7.15 GEOLOGIC HAZARDS AND RESOURCES

In accordance with California Energy Commission (CEC) requirements, this section of the report presents information on the geological and tectonic setting of the region and site vicinity. Following this discussion, geologic hazards and resources are described to provide background information on the conditions surrounding the proposed Marsh Landing Generating Station (MLGS) site. Unless specified otherwise, all discussions in this chapter referring to the proposed MLGS site also refer to the project, which, by definition includes (1) the plant itself, (2) the water supply and discharge pipelines along the Wilbur Avenue right-of-way, and (3) the wastewater treatment facility at the Bridgehead Lift Station. The discussion of geologic hazards includes surface fault rupture, strong ground shaking, liquefaction, mass wasting/slope stability, subsidence, and expansive soils. Potential impacts of the project on the geologic resources at the site are also addressed. Based on this evaluation, measures are recommended to mitigate potential impacts from the project.

The final portion of this section describes laws, ordinances, regulations, and standards (LORS) relevant to potential geologic impacts of the project, as well as the contacts in cognizant regulatory agencies. Required permits are discussed.

7.15.1 Affected Environment

The MLGS site is at the northern end of the Diablo Range within the northern Coast Ranges physiographic province (Figure 7.15-1). This province is characterized by north-northwest trending mountains and intervening valleys that extend from the Oregon border to the Transverse Ranges of southern California. The ridge and valley topographic character of the Coast Ranges province is predominantly controlled by the structural grain of the underlying geological units and subsequent erosion.

The MLGS site is on the southern side of the San Joaquin River near the western edge of the Sacramento River delta. To the south, the Diablo Range's Los Medanos Hills reach elevations of about 1,300 feet. To the north of the site, the Sacramento River delta containing West and Sherman Islands is at sea level, and many of the delta's islands are surrounded by man-made levees.

The MLGS area is underlain by fluvial/deltaic deposits of Pleistocene and Holocene age (Atwater, 1982). Elevations range from about 5 to 23 feet above mean sea level (msl). The site is essentially flat, with topographic relief limited to slope faces along the shoreline, and around buildings, tanks, or other developed features.

7.15.1.1 Regional Geology

The Coast Ranges represent northwest-southeast trending structural blocks comprised of a variety of basement lithologies that are juxtaposed by major geologic structures. The Coast Ranges-Sierran Block boundary zone lies to the east of the site. To the west, the major boundary is the San Andreas fault zone, which separates Franciscan Complex rocks of the North American plate from the Salinian basement rocks on the Pacific plate. The Coast Ranges ophiolites within the Franciscan Complex have been deformed by a series of thrust faults, most of which appear to be inactive.

The Diablo Range, just south of the proposed MLGS site, extends from the Sacramento River delta, south along the western side of the San Joaquin Valley. Rocks of the Mesozoic Great Valley sequence are thrust upon Franciscan basement along the San Joaquin Valley margin, and are covered locally by younger sediments of Paleocene to Pleistocene age.

Faults of the San Andreas system separate the Diablo Range from the remainder of the Coast Ranges. Mount Diablo is separated from the western East Bay Hills by the Calaveras fault and from the southern extension of the Diablo Range by the Livermore Valley, an east-west-trending Cenozoic basin. The Diablo Range is bounded to the east by the Coast Range-Sierran Block boundary zone, which typically is represented by a series of blind and partially concealed thrust faults (Wong et al., 1988; Unruh and Moores, 1992). The eastern side of Mount Diablo is bounded by the San Joaquin fault (Sowers et al., 1992).

The Diablo Range comprises a series of large en echelon anticlines, with intervening synclines. The anticlines are composed of Franciscan Complex rocks, while the synclines contain younger rocks. The folds are frequently cut by east- and west-verging thrust faults. These thrust faults are displaced or truncated by strike-slip movement on the northwest-striking, right-lateral faults of the San Andreas fault system.

7.15.1.2 Regional Seismotectonic Setting and Seismicity

As described above, the site lies within the broad San Andreas fault system that accommodates the majority of the plate motion between the Pacific and North American plates. Although the most active faults within the system lie to the west of the site, active deformation related to the system also occurs in the site vicinity. Compressional tectonics reflected in the Coast Ranges also result in folds and thrusts subparallel to the San Andreas fault system.

Significant Faults

The most significant Quaternary faults within 50 miles of the proposed MLGS site, as well as estimates of the maximum earthquake for each fault, are listed on Table 7.15-1. Maximum earthquake magnitude estimates are based on the Working Group on Northern California Earthquake Potential (WGNCEP, 1996). Table 7.15-1 also indicates the closest distance from each fault to the MLGS.

Figure 7.15-2 illustrates the location of the proposed MLGS site with respect to the major late-Quaternary faults in the site region. Fault data have been obtained from Bortugno et al. (1991), Jennings (1994), Unruh and Sawyer (1997), Simpson et al. (1992), Lienkaemper et al. (1991), and the WGNCEP (1996). The following describes each of the major faults listed in Table 7.15-1.

San Andreas Fault. The San Andreas fault is the largest active fault in California, extending from the Gulf of Mexico on the south some 750 miles to Cape Mendocino on the north. The San Andreas fault was the source of the 1906 Moment Magnitude (M_W) 7.9 San Francisco earthquake (Wallace, 1990), which ruptured approximately 280 miles of the fault from San Juan Batista to Shelter Cove. The fault is about 46 miles west of the site at its closest approach.

The San Andreas fault can be divided into a number of segments, based on differences in geomorphology, geometry, paleoseismic chronology, seismicity, and historic displacements. In the Bay Area, these segments include the Southern Santa Cruz Mountains segment, possible source of the 1989 M_W 7.0 Loma Prieta earthquake; the Peninsula segment; and the North Coast segment. These segments have been assigned maximum earthquakes of M_W 7.0, M_W 7.1, and M_W 7.9, respectively, by the WGNCEP (1996).

Hayward Fault. The Hayward fault is about 62 miles long and extends from Evergreen (east of San Jose) to Point Pinole, where it projects offshore into Suisun Bay. The fault demonstrates systematic right-lateral creep offset of cultural features along its entire length (e.g., Lienkaemper et al., 1991). The October 1868 Local Magnitude (M_L) 6.8 event was the last major earthquake to occur on the Hayward fault. The epicenter of this event was along the southern segment of the fault near Fremont.

The WGNCEP (1996) has divided the Hayward fault into two fault segments: a longer southern segment, and a shorter northern segment. Based on the fault lengths associated with these segments and uncertainties in length measurements, maximum earthquakes of M_W 6.9 have been assigned for both the northern and southern segments of the Hayward fault. The fault is located approximately 28 miles from the proposed MLGS site. This structure is considered to be the most likely source of the next major earthquake in the San Francisco Bay area (Working Group on California Earthquake Probabilities [WGCEP], 1990).

Concord-Green Valley Fault System. The Concord-Green Valley fault is a northwest-striking, right-lateral strike-slip fault zone that extends about 33 miles from the Walnut Creek area across Suisun Bay to the north. The Concord segment extends approximately 12 miles, from the northern slopes of Mount Diablo to Suisun Bay. North of Suisun Bay, the Green Valley fault continues to the north for about 28 miles. The Concord fault is an actively creeping structure that has a long-term creep rate of approximately 5 millimeters per year (mm/yr). Recent investigations yielded geological evidence of previous large surface fault rupturing events.

Based on the length of the combined Concord and Green Valley fault segments, geometry, and previous rupture history, an earthquake involving both fault segments would produce a maximum earthquake of about M_W 6.9 with a recurrence interval of approximately 180 years (WGNCEP, 1996). At its closest point, the Concord fault is about 17.5 miles from the proposed MLGS site.

Calaveras Fault. The Calaveras fault represents a significant seismic source in the southern and eastern San Francisco Bay region. It extends from an intersection with the Paicines fault south of Hollister, through the Diablo Range east of San Jose, and along the Pleasanton-Dublin-San Ramon urban corridor. The fault consists of three major sections: the 15-mile-long southern Calaveras fault (from the Paicines fault to San Felipe Lake), the 38-mile-long central Calaveras fault (from San Felipe Lake to Calaveras Reservoir), and the 24-mile-long northern Calaveras fault (from Calaveras Reservoir to Danville). The poorly constrained slip rate on the southern section is interpreted to be 15 ± 2 mm/yr, although some workers have postulated rates as high as 19 or 20 mm/yr. The central and northern sections have geologic slip rates of 14 ± 5 mm/yr and 6 ± 2 mm/yr, respectively. The level of contemporary seismicity along the southern section is low to moderate, whereas the central section has generated numerous moderate earthquakes in historic time. The northern section has a relatively low level of seismicity and may be locked. Geologic and seismologic data suggest that the northern section may produce earthquakes as large as M_W 7.0. Paleoseismologic studies suggest a recurrence interval for large ruptures of between 250 and 850 years on the northern fault section. The timing of the most recent rupture on the northern Calaveras fault is unknown, but may be several hundred years ago (Kelson, 1999).

The WGNCEP (1996) estimated a maximum earthquake of M_W 7.0 for the northern Calaveras fault. This section of the fault is located approximately 19 miles to the southwest of the MLGS site.

Greenville-Clayton Fault. The Greenville-Clayton fault is a northwest-striking strike-slip fault on the eastern side of the Diablo Range. The fault extends about 45 miles from Bear Valley to just north of the Livermore Valley. This fault has a lower slip rate than other structures within the San Andreas system, with a long-term rate of approximately 1 to 3 mm/yr. However, this fault produced a moderate magnitude earthquake in 1980 that caused minor surface fault rupture and damage to I-580 east of Livermore, as well as damage to the Livermore Valley area.

Research is currently being conducted on the fault zone to better constrain its slip rate and its history of past earthquakes. The WGNCEP (1996) assigned a maximum earthquake of M_W 6.9 to the Greenville fault; the recurrence interval is estimated to be about 550 years. The fault is located about 9.5 miles south of the MLGS site.

Rodgers Creek Fault. The Rodgers Creek fault is a 28-mile-long northwest-striking, right-lateral strike-slip fault that extends northward from the projection of the Hayward fault on the south side of San Pablo Bay. The Rodgers Creek has a similar long-term geological slip rate to the Hayward fault and has also produced a large magnitude historical earthquake in the late 1800s. Marine geophysical evidence suggests that the Hayward and Rodgers Creek faults are connected by a series of normal faults that extend across a 3-mile right step underneath San Pablo Bay. Current research suggests a low probability for the two faults to connect across this step-over during a large earthquake; instead, they are more likely to behave as separate structures. Paleoseismic investigations by Schwartz et al. (1992) identified evidence for three earthquakes in the last 925 to 1,000 years, yielding a preferred earthquake recurrence interval of 230 years for an M_W 7.0 earthquake. The fault is about 35 miles from the MLGS site. The WGNCEP (1996) has assigned a maximum earthquake magnitude of M_W 7.0 to the Rodgers Creek fault.

West Napa Fault. The West Napa fault consists of a north-northwest–striking zone of short right-lateral strike-slip fault segments in the hills to the west of the city of Napa (Bryant, 1982). The fault extends about 19 miles from Napa to Yountville. It is characterized by well-defined active fault features such as tonal lineations, scarps in late Pleistocene and Holocene alluvium, closed depressions, and right-laterally deflected drainages. The WGNCEP (1996) has assigned a maximum earthquake of M_W 6.5 for the West Napa fault based on fault length and continuity. The fault is located approximately 28 miles to the northwest of the MLGS site.

Coast Range-Sierran Block Boundary Zone. The Coast Range-Sierra– Block (CRSB) boundary zone consists of a complex zone of thrust faulting marking the boundary between the Coast Ranges block and the Sierran basement rocks concealed beneath the Great Valley sedimentary sequence of the Sacramento and San Joaquin valleys. The basal detachment within the CRSB boundary zone is a low-angle, west-dipping thrust accommodating eastward thrusting of the Coast Range block over the Sierran block. Above this detachment is a complex array of west-dipping thrusts and east-dipping back-thrusts. The CRSB extends from near Red Bluff in the northern Sacramento Valley to Wheeler Ridge in the southern San Joaquin Valley (Wong et al., 1988; Wakabayashi and Smith, 1994).

The CRSB boundary zone was the probable source of the two M_W 6.25 to 6.75 earthquakes recorded in 1892 near Winters, and the 1983 M_W 6.5 Coalinga earthquake in the western San Joaquin Valley (Wong et al., 1988). Although the faults themselves do not have surface expression, the CRSB boundary zone is marked by an alignment of fault-propagation folds such as the Rumsey Hills along much of its length (Unruh and Moores, 1992). Empirical relationships between fault length and earthquake magnitude suggest that these segments of the CRSB are capable of generating maximum earthquakes of M_W 6.5 to 6.75, with an average recurrence interval of 360 to 440 years (Wakabayashi and Smith, 1994). The CRSB boundary zone is located about 5 miles from the MLGS site.

Pittsburg-Kirby Hills Fault. The Pittsburg-Kirby Hills fault (PKHF) extends a distance of approximately 26 miles from the Kirby Hills north of the Sacramento River, to the eastern flank of Mount Diablo, south of Pittsburg. Unruh et al., (1997) suggest that the structure is a right-lateral tear fault bounding the eastern margin of a series of thrusts and folds in the Grizzly Bay-Van Sickle Island area. The fault is defined by a linear alignment of microseismicity, which is unusual in that it occurs at depths of 20 to 25 km (Wong et al., 1988). Focal mechanisms indicate that the movement on the fault is almost pure right-lateral strike-slip. Empirical relationships among various fault parameters and earthquake magnitude indicate that the maximum earthquake for the PKHF is M_W 6.75 (Wells and Coppersmith, 1994). The fault zone is located approximately 5 miles west of the MLGS site.

It should be noted that, although the PKHF is a known seismogenic structure, it is not included in the regional tectonic model used to predict future earthquake activity in the San Francisco Bay Area (WGCEP, 1999, 2003). This is due to the fact that the model only includes fault structures with a demonstrated slip rate of ≥1 mm/yr and the PKHF does not meet this criterion. Furthermore, recent trenching studies conducted within the City of Pittsburg (TERRASEARCH, Inc., 2005) failed to clarify the "Pittsburg" fault in the near subsurface. Accordingly, this fault structure has been removed from the City of Pittsburg's Health & Safety Element to the General Plan (2001).

Mount Diablo Thrust. The Mount Diablo thrust fault is a northeast-dipping structure located beneath the Mount Diablo anticline approximately 9.5 miles from the MLGS. Unruh and Sawyer (1995) proposed that slip on the northern Greenville fault appears to die out northward because the fault steps to the northwest (left) across Mount Diablo to join with the right-lateral Concord fault. This implies that Mount Diablo is an asymmetric, southwest-vergent fault-propagation fold underlain by a northeast-dipping blind thrust fault that links the northern Greenville fault to the Concord fault.

Unruh and Sawyer (1997) estimated long-term average Quaternary shortening rates across the Mount Diablo region, from balanced cross sections, to be 3.4 ± 0.9 mm/yr. Taking into consideration the presumed fault geometry, an average slip rate for the Mount Diablo thrust is calculated to be approximately 4.1 ± 1.4 mm/yr. This blind thrust fault is judged capable of generating a maximum earthquake of M_W 6.25.

Antioch Fault. The Antioch fault, about 2.5 miles west of the MLGS site, was previously considered active and was zoned under the Alquist-Priolo Act as potentially capable of surface rupture. A recent study by Wills (1992) indicates that the Antioch fault is not active and does not pose a surface-faulting hazard. The fault is no longer zoned by the State of California as an earthquake fault zone under the Alquist-Priolo Act. Accordingly, it is not listed on Table 7.15-1.

Historical Seismicity

The historical seismicity for the San Francisco Bay region is largely associated with the San Andreas, Hayward, Rodgers Creek, Concord-Green Valley, Pittsburg-Kirby Hills, Calaveras, and Greenville faults (see Significant Faults, above). Several of these structures have produced large-magnitude historical earthquakes that caused damage to buildings and structures in the Bay Area. As a number of the earthquakes occurred before modern instruments were developed, the magnitude and distribution of damage can only be surmised from written historical documents. The earliest accounts of earthquakes in the San Francisco Bay Area were written in the 1800s, frequently in the logs of the Spanish missions.

Significant Earthquakes

There have been 14 historical earthquakes of Magnitude (M) 6.0 or greater in the San Francisco Bay region (Figure 7.15-2). Earthquakes of this magnitude can pose significant ground-shaking hazard to the project area. The following paragraphs discuss several of these significant historic earthquakes that are considered of relevance to the MLGS site.

May 19, 1889. Of the historic earthquakes of M 6.0 or greater in the San Francisco Bay Area, this earthquake occurred closest to the MLGS site. This event may have been associated with the Pittsburg-Kirby Hills fault (see Significant Faults, above). Many chimneys toppled in Antioch and two small fissures were reported on Main Street. Toppozada et al. (1981) estimated the magnitude of the earthquake to be M_L 6, while Ellsworth (1990) assigned a M 6.25.

April 19 and 21, 1892. This pair of earthquakes occurred within the CRSB on the western side of the Sacramento Valley (Wong et al. 1988; Unruh and Moores, 1992), causing extensive damage in Winters, Dixon, and Vacaville (Figure 7.15-2). The maximum reported intensities for both events was Modified Mercalli Intensity (MMI) IX, and the magnitudes have been estimated at M_L 6.75 to 7, and 6.5 to 6.75, respectively (Wong et al., 1988). It is not clear whether surface faulting accompanied these events.

March 31, 1898. On March 31, 1898, the San Francisco Bay region experienced an earthquake that appeared to be centered near Mare Island at the north end of San Pablo Bay. A maximum intensity of MM VIII or greater was reported, and buildings throughout the Bay Area were damaged. Toppozada et al. (1992) have compared this event with other historical earthquakes and have assigned a magnitude of M_L 6.7.

April 18, 1906. The Great San Francisco earthquake of 1906, M_W 7.9, centered near Olema, was the most destructive earthquake to have occurred in northern California in historical times. Its effects were felt from southern Oregon to south of Los Angeles, and as far east as central Nevada. Damage from shaking was widespread in northern California and was most severe in areas of saturated or loose, young soils.

October 17, 1989. The M_W 7.0 Loma Prieta earthquake occurred on or adjacent to the southern Santa Cruz Mountains segment of the San Andreas fault, severely damaging the cities of Los Gatos, Watsonville, Santa Cruz, San Francisco, and Oakland. Shaking was felt as far south as San Diego and as far east as Nevada. Similar to the 1906 San Francisco earthquake, the worst shaking damage occurred to buildings on unconsolidated or saturated soils, or with unreinforced masonry or improperly designed structures.

7.15.1.3 Local Geology

The surficial geology in the vicinity of the MLGS site is composed of late Tertiary sedimentary deposits in the southernmost portion of the 2-mile radius, while the remainder of the site area is composed entirely of late Quaternary to Holocene alluvial deposits and recent artificial fill (Figure 7.15-1). The geologic units were formed as a result of deposition of sediments from the San Joaquin River to the east, wind-blown transport of fine-grained silts and sand, and local drainages originating from the Diablo Range to the south.

Structure

The site is located within the “Mount Diablo fold and thrust belt” of Unruh and Sawyer (1995) at the northern end of the Diablo Range. The faults of the San Andreas system strike north-northwest, while the folds and thrust faults strike approximately east-west to northwest-southeast. The folds are closely related to the thrust faults because movement on the thrusts causes the formation of folds in the overlying strata. This fold and thrust belt is bounded by the PKHF to the east and the Potrero Hills thrust to the north. Movement on the Potrero Hills thrust and other thrusts has resulted in the formation of the Potrero Hills and Kirby Hills anticlines, as well as Honker Bay-Van Sickle Island, Los Medanos, and Concord anticlines. These anticlines are cut by several relatively short northeast-striking tear faults. This series of folds and thrusts is bounded to the south and west by the right-lateral Concord fault. The folds within this area plunge both to the east and the west, forming domes or structural traps for hydrocarbons within the Concord, Los Medanos, and Honker Bay-Van Sickle Island oil and gas fields.

Stratigraphy

The stratigraphy beneath the site “proper” comprises alluvial sediments of the San Joaquin River; no bedrock occurs at the site. A thin strip of land to the north of the plant site adjacent to the San Joaquin River consists of artificial fill overlying Holocene peaty mud deposits. In the 2-mile area around the site, the stratigraphy includes, from oldest to youngest, Cenozoic sedimentary rocks, Quaternary sediments, Holocene sediments, and artificial fill as shown on Figure 7.15-1 and described below.

Tulare Formation

The Tulare Formation consists of poorly consolidated, nonmarine, gray to maroon siltstone, sandstone, and conglomerate. This formation contains the Putah Tuff, which has been dated at about 3.3 million years old (Graymer et al., 1994).

Quaternary Alluvial Fan and Fluvial Deposits

The unconsolidated quaternary alluvial fan and fluvial deposits are divided by Helley and Graymer (1997) into older Pleistocene and younger Holocene units. Alluvial fans and fluvial deposits of Pleistocene age consist of brown dense gravelly and clayey sand or clayey gravel that fines upward to sandy clay. They are distinguished from younger alluvial fans and fluvial deposits by higher topographic position, greater degree of dissection, and development of a more extensive soil profile. They are overlain by Holocene deposits on lower parts of the alluvial plain, and incised by channels that are partly filled with Holocene alluvium on higher parts of the alluvial plain.

Alluvial fan and fluvial deposits of Holocene age are predominantly brown or tan, medium dense to dense, gravely sand or sandy gravel that generally grades upward to sandy or silty clay.

7.15.1.4 Geologic Hazards

The following paragraphs discuss potential geologic hazards that may occur relative to the project at the MLGS site.

Surface Fault Rupture

No active or potentially active faults are mapped on the proposed MLGS site. The closest fault zone to the site zoned under the Alquist-Priolo (AP) Earthquake Fault Zoning Act is the Greenville fault, about 10 miles to the south. The AP Act requires the California Geological Survey (CGS) to designate faults considered active or potentially active, and establishes zones within which studies are required for structures involving human occupancy. All of the faults discussed in Significant Faults, above, are shown on Table 7.15-1 except the PKHF, the CRSB, the West Napa fault and the Mount Diablo thrust are zoned in accordance with the AP Act. Based on the lack of geomorphic expression of active faulting and the absence of AP-zoned faults in the MLGS area, the hazard from ground rupture is considered negligible.

Earthquake Ground Shaking

Strong ground shaking due to future seismic events is probably the most significant geologic hazard anticipated at the proposed MLGS site. The site has experienced strong ground motions in the past and will do so in the future. Based on the USGS Seismic Hazard Mapping Program (Petersen et al., 2008) bedrock motions with a 10 percent probability of being exceeded within the next 50 years are estimated at 0.4 g.

Liquefaction

Liquefaction is the phenomenon during which loose, saturated, cohesionless soils temporarily lose shear strength during strong ground shaking. Significant factors known to affect the liquefaction potential of soils are the characteristics of the materials such as grain size distribution, relative density, degree of saturation, the initial stresses acting on the soils, and the characteristics of the earthquake, such as the intensity and duration of the ground shaking.

Potential hazards at the site include compaction consolidation (settlement) and seismically induced settlement. Dissipation of excess pore pressure generated by ground shaking would produce volume changes within the liquefied soil layers, which would be manifested at the ground surface as settlement.

During reconnaissance of the plant site in 2000, it was observed that areas around the plant perimeter have experienced differential settlement. Warping or undulation of the pavement surface, and settlements of pavement relative to the main power plant suggest that settlement of up to 1.5 feet may have occurred.

It should be noted that no settlements were observed beneath the main plant area. This settlement during a seismic conditions suggests that increased settlement may occur during seismic strong ground shaking.

A review of more than 70 geotechnical borings drilled at the CCPP site, which includes the Gateway Generating Station currently under construction as well as the MLGS site (Dames & Moore, 1949, 1962, 1973; URS, 2001), indicates that:

- Most of the sandy deposits below the water table are moderately dense to dense, with appreciable fines content (silts and clays); thus, their susceptibility to liquefaction would be considered low to moderate;
- Layers (typically 3 to 8 feet thick) of looser, cleaner materials with relatively low blow counts, indicating a higher liquefaction potential, are observed locally, at varying depths;
- The units showing a high liquefaction potential seem to be isolated, not laterally continuous.

Of the total number of geotechnical borings drilled at the CCPP site, about 10 are considered relevant to the MLGS site (Dames & Moore, 1949, 1973); however, none are located at or in the immediate vicinity of proposed major plant or project structures. Nevertheless, the existing subsurface data are suitable for assessing general geologic/geotechnical conditions for purposes of the AFC.

Mass Wasting and Slope Stability

The MLGS site is on a flat alluvial plain, approximately 2.5 miles north of the Mount Diablo range-front. The lack of significant slopes on or near the site indicates that the hazard from slope instability, both landslides and debris flows, is negligible.

The site is immediately adjacent to the San Joaquin River, and therefore, erosion may pose a hazard to the plant area. However, stream bank protection appears to control or mitigate this hazard. Drainage on and around the site is controlled by a series of flood control drains; therefore, the hazard of erosion from surface runoff is also considered to be negligible.

Subsidence

Subsidence of the land surface can be attributed to natural phenomena, such as tectonic deformation, consolidation, hydrocompaction, collapse of underground cavities, oxidation of organic-rich soils, or rapid sedimentation, and also by the activities of man, such as the withdrawal of groundwater or hydrocarbons. Most of the physical conditions responsible for areal land subsidence are not known to exist at the MLGS site. Subsidence caused by groundwater withdrawals is not expected to be a significant problem at the MLGS site; however, future changes in groundwater pumping or development of hydrocarbon reserves in the Sacramento Delta could theoretically impact the site.

Expansive Soils

Most of the CCPP site and all of the MLGS site is underlain by soil identified as Delhi sand (on 2 to 9 percent slopes), characterized by rapid permeability. The Delhi sand has low shrink-swell potential (Welch, 1977).

Tsunami and Seiche

Tsunami (commonly, but mistakenly, called tidal waves) are sea waves caused by submarine fault movements or landslides. The MLGS site is not known to have experienced tsunamis in the historic past, and the U.S. Geological Survey estimates, based on records from 1960 and 1964 events, that attenuation results in a reduction of the wave height measured at the Golden Gate by 90 percent by the time it reached the vicinity of the Carquinez Strait (Ritter and Dupre, 1972).

Recent studies (Borrero, Dengler, Uslu and Synolakis, 2006) suggest that the maximum tsunami anticipated for San Francisco Bay would be generated by a M 9.2 earthquake in the Aleutian Islands, a return period of approximately 500 years. This event would result in a calculated wave of 5.4 m (17.7 feet) at the Golden Gate, diminishing to 0.54 m (1.8 feet) at the Carquinez Strait. For example the 1964 Alaskan earthquake generated a wave 2.6 m (8.5 feet) high at the Golden Gate, decreasing to 0.37 m (1.2 feet) at the Carquinez Strait. Because the MLGS is over 25 miles upriver from the Carquinez Strait the maximum anticipated wave would be several inches high, thus, tsunami is not considered a hazard to the MLGS site.

Seiches result from the "sloshing" action of confined bodies of water during seismic events. Because no such bodies of water are present at the MLGS site, seiche is not considered to be a hazard.

7.15.1.5 Geologic Resources

The following geologic resources are found in the vicinity of the MLGS site.

Sand and Gravel Aggregate Resources

In 1987, the CDMG published a comprehensive mineral land classification for aggregate materials in the San Francisco-Monterey Bay Area (Stinson et al., 1987). Lands were 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 a high likelihood for their presence exists.

MRZ-3: Areas containing mineral deposits, the significance of which cannot be evaluated from available data.

According to these definitions, approximately the northernmost third of the MLGS is classified as MRZ-1 and the remainder MRZ-3, based on 6 drill holes located to the south of the property. A map of mineral resource zones is shown on Figure 7.15-3. A zone immediately adjacent to the proposed MLGS site on the west, along the north bank of the San Joaquin River, about 800 feet wide and 2 miles long, has been classified MRZ-2, for sand and gravel resources. In addition, sandstones of the Wolfskill Formation located in the hills about 2 miles south of the MLGS site have been identified as a source of non-Portland Cement Concrete aggregate.

Oil and Gas Resources

The Sacramento River delta region contains a large number of small and medium-sized gas fields formed within Tertiary units by structural traps, typically faulted anticlines and domes. Several exploratory wells are located within several miles of the site. The closest proven hydrocarbon resources to the MLGS site are beneath Honker Bay, approximately 9 miles to the north-northwest, and the larger Rio Vista gas field about 9 miles to the northeast (Bowen, 1962). There are no known hydrocarbon resources in the MLGS site.

Mineral Resources

The Black Diamond Mines of the Mount Diablo Coalfield, the largest known and most extensively mined coal deposit in California (Sullivan and Waters, 1980), are located several miles to the south of the proposed MLGS site. These subbituminous deposits were worked for almost 50 years, from the 1860s to the early part of the 1900s. The coal seams are located within the upper Domengine Formation and at the top of the Lower Domengine (Sullivan et al., 1995). The coal seams are of relatively poor quality, consisting predominantly of lignite, with some subbituminous coal interbedded with fine-grained units. The estimated reserves remaining at Black Diamond are approximately 8 million tons. The poor quality of the remaining coal, however, precludes these reserves from being exploited as economic reserves in the near future.

7.15.2 Environmental Consequences

Significance criteria have been selected based on California Environmental Quality Act (CEQA) Guidelines (Appendix G, Environmental Checklist Form) as well as performance standards adopted by responsible agencies. An impact may be considered significant from a geologic standpoint if the project results in:

- Severe damage or destruction of any project component, release of a toxic or other hazardous substance into the environment, or exposure of people or property to substantial adverse effects as the direct consequence of a geologic event; for example:
  - earthquake fault rupture
  - strong ground shaking during a seismic event
  - seismically induced ground failure such as liquefaction and/ or lateral spreading
  - subsidence
  - expansive soils
  - mass wasting, landslides, rockfalls, or other slope failures
  - inundation by seiche or tsunami
- Loss of availability of a known mineral source classified MRZ-2 by the State Geologist or a locally important mineral resource site

7.15.2.1 Proposed Project

Geologic Hazards

Seismically induced ground shaking presents a significant hazard to the MLGS site. The potential for liquefaction during future seismic events is also considered to be locally high at the plant site. The native soils beneath the plant area do not have a potential for undergoing shrink-swell behavior. With incorporation of the project design features discussed in Section 7.15.4, the hazards will be reduced to an acceptable level. No other geologic hazards with the potential to significantly affect the power plant or other project elements were identified.

Geologic Conditions and Topography

Potential impacts of the project on the geologic environment can be divided into those involving construction activities and those related to plant operation. Construction-related impacts to the geologic environment primarily involve terrain modifications including cuts, fills, and dust generation. Most of the MLGS site is occupied by five fuel oil storage tanks. Prior to their construction, historical topographic mapping (Dames & Moore, 1949) indicates that the northern portion of the property (Tanks 1 and 2) featured sand dunes ranging from elevation +15 feet to +40 feet (mean lower low water datum) while the southern portion was at about elevation +5 feet (Tank 4) to +10 feet (Tank 5). Significant grading was accomplished resulting in the present configuration with the bottom of each tank “cell” at approximately elevation 8 to 10 feet (mean sea level datum) and perimeter dikes reaching about elevation 20 to 23 feet. Thus, in order to achieve the final nominal plant grade of +9 to +15 feet, cuts on the order of up to 13 feet and fills on the order of up to 6 feet will be required. Site grading is not expected to result in significant adverse impacts to the geologic environment. No significant adverse impacts on the geologic environment are expected from the operation of the MLGS.

7.15.2.2 Geologic Resources

Natural resources occurring within the vicinity of the MLGS site include sand, gravel, natural gas, and coal (lignite and subbituminous coal). All of these resources have been exploited to some extent in the site vicinity, but with the exception of natural gas, no active development operations are occurring at this time. No significant impacts on geologic resources would occur as a result of project implementation.

7.15.3 Cumulative Impacts

No cumulative impacts are anticipated to the geologic environment as a result of MLGS activities.

7.15.4 Mitigation Measures

The following sections describe mitigation measures that might be employed to reduce potential significant geologic hazards to acceptable levels.

GEO-1 Seismic Design Requirements

The power plant may be subjected to strong earthquake motions in the future. Thus, plant components will be designed and constructed to the seismic design requirements for ground shaking specified in the International Building Code (2006) for Seismic Design Category D.

GEO-2 Geotechnical Investigation

The hazard from seismically induced liquefaction at the plant area is considered to be locally high. The nature of the alluvial and fluvial deposits on which the plant will be sited and the presence of potentially liquefiable materials indicates that liquefaction and lateral spreading could occur. Because of the location of new structures with respect to the existing geotechnical database, a site-specific program of exploratory borings and accompanying laboratory testing will be required to delineate potentially liquefiable materials underneath the construction area. These geotechnical investigations will also be required for consideration prior to foundation design and development of site-specific design criteria. These are normal design and construction techniques.

GEO-3 Engineering Geologist

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. 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 Chief Building Officer for the grading permit.

2. Monitor geologic conditions during construction.

3. Prepare the Final Engineering Geology Report.

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 an appropriate California license.

7.15.5 Laws, Ordinances, Regulations, and Standards

The project will be constructed and operated in accordance with all LORS applicable to geologic hazards and resources. LORS relevant to this project are discussed in the following sections and shown on Table 7.15-2.

7.15.5.1 Federal

Acceptable design criteria for excavations and structures for static and dynamic loading conditions are specified by the International Building Code (IBC, 2006).

7.15.5.2 State

Given the nature of the project, the California Building Code (CBC, 2007) would be superceded by the IBC as discussed above.

7.15.5.3 Local

Depending on the status of annexation, grading and building would be regulated by either Contra Costa County or the City of Antioch.

7.15.6 Involved Agencies and Agency Contacts

Involved agencies and agency contacts are listed in Table 7.15-3.

7.15.7 Permits Required and Permit Schedule

Required permits are listed in Table 7.15-4.

7.15.8 References

Atwater, B. F., 1982. Maps of the Sacramento-San Joaquin Delta, California. USGS Miscellaneous Field Studies Map MF-1401, Boulder, Colorado.

Borrero, J., Dengler, L., Uslu, B., and Synolakis, C., 2006, Numerical modeling of tsunami effects at Marine Oil Terminals in San Francisco Bay, Report prepared for: Marine Facilities Division of the California State Lands Commission, June 8.

Bowen, Oliver E., 1962. Geologic Guide to the Gas and Oil Fields of Northern California, California Division of Mines and Geology, Bulletin 181, Oliver E. Bowen Jr., Editor.

Bortugno, E. J., R. D. McJunkin, and D. L. Wagner, 1991. Map showing recency of faulting, San Francisco-San Jose Quadrangle, California. California Division of Mines and Geology. Geologic Map of the San Francisco-San Jose Quadrangle, 1:250,000.

Bryant, W. A., 1982. West Napa fault zone and Soda Creek (East Napa) fault. California Division of Mines and Geology. Fault Evaluation Report FER-129. 10 p.

CBC (California Building Code), 2007. International Code Council.

City of Pittsburg, 2001. Health & Safety Element to the General Plan adopted November 2001, as amended by City Council Resolution No. 07-10779, May 21, 2007.

Dames & Moore, 1973. Report of Foundation Investigation, Proposed Fuel Oil Storage Tanks 6, 7, and 8. Contra Costa Power Plant, Antioch, California, for the Pacific Gas and Electric Company, Part I: Soils Investigation and Geotechnical Studies, May 30.

Dames & Moore, 1962. Foundation Investigation, Contra Costa Power Plant Units 6 and 7, Antioch, California, for the Pacific Gas and Electric Company, February 26.

Dames & Moore, 1949. Report of Foundation Investigation, Proposed Contra Costa Steam Plant, Antioch, California, for the Pacific Gas and Electric Company, July 25.

Ellsworth, W. L., 1990. Earthquake History, 1769-1989. In R. E. Wallace, ed., *The San Andreas Fault System, California.* U.S. Geological Survey Professional Paper 1515. 1990. p. 153-181.

Graymer, R. W., D. L. Jones, and E. E. Brabb, 1994. Preliminary Geologic Map Emphasizing Bedrock Formations in Contra Costa County, California: A Digital Database. U.S. Geological Survey, Open Report 94-622.

IBC (International Building Code), 2006. International Code Council.

Helley, E. J. and R. W. Graymer, 1997. Quaternary geology of Contra Costa County, and surrounding parts of Alameda, Marin, Sonoma, Solano, Sacramento, and San Joaquin Counties, California: A digital database. U.S. Geological Survey, Open-File Report 97-98.

Jennings, C. W., 1994. Fault activity map of California and adjacent areas. California Division of Mines and Geology. California Geologic Data Map Series, Map No. 6. 1:750,000 scale.

Kelson, K., 1999. In Review. *Geologic characterizations of the Calaveras Fault as a potential seismic source*. Submitted to AEG Volume, Engineering geology in Northern California.

Lienkaemper, J. J., G. Borchardt and M. Lisowski, 1991. Historic creep rate and potential for seismic slip along the Hayward fault, California. *Journal of Geophysical Research.* 96B:18261-18283.

Petersen, Mark D., Frankel, Arthur D., Harmsen, Stephen C., Mueller, Charles S., Haller, Kathleen M., Wheeler, Russell L., Wesson, Robert L., Zeng, Yuehua, Boyd, Oliver S., Perkins, David M., Luco, Nicolas, Field, Edward H., Wills, Chris J., and Rukstales, Kenneth S., 2008. Documentation for the 2008 Update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008-1128, 61 pp.

Ritter, J. R. and W. R. Dupre, 1972. Map showing Areas of Potential Inundation by Tsunamis in the San Francisco Bay Region. U.S. Geological Survey. Miscellaneous Field Studies Map MF-480.

Schwartz, D. P., D. Pantosti, S. Hecker, K. Okomura, K. E. Budding and T. Powers, 1992. Late Holocene behavior and seismogenic potential of the Rodgers Creek fault zone. Sonoma County, California, in Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area. Borchardt, G., Hirschfeld, S. E., Lienkaemper, J. J., McClellan, P., Williams, P. L. and Wong, I. G. (eds.). California Department of Conservation, Division of Mines and Geology. p. 393-398.

Simpson, G. D., W. R. Lettis and K. I. Kelson, 1992. Segmentation model for the northern Calaveras fault, Calaveras Reservoir to Walnut Creek, in Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area. Borchardt, G., Hirschfeld, S. E., Lienkaemper, J. J., McClellan, P., Williams, P. L. and Wong, I. G. (eds.). California Department of Conservation, Division of Mines and Geology. p. 253-259.

Sowers, J. M., J. S. Noller and J. R. Unruh, 1992. Quaternary deformation and blind-thrust faulting on the east flank of the Diablo Range near Tracy, California. In Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area. Borchardt, G., Hirschfeld, S. E., Lienkaemper, J. J., McClellan, P., Williams, P. L. and Wong, I. G. (eds.). California Department of Conservation, Division of Mines and Geology. p. 377-383.

Stinson, M. C., M. W. Manson and J. J. Plappert, 1987. Mineral land classification: Aggregate materials in the San Francisco-Monterey Bay area Part II Classification of aggregate resource areas South San Francisco Bay Production-Consumption Region. California Division of Mines and Geology. Special Report 146, Part 11. 74 p.

Sullivan, R. and J. Waters, 1980. Mount Diablo coalfield, Contra Costa County, California. *California Geology.* 33:51-59.

Sullivan, R., J. Waters and M.D. Sullivan, 1995. Geology and sequence stratigraphy of the Black Diamond Mines Regional Preserve. *Northern California Geological Society, Guidebook.*

TERRASEARCH, Inc., 2005. Fault Rupture Hazard Investigation, Mariner Walk Site, Herb White Way and 8th Avenue, Pittsburg, California, for The Olson Company, April 5.

Toppozada, T. R., J. H. Bennett, C. L. Hallstrom, and L. G. Youngs, 1992. 1898 "Mare Island" earthquake at the southern end of the Rodgers Creek fault., in G. Borchardt and others (eds.). Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area. California Department of Conservation, Division of Mines and Geology Special Publication 113. p. 385-392.

Toppozada, T. R., C. R. Real and D. L. Parke, 1981. Preparation of isoseismial maps and summaries of reported effects of the pre-1900 California earthquakes. California Division of Mines and Geology. Open-File Report 81-11, 181 p.

Unruh, J. R., S. T. Hector, P. L. Williams and, J. W. Rector, 1997. Transpressional tectonics of the western Sacramento-San Joaquin delta, eastern San Francisco Bay region, California. EOS, Transactions of the American Geophysical Union. v. 78. p. F63 1.

Unruh, J. R. and E. M. Moores, 1992. Quaternary blind thrusting in the southwestern Sacramento Valley, California. Tectonics. 11: 192-2033.

Unruh, J. R. and T. L. Sawyer, 1997. Assessment of blind seismogenic sources, Livermore Valley, eastern San Francisco Bay region. William Lettis and Associates, Final Report for U.S. Geological Survey National Earthquake Hazards Reduction Program Award Number 1434-95-G-2611. 95 p.

Unruh, J. R. and T. L. Sawyer, 1995. Late Cenozoic growth of the Mt. Diablo fold-and-thrust belt, central Contra Costa County, California, and implications for transpressional deformation of the northern Diablo Range. American Association of Petroleum Geologists Bulletin. 79:600.

URS (URS Corporation), 2001, Soils Engineering and Engineering Geology Report, Contra Costa Power Plant, Unit 8 Project, Contra Costa County, California, for Mirant Corporation, June 29.

Wakabayashi, J. and D. L. Smith, 1994. Evaluation of recurrence intervals, characteristic earthquakes and slip-rates associated with thrusting along the Coast Range-Central Valley geomorphic boundary. Bulletin of the Seismological Society of America. 84:19604 970.

Wallace, R. E., 1990. The San Andreas Fault System, California. U.S. Geological Survey Professional Paper 1515. 283 p.

Welch, L. E., 1977. Soil Survey of Contra Costa County, California. U.S. Department of Agriculture, Soil Conservation Service. 125 pp.

Wells, D. L. and Coppersmith, K. J., 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin of the Seismological Society of America. v. 84. p. 974-1002.

WGCEP (Working Group on California Earthquake Probabilities), 2003. Earthquake Probabilities in the San Francisco Bay Region: 2002 to 2031, U.S. Geological Survey Open File Report 03-214.

WGCEP (Working Group on California Earthquake Probabilities), 1999. Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030 – A Summary of Findings, U.S. Geological Survey, Open File Report 99-517.

WGCEP (Working Group on California Earthquake Probabilities), 1990. Probabilities of large earthquakes in the San Francisco Bay region, California. U.S. Geological Survey, Circular 1053. 51 p.

WGNCEP (Working Group on Northern California Earthquake Potential), 1996. Database of potential sources for earthquakes larger than magnitude 6 in northern California. U.S. Geological Survey. Open-File Report 96-705. 53 p.

Wills, C. J., 1992. The elusive Antioch fault, in Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area. Borchardt, G., Hirschfeld, S. E., Lienkaemper, J. J., McClellan, P., Williams, P. L. and Wong, I. G. (eds.). California Department of Conservation, Division of Mines and Geology. p. 325-331.

Wong, I. G., Ely, R. W. and Kollmann, A. C., 1988. Contemporary seismicity and tectonics of the Northern and Central Coast Ranges-Sierran Block Boundary zone, California. *Journal of Geophysical Research.* 93:7,813-7,833.

❖❖❖

Table 7.15-1
Major Faults in Proposed MLGS Site Vicinity

Fault Name	Fault Segment Length (miles)	Horizontal Distance to MLGS Site (miles)	Maximum Magnitude M_W
San Andreas	280	46	7.9
Hayward	26	28	6.9
Concord-Green Valley	33.6	17.5	6.9
Calaveras	38	19	7.0
Greenville-Clayton	45	9.5	6.9
Rodgers Creek	42	35	7.0
West Napa	19	28	6.5
Coast Range-Sierra Block Boundary Zone	21	5	6.75
Pittsburg-Kirby Hills	26	5	6.75
Mount Diablo Thrust	~15	9.5	6.25

Sources: WGNCEP (1996), WGCEP (1999), Wells and Coppersmith (1994)

Table 7.15-2
Applicable Geological Hazards Laws, Ordinances, Regulations, and Standards

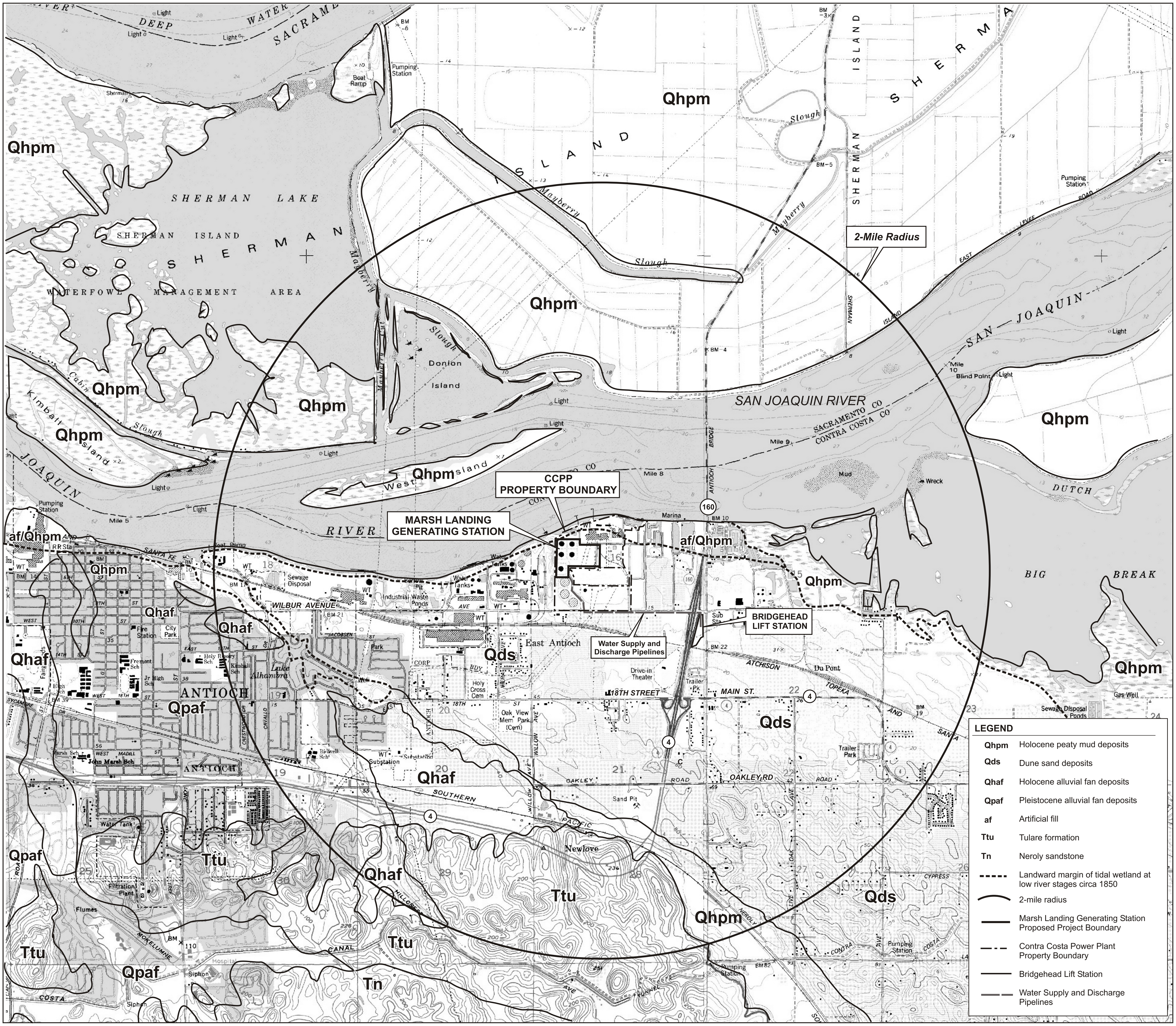
Laws, Ordinances, Regulations, and Standards	Applicability	Administering Agency	AFC Section
Federal			
International Building Code (IBC), 2006	Design criteria for excavations and structures under static and dynamic loading conditions	Contra Costa County and/or City of Antioch	7.15.5.1
State			
California Building Code, 2007	Superseded by IBC	N/A	7.15.5.2
Local			
Contra Costa County General Plan Safety Element (2005)	Outlines policies and goals related to seismic ground failure and landslide hazards	Contra Costa County	7.15.5.3
City of Antioch General Plan (2003) Environmental Hazards Chapter	Outlines City objectives and policies related to Geology and Seismicity	City of Antioch	7.15.5.3

Table 7.15-3
Involved Agencies and Agency Contacts

Issue	Agency/Address	Telephone
Geologic Resources	California Geological Survey Headquarters/Office of the State Geologist 801 K Street, MS 12-30 Sacramento, CA 95814 cgshq@consrv.ca.gov	(916) 445-1825 (916) 445-5718 fax

Table 7.15-4
Permits Required

Responsible Agency	Permit/Approval	Schedule
Contra Costa County or City of Antioch	Grading and Construction Permit	To be obtained before construction begins.



Sources:

USGS Quaternary Geology of Contra Costa County, California, and Surrounding Areas
E.J.Heller and R.W. Graymer, 1997

Preliminary Geologic Map Emphasizing Bedrock Formations in Contra Costa County, California,
R.W. Graymer, D.L. Jones, and E.E. Brabb, 1994

Preliminary Geologic Map of the Antioch South Quadrangle, Contra Costa County,
Thomas W. Dibblee, Jr., 1980

USGS Topographic Maps, 7.5 Minute Series:
Antioch North, California, 1978, Antioch South, California, 1980, Jersey Island, California, 1978,
Brentwood, California, 1978 quadrangles

N

0 .5 1
Scale in Miles

0 2000 4000
Scale in Feet
1:24,000

REGIONAL GEOLOGIC MAP

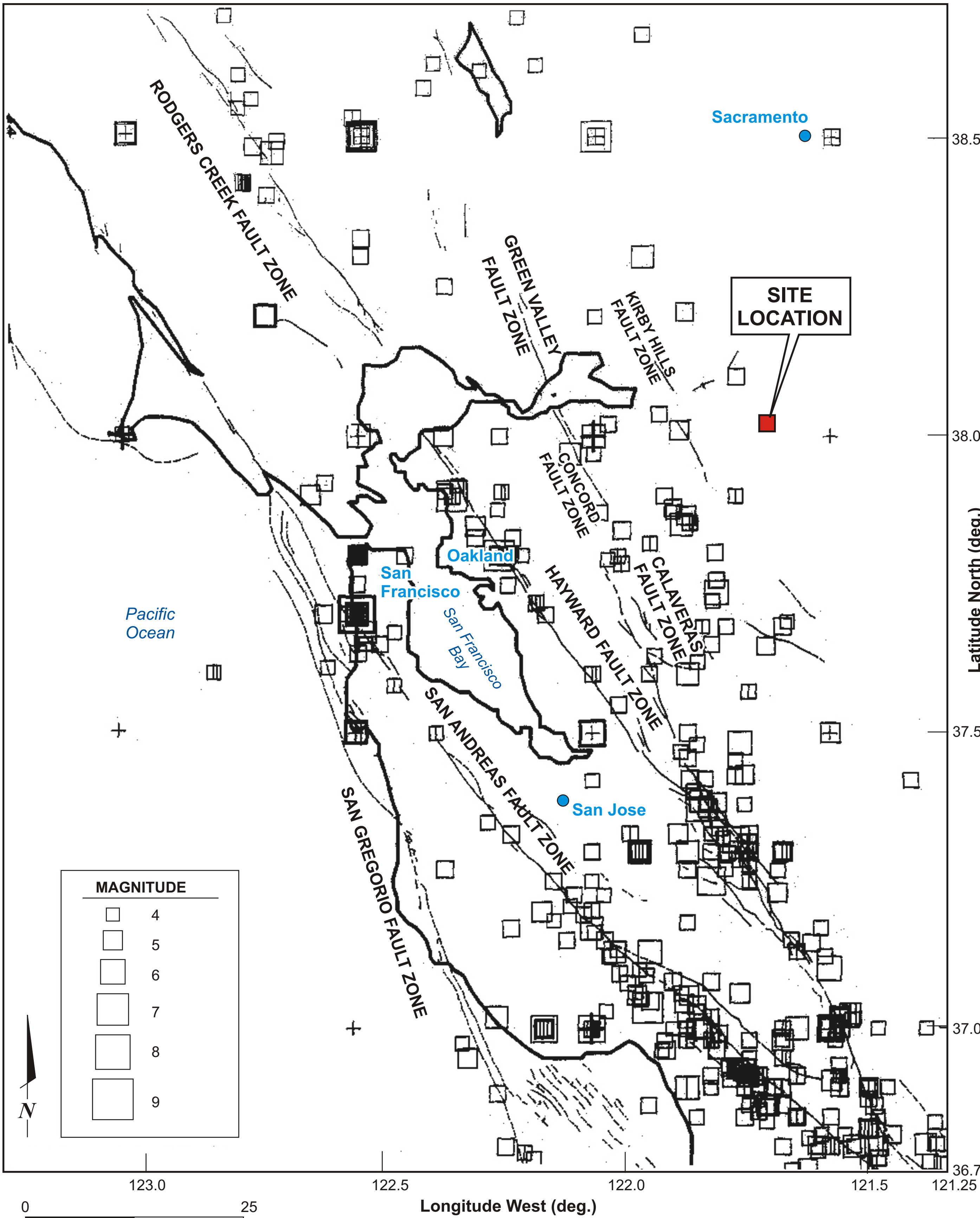
May 2008
28067344

Marsh Landing Generating Station
Mirant Marsh Landing, LLC
Contra Costa County, California

URS

FIGURE 7.15-1

5/23/08 vsa ..T:\Mirant Contra Costa-Marsh Landing\Graphics\7.15 Geology\7.15-1_reggeo.cdr



Source:
National Geophysical Data Center,
(NGDC), Boulder, CO

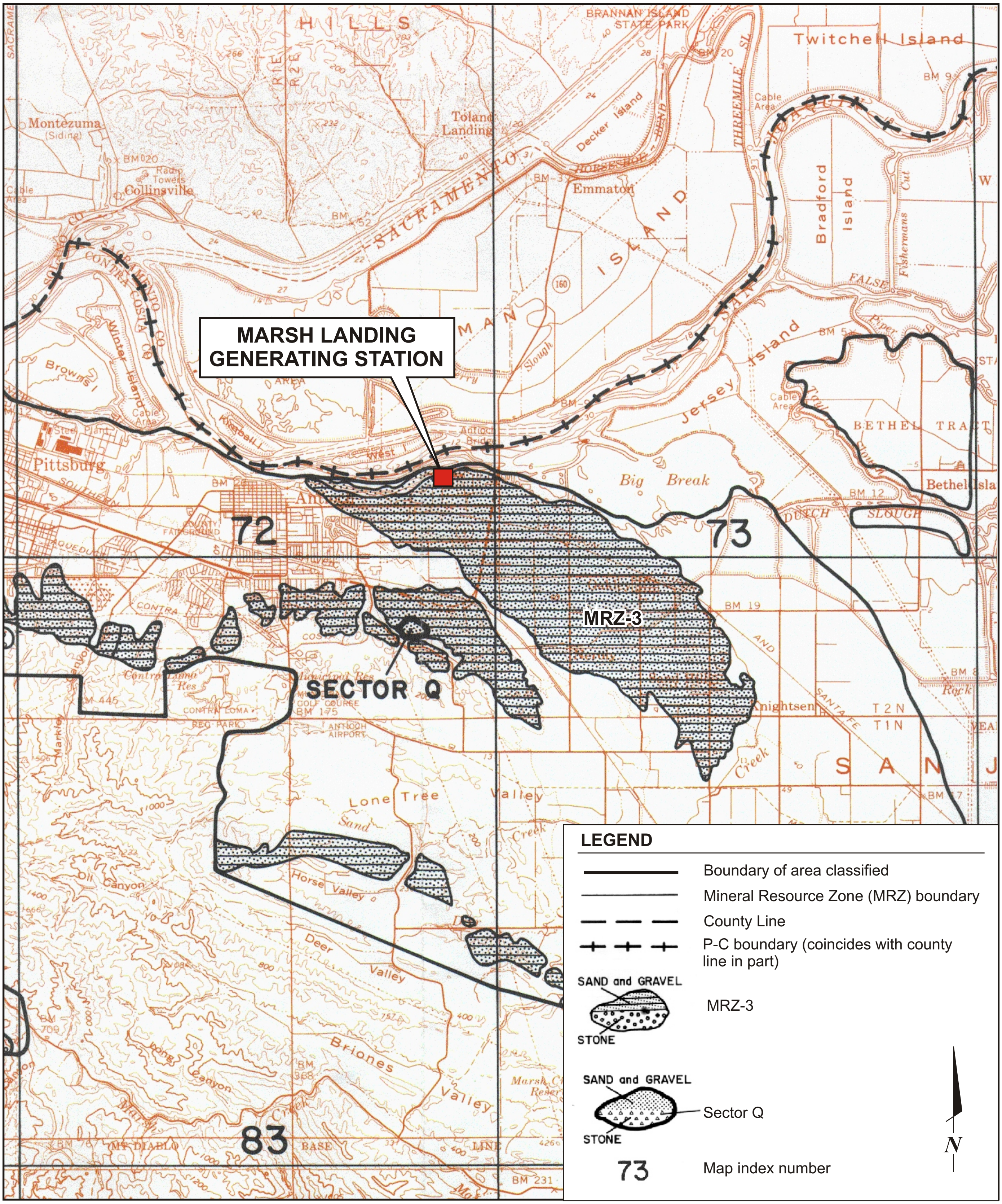
REGIONAL SEISMICITY DATA

Marsh Landing Generating Station
Mirant Marsh Landing, LLC
Contra Costa County, California

May 2008
28067344

URS

FIGURE 7.15-2



Source: USGS
M.C. Stinson, M.W. Manson, and J.J. Plappert 1980

0 1 2
Scale in Miles

Map Number	*Quadrangle*
72	Antioch North
73	Jersey Island
83	Antioch South
84	Brentwoood

MINERAL RESOURCE ZONES AND RESOURCE SECTORS

May 2008
28067344

Marsh Landing Generating Station
Mirant Marsh Landing, LLC
Contra Costa County, California

URS

FIGURE 7.15-3

4/30/08 vsa ..T:\Mirant Contra Costa-Marsh Landing\Graphics\7.15 Geology\7.15-3_mineral zones.cdr