this area are considered complex due to the interaction of the groin and other existing shoreline features. The areas north and south of the groin may be considered to be accreting and eroding zones, respectively. Seasonal variations in beach elevations are to be expected in these areas. Due to beach maintenance by others and the lack of historical beach profiling data in this area, an assessment of the relative erosion rates has not been established for this report. Nevertheless, it is likely that moderate to high wave conditions have overwashed the project area shoreline in the historic past.

As previously stated, landward erosion is a constant force acting on the shoreline. This may be accompanied by a down wearing of the average back beach elevation. In this respect, the shoreline is considered to be actively eroding and vulnerable to wave attack during combined high tide and moderate to high wave conditions. However, to a lesser degree, the project area is also susceptible to erosion any time of the year. Therefore, shoreline erosion and wave-induced damage is a serious threat to inadequately protected development in the area. In recent years, winter storms in 1980, 1982-83, 1988, and 1998 have caused significant shoreline erosion and coastal damage in many areas of southern California.

For design, the beach may be assumed to have fully eroded down to an elevation of about 0 feet MLLW in front of the existing westerly rock revetment. This scour level assumes that beach deposits are completely eroded and that existing engineered shoreline protection arrests direct landward retreat. The resulting shoreline may be assumed to have an inclination on the order of 100:1 or flatter.

5.3.1.1.7.7.11 ***Existing Coastal Structures.*** There are numerous existing coastal structures and shoreline protection devices located in the immediate vicinity, of which, the most significant one is the seaward-extending rock groin and rock revetment adjacent to the project site. To a lesser extent, perimeter walls around portions of the project site may be capable of providing some additional wave runup protection. The interaction of existing coastal structures with an anticipated eroded shoreline, high tides, and storm wave conditions should be evaluated during the design phases of the project.

5.3.1.1.7.7.12 ***Wave Runup and Overtopping.*** The anticipated eroded shoreline geometry and storm wave conditions may allow for waves breaking directly on the existing shoreline protection devices. Wave runup and wave spray may reach elevations as high as +20 to +30 feet MLLW depending on wave period and actual scour conditions. Therefore, the site could be impacted by significant overtopping of the shoreline protection.

Hence, it should be anticipated that occasional uprushing water and wind blown spray during large storms would go behind the existing shoreline protection, over the bike path, and into the plant site if unprotected by a solid perimeter wall.

Overtopping rates during individual high wave runup conditions for vertical seawalls with wave deflectors are considered negligible when there is not a significant onshore wind. Nevertheless, overtopping rates may be assumed to be several cubic feet per foot of shoreline per wave with a moderate onshore wind for the combined design storm wave and erosion conditions.

5.3.1.2 Ancillary Pipelines

This section describes the affected environment for the ancillary pipelines that include the water supply pipelines, the sanitary discharge pipeline, and the aqueous ammonia supply line. The physiographic setting, stratigraphy, structure, tectonic setting and geologic hazards for the ancillary pipelines are very similar to those described at the plant site. A brief discussion of the minor differences or key elements of affected geologic environment for each of the pipelines are described below. Refer to Section 5.3.1 for details of the affected environment in the project area.

5.3.1.2.1 Water Supply Pipelines. Two water supply pipelines are proposed to bring reclaimed water and firewater to the site. Both pipelines follow the same alignment and are planned in a shared trench that will extend approximately 1.9 miles to tie in sites located along El Segundo Boulevard located to the northeast of the plant site. This alignment is located within city streets that are underlain by localized fill soils and Pleistocene aged Older Dune Sand. The alignment rises in elevation from the plant site to the east as it crosses elongate, northwesterly trending ridges and intervening troughs as shown on Figure 3.2-1. These ridges and troughs represent the relict dune forms characteristic of a coastal dune field setting. The eastern end of the alignment reaches an elevation of approximately +100 feet MSL.

The geologic hazards for the western end of the pipelines are similar to those at the plant site. To the east the hazards related to liquefaction and coastal flooding or tsunami become remote given the increasing depth to groundwater and the increasing distance to the coastline. Based on a review of the topographic setting of the site and published hazard mapping there are no significant slope hazards along the road easement that the pipelines will follow. In summary, there are no significant impacts to the offsite portion of the water supply pipelines resulting from geologic hazards. The onsite portions are subject to potentially significant impacts primarily from possible lateral spreading.

5.3.1.2.2 Sanitary Discharge Pipelines. The sanitary discharge pipeline will consist of routing approximately 200 feet of 3-inch PVC. The proposed line extends from the south property line southward to a tie-in at an existing manhole. Discussions of affected environmental conditions for the sanitary discharge pipeline are the same as those for the plant site. The only significant impact to the sanitary discharge pipeline would be from lateral spreading. The impact is discussed in detail in Section 5.3.1.1.7.

5.3.1.2.3 Aqueous Ammonia Supply Pipeline. The aqueous ammonia supply line will extend approximately 0.5 miles from a point within the Chevron Refinery to the northern perimeter fence of the plant site. This alignment is underlain by the Pleistocene aged Older Dune Sand and localized fill soils that are associated with the urban and industrial developments in the area. Topographically the pipeline alignment rises from the northern perimeter fence to an elevation of approximately + 90 feet MSL. The offsite portion of the alignment lies outside of the zones of liquefaction or slope hazards based on this review. The onsite portion of the alignment is subject to the same geologic hazard conditions that are described for the plant site. The most significant potential impacts to pipelines are lateral spreading and slope instability. These impacts are discussed in Section 5.3.1.1.7.

5.3.1.2.4 Worker Parking and Equipment Staging Areas. Discussions of regional geologic, tectonic and seismic setting are the same as those for the plant site in Section 5.3.1. These elements of the project involve temporary use during construction and involve no new construction. These sites share similar exposure to geologic hazards with the plant site as discussed in Section 5.3.1. Given the temporary nature of the activities proposed for these areas, the likelihood of significant impact to the project resulting from geologic hazards effecting the parking or staging areas is considered very low.

5.3.2 Environmental Consequences

Natural resources occurring within the area include sand deposits and oil and gas resources. The following section discusses these resources in the vicinity of the plant site and ancillary pipelines.

5.3.2.1 Sand and Gravel Aggregate Resources

In 1994 the CDMG issued an Open File Report No. 94-14 with an update of mineral land classification of Portland Cement Aggregate in Ventura, Los Angeles, and Orange County California. Lands are classified in the following categories:

- **MRZ-1:** Areas where adequate information indicates that no significant mineral deposits are present, or where it is judged that little likelihood exists for their presence.
- **MRZ-2:** Areas where adequate information indicates that significant mineral deposits are present, or where it is judged that high likelihood exists for their presence.
- **MRZ-3:** Areas where adequate information indicates undetermined mineral resource significance, or no mineral deposit occurrence, or inferred mineral deposit occurrence.

According to these definitions the site area is classified as MRZ-3. The closest potential aggregate mineral resources are Quaternary sand deposits on and to the east of the site.

5.3.2.2 Oil and Gas Resources

According to the 1999 Munger Map Book of California – Alaska Oil and Gas Fields, the site is located approximately one mile west of the El Segundo Oil Field, and one half mile south of an Occidental Petroleum producing oil well.

5.3.2.3 Mineral Resources

No mineral resources are identified or are under development at the site or along the ancillary pipeline routes.

5.3.2.4 Consequences to Natural Resources

Natural resources occurring within the region include sand and gravel as aggregate resource and oil and gas. All of these resources have been exploited, at least in a limited manner, in the vicinity of the ESGS facility. There are currently no significant sand and gravel mines in the area and given the urban setting there is little or no potential for new production in the area.

There are producing oil wells in the general site region. However, the proposed construction within the plant site or along the ancillary pipelines will not impact existing or future oil or gas production in the area. No significant impacts on geologic resources would occur as a result of project implementation.

5.3.2.5 Cumulative Impacts

We have reviewed existing site conditions, proposed project developments and the descriptions of proposed projects that might incur cumulative impacts. There are no identified cumulative impacts from geologic hazards or to geologic resources resulting from the ESPR project.

5.3.3 Stipulated Conditions

As a means of cooperating with the CEC and establishing a conciliatory relationship, and an open efficient AFC process that allows the Commission to utilize its resources in the most efficient manner possible, ESPR expresses a willingness to stipulate to and accept the following CEC standard general conditions as promulgated by the CEC that apply to the issue area of Geologic Hazards and Resources.

GEO-1: Prior to the start of construction, the project owner shall assign to the project an engineering geologist(s), certified by the State of California, to carry out the duties required by the 1998 edition of the California Building Code (CBC) Appendix, Chapter 33, Section 3309.4. The certified engineering geologist(s) assigned must be approved by the Compliance Project Manager (CPM). The functions of the engineering geologist can be performed by the responsible geotechnical engineer, if that person has the appropriate California license.

Verification: At least 30 days (or a lesser number of days mutually agreed to by the project owner and the Chief Building Official (CBO)) prior to the start of construction, the project owner shall submit to the CPM for approval the name(s) and license number(s) of the certified engineering geologist(s) assigned to the project. The submittal should include a statement that CPM approval is needed. The CPM will approve or disapprove of the engineering geologist(s) and will notify the project owner of its findings within 15 days of receipt of the submittal. If the engineering geologist(s) is subsequently replaced, the project owner shall submit for approval the name(s) and license number(s) of the newly assigned individual(s) to the CPM. The CPM will approve or disapprove of the engineering geologist(s) and will notify the project owner of the findings within 15 days of receipt of the notice of personnel change.

GEO-2: Prior to the completion of the final design of the project and the linear facilities, the owner shall have a liquefaction analysis conducted for each of the major project components (the Wastewater Connector Line, the Project Site and the Water Supply Pipeline). Each of the liquefaction analyses shall be implemented by following the recommended procedures contained in “Recommended Procedures for Implementation of California Division of Mines and Geology Special Publication 117, Guidelines for Analyzing and Mitigating Liquefaction Hazards in California” dated March 1999. (The document is available through the Southern California Earthquake Center at the University of Southern California.)

Verification**:** The project owner shall include in the application for a grading permit (see Condition of Certification GEO-3, below) a report of the liquefaction analysis, and a summary of how the results of this analysis were incorporated into the project grading plan, for the CBO’s review and comment.

GEO-3: The assigned engineering geologist(s) shall carry out the duties required by the 1998 CBC, Appendix Chapter 33, Section 3309.4 Engineered Grading Requirement, and Section 3318.1 **–** Final Reports. Those duties are:

1. Prepare the Engineering Geology Report. This report shall accompany the Plans and Specifications when applying to the CBO for the grading permit.

2. Monitor geologic conditions during construction.

3. Prepare the Final Engineering Geology Report.

Protocol: The Engineering Geology Report required by the 1998 CBC Appendix Chapter 33, Section 3309.3 Grading Designation, shall include an adequate description of the geology of the site, conclusions and recommendations regarding the effect of geologic conditions on the proposed development, and an opinion on the adequacy of the site for the intended use as affected by geologic factors.

The Final Engineering Geology Report to be completed after completion of grading, as required by the 1998 CBC Appendix Chapter 33, Section 3318.1, shall contain the following: A final description of the geology of the site and any new information disclosed during grading; and the effect of same on recommendations incorporated in the approved grading plan. The engineering geologist shall submit a statement that, to the best of his or her knowledge, the work within their area of responsibility is in accordance with the approved Engineering Geology Report and applicable provisions of this chapter.

Verification: (1) Within 15 days after submittal of the application(s) for grading permit(s) to the CBO, the project owner shall submit a signed statement to the CPM stating that the Engineering Geology Report has been submitted to the CBO as a supplement to the plans and specifications and that the recommendations contained in the report are incorporated into the plans and specifications. (2) Within 90 days following completion of the final grading, the project owner shall submit copies of the Final Engineering Geology Report required by the 1998 CBC Appendix Chapter 33, Section 3318 Completion of Work, to the CBO, and to the CPM on request.

5.3.4 Other Mitigation

The following measures are proposed to mitigate any potentially significant geologic hazards to less than significant levels for the plant site and the ancillary pipelines. No unavoidable adverse impacts that can not be mitigated have been identified for the ESPR project. These mitigation measures are more accurately described as project design features. They are presented here for clarity.

5.3.4.1 <u>Surface Faulting Rupture</u>

No active (Holocene) or potentially active (Quaternary) faults were found to cross either the plant area or any of the linear facility corridors in this review (Jennings, 1994). The potential impact from ground rupture is negligible on the basis of this information, and, therefore, no mitigation measures are required.

5.3.4.2 Earthquake Ground Shaking

The power plant and associated facilities will likely be subjected to moderate or strong earthquake motions in their lifetime. Thus, they will need to be designed and constructed at a minimum to the seismic design requirements for ground shaking specified in the UBC for seismic zone 4. Proper design and construction will reduce impacts from ground shaking to less than significant.

5.3.4.3 Flooding

The coastal flooding potential is a geologic hazard dependent on many factors occurring simultaneously. These include having an eroded shoreline, high tides, storm waves, low atmospheric pressure, and effectiveness of structural shoreline protection devices. The project site is subject to significant landward flooding when the coastal climate is adverse. Based on the site setting, there is a potential impact to the site from coastal flooding. A perimeter containment wall will be constructed to mitigate the most significant component of coastal flooding. This will reduce the impact to the site from flooding to less than significant.

- **Perimeter Containment Wall –** The potential flooding hazard at the site can be reduced with a masonry or reinforced concrete perimeter containment wall located along the westerly side of the plant. The wall would be the final line of coastal defense behind the beach and rock revetment. The top of the wall will be 5 to 10 feet above the existing site grades. The shallow foundation for the wall would extend several feet below the ground surface in order to reduce the potential for wave-induced undermining. Likewise, the wall would be designed to withstand the direct impact of a broken wave that uprushes the beach and breaches the rock revetment. The wall could be provided with a deflector top that further reduced the potential for wave spray and overtopping into the plant site. Conventional concrete and masonry construction methods would be used for the wall. The wall can be colored and textured as desired to minimize visual impacts.

5.3.4.4 Tsunamis

Because of the low probability of occurrence, shoreline protection structures along the southern California coastline are typically not specifically designed for tsunami conditions. Storm wave conditions generally control coastal design. The adequacy of the existing shoreline protection, including past beach nourishment, rock revetment enhancement, and perimeter walls reduces the impact to the site from tsunamis to less than significant.

5.3.4.5 Slope Stability

The various options, built into the Project Description, for ensuring that any potential geological slope stability hazard is designed for, are discussed in Section 3.3.2.4 of Chapter 3.

5.3.4.6 Liquefaction

The various options, built into the project description, for ensuring that any potential geological liquefaction hazard is designed for, are discussed in Section 3.3.2.3 of Chapter 3.

5.3.4.7 Shoreline Erosion

The various options, built into the project description, for ensuring that any potential geological shoreline erosion hazard is designed for, are discussed in Section 3.3.2.5 of Chapter 3.

5.3.5 Applicable Laws, Ordinances, Regulations, and Standards

The ESPR will comply with applicable laws, ordinances, regulations, and standards (LORS) during construction and operations. Applicable LORS are discussed below and summarized in Table 5.3.2

TABLE 5.3-2

LORS APPLICABLE TO GEOLOGIC HAZARDS & RESOURCES

LORS	Applicability	Conformance (section)
Federal		
No federal LORS are applicable. (See also Section 3.12)		
State		
Cal PRC §25523(a), Alquist-Priolo Special Study Zone	N/A	Section 5.3.5.2
Local		
California Building Code, Chapters 16 and 33	Codes address excavation, grading and earthwork construction, including construction applicable to earthquake safety and seismic activity hazards.	Sections 3.5, 5.3.5.3, Appendix G

5.3.5.1 Federal

No Federal LORS are applicable.

5.3.5.2 State

California Public Resources Code § 25523(a): 20 CCR § 1752(b) and (c). No project components cross an Alquist-Priolo Special Study Zone (APSSZ). The ESPR will not be subject to requirements for construction within the APSSZ.

5.3.5.3 Local

The project site is located in the City of El Segundo and would be subject to the LORS for the City.

California Building Code (CBC), Appendix Chapter 33. This element sets forth rules and regulations to control excavation, grading and earthwork construction, including fills and embankments. It establishes basic policies to safeguard life, limb, property and public welfare by regulating grading on private property.

The Geotechnical Engineer and Engineering Geologist will certify the placement of fills and the adequacy of the site for structural improvements in accordance with the CBC, Appendix Chapter 33.

The Geotechnical Engineer will address Sections 3309 (Grading Permit Requirements), 3312 (Cuts), 3315 (Drainage and Terracing), 3316 (Erosion control), 3317 (Grading Inspection), and 3318 (Completion of Work) of CBC, Appendix Chapter 33. Additionally, the Engineering Geologist will present findings and conclusions pursuant to PRC, Section 25523(a) and 20 CCR, Section 1752(b) and (c).

California Building Code 1998, Volume 2, Chapter 16. This elements sets forth rules and regulations that address potential seismic hazards.

The administering agency for the above authority is the Los Angeles County Building Department.

5.3.5.4 Agencies and Agency Contacts

Agencies with jurisdiction to issue applicable permits and/or enforce LORS related to geologic hazards and resources and the appropriate contact person are shown in Table 5.3-3.

TABLE 5.3-3

INVOLVED AGENCIES AND AGENCY CONTACTS

Agency	Contact/Title	Telephone
California Division of Mines and Geology*	Jim Davis, State Geologist, Office of the State Geologist	(916) 445-1923
El Segundo Fire Department, Environmental Safety Division	Steve Tsumura, Environmental Safety Manager	(310) 524-2242
El Segundo Building Safety Division	Simon Juries, Building Safety Manager	(310) 524-2345

*Geological resources an hazards fall under the jurisdiction of the CDMG.

5.3.5.5 Applicable Permits

There are no applicable permits required related to geological hazards.

5.3.5 REFERENCES

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Adequacy Issue: Adequate ____ Inadequate ____

DATA ADEQUACY WORKSHEET

Revision No. 0 Date ____

Technical Area: **Geological Hazards** Project: ____ Technical Staff: ____

Project Manager: ____ Docket: ____ Technical Senior: ____

SITING REGULATIONS	INFORMATION	AFC PAGE NUMBER AND SECTION NUMBER	ADEQUATE YES OR NO	INFORMATION REQUIRED TO MAKE AFC CONFORM WITH REGULATIONS
Appendix B (g) (1)	...provide a discussion of the existing site conditions, the expected direct, indirect and cumulative impacts due to the construction, operation and maintenance of the project, the measures proposed to mitigate adverse environmental impacts of the project, the effectiveness of the proposed measures, and any monitoring plans proposed to verify the effectiveness of the mitigation.	Sections 5.3.1, 5.3.2, 5.3.4, & 5.3.5		
Appendix B (g) (17) (A)	A summary of the geology, seismicity, and geologic resources of the project site and related facilities;	Sections 5.3.1.1.2 - 5.3.1.1.7.7.12		
Appendix B (g) (17) (B)	A map at a scale of 1:24,000 and description of all recognized stratigraphic units, geologic structures, and geomorphic features within 2 miles of the project site. Include an analysis of the likelihood of ground rupture, seismic shaking, mass wasting and slope stability, liquefaction, subsidence, and expansion or collapse of soil structures.	Sections 5.3.1.1.7 *et seq.* Sections 5.3.4 *et seq.*		
Appendix B (g) (17) (C)	A map and description of geologic resources of recreational, commercial, or scientific value which may be affected by the project. Include a discussion of the techniques used to identify and evaluate these resources.	Section 5.3.1 Figures 5.3-1, 5.3-2, 5.3-3		

Adequacy Issue: Adequate ____ Inadequate ____

DATA ADEQUACY WORKSHEET

Revision No. 0 Date ____

Technical Area: **Geological Hazards** Project: ____ Technical Staff: ____

Project Manager: ____ Docket: ____ Technical Senior: ____

SITING REGULATIONS	INFORMATION	AFC PAGE NUMBER AND SECTION NUMBER	ADEQUATE YES OR NO	INFORMATION REQUIRED TO MAKE AFC CONFORM WITH REGULATIONS
Appendix B (h) (1) (A)	Tables which identify laws, regulations, ordinances, standards, adopted local, regional, state, and federal land use plans, and permits applicable to the proposed project, and a discussion of the applicability of each. The table or matrix shall explicitly reference pages in the application wherein conformance, with each law or standard during both construction and operation of the facility is discussed;	Section 5.3.5 Table 5.3-2		
Appendix B (h) (1) (B)	Tables which identify each agency with jurisdiction to issue applicable permits and approvals or to enforce identified laws, regulations, standards, and adopted local, regional, state and federal land use plans, and agencies which would have permit approval or enforcement authority, but for the exclusive authority of the commission to certify sites and related facilities.	Section 5.3.5.4 Table 5.3-3		
Appendix B (h) (2)	A discussion of the conformity of the project with the requirements listed in subsection (h)(1)(A).	Sections 5.3.1, 5.3.2, 5.3.3, 5.3.5.1, 5.3.5.2, 5.3.5.3		
Appendix B (h) (3)	The name, title, phone number, and address, if known, of an official within each agency who will serve as a contact person for the agency.	Section 5.3.5.4 Table 5.3-3		