3.5 Geology, Soils and Seismicity

3.5.1 Physical Setting

Methodology

Geologic, seismic and soil characteristics for the South Bay and the SBSP Restoration Project Area were evaluated using existing published data. Sources of data included the following:

- General distribution of geologic materials in the San Francisco Bay Region (Wentworth 1997);
- Fault Activity Map of California (Jennings 1994);
- Liquefaction Susceptibility (Knudsen and others 2006);
- Late Quaternary Depositional History, Holocene Sea Level Changes, and Vertical Crustal Movement, Southern San Francisco Bay, California (Atwater and others 1977);
- Flatland Deposits – Their Geology and Engineering Properties and Their Importance to Comprehensive Planning (Helley and others 1979);
- Soil and Geologic Data Collection, Bay Lands Flood Control Planning Study (Woodward-Lundgren & Associates 1971);
- Soil Surveys from the Soil Conservation Service / US Department of Agriculture (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1958; US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1980; US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1991); and
- Previously published consultant reports including Geological and Geotechnical Hazard Assessment for the Santa Clara Valley Water District Reliability Project (Geomatrix 2004) and the South Bay Salt Ponds Restoration Project Environmental Setting Report (Brown and Caldwell 2005).

Regional Setting

The regional setting is relevant to the SBSP Restoration Project Area.

Geology

The San Francisco Bay Region is located along the boundary between the Pacific and North American plates, two large crustal plates that are separated by the north-northwest trending San Andreas Fault, within the California Coast Ranges Geomorphic Province. A map showing an overview of geology in the Bay Area from the US Geological Survey is shown in Figure 3.5-1 (Wentworth 1997). The geomorphology of the region includes parts of three prominent, northwest-trending geologic/geomorphic features, which include from west to east the Santa Cruz Mountains, Santa Clara Valley, and the Diablo Range. Santa Clara Valley forms part of an elongated structural block (the San Francisco Bay block) within the central Coast Ranges that contains San Francisco Bay and its surrounding alluvial margins

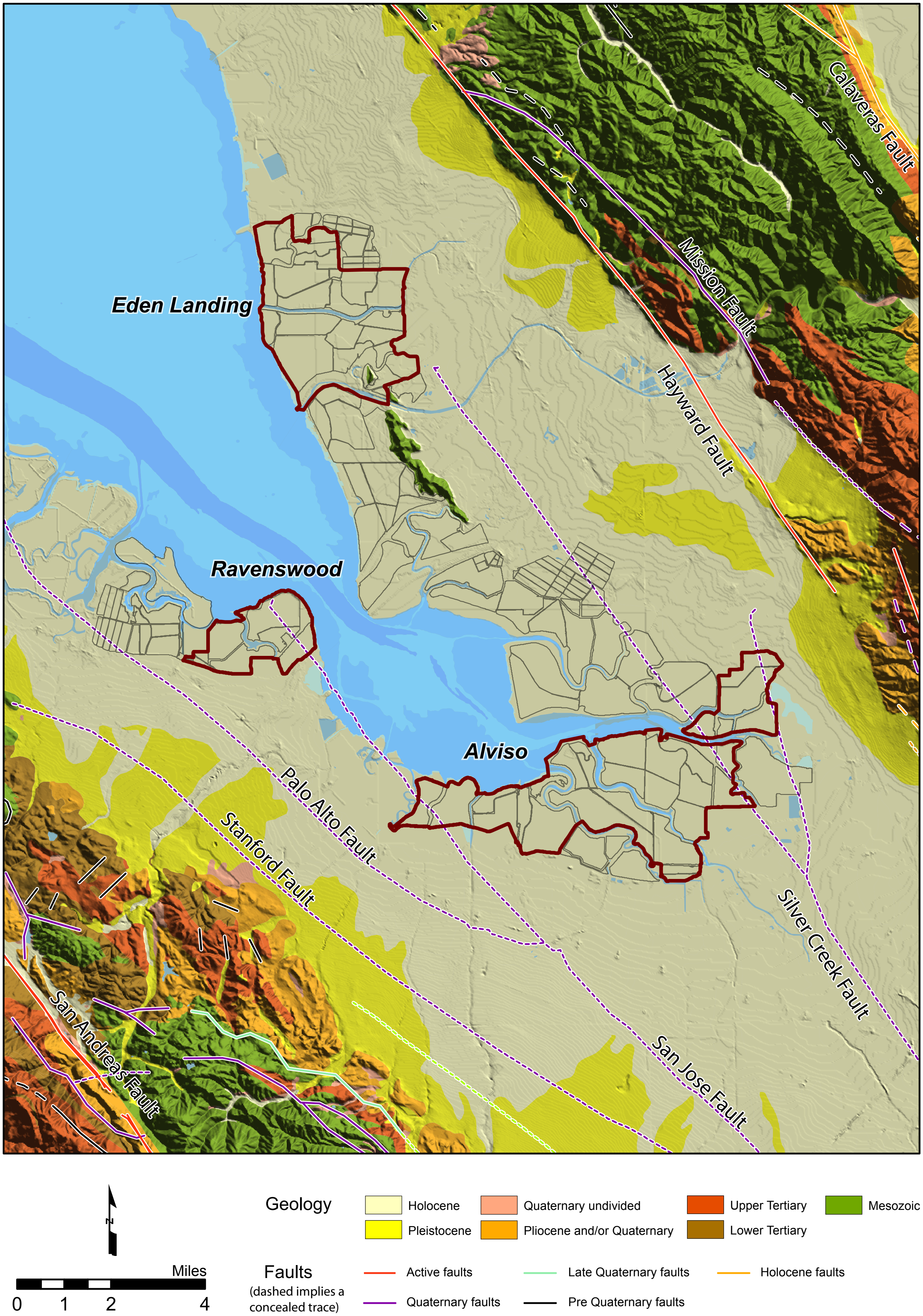

Figure 3.5.1 - Geology and mapped faults within the SBSP Restoration Project area

(Page 1989). This structural block is bounded by the San Andreas Fault to the southwest and the Hayward-Calaveras Fault zone to the northeast.

The oldest rocks in the region belong to the Franciscan Complex of Jurassic to Cretaceous age (205 to 65 million years before present [Ma]). These rocks are intensely deformed (*i.e.*, folded, faulted, and fractured) due to ancient tectonic processes and, to a lesser extent, from more recent tectonic processes associated with the San Andreas Fault system. Franciscan rocks generally comprise the "basement" of the Coast Ranges northeast of the San Andreas Fault; Cretaceous granitic rocks, known as the Salinian block, comprise the basement of the ranges located southwest of the San Andreas Fault. A sequence of Tertiary (65 to 1.8 Ma) marine and nonmarine sedimentary rocks unconformably overlies the granitic and Franciscan basement rocks in the region. This unconformity represents an erosional surface, creating a gap in the depositional sequence separating the younger Tertiary rocks from the old Jurassic to Cretaceous rocks. In places the contact between the sediments and the older basement rocks is locally faulted.

Quaternary (1.6 Ma to present) surficial deposits are concentrated in the Santa Clara Valley and locally overlie the complexly deformed Cretaceous rocks and Tertiary strata in the adjacent hills. During the Plio-Pleistocene (5 Ma to 11,000 years ago [ka]) epochs, sediments eroded from the uplifting Diablo Range and the Santa Cruz Mountains formed broad alluvial fan complexes along the margins of Santa Clara Valley. The 5 Ma to 300,000 year old (Plio-Pleistocene) Santa Clara Formation, which consists of a sequence of fluvial and lacustrine sediments, was deposited unconformably on the older Tertiary and Franciscan rocks along the margins of Santa Clara Valley during this time and has subsequently folded, faulted, and eroded. Although the deposition of the Santa Clara Formation spans a relatively long interval and the stratigraphy of the formation is complex, it has been used as a "marker horizon" for evaluating the relative age of faulting in the Santa Clara Valley region. The Santa Clara Formation is unconformably overlain by younger Quaternary and Holocene (11 ka to present) alluvial and fluvial deposits (stream channel, overbank, and flood basin environments), which interfinger to the north with estuarine muds of San Francisco Bay (Helley and others 1979).

South San Francisco Bay is a north-northwest trending subsiding basin that is filled primarily with Quaternary alluvium (stream) deposits eroded from the surrounding margins and estuarine (Bay mud). The Sangamon and Holocene Bay muds are separated by the Quaternary alluvium and eolian (wind blown) sand deposits. Alluvium deposits consist of sediments eroded from the surrounding Santa Cruz Mountains and Diablo Range uplands. These alluvial sediments were transported and deposited by streams and include a mixture of sands, gravels, silts, and clays with highly variable permeability. In contrast, the fine-grained Bay muds have very low permeability. The youngest Holocene Bay muds underlie almost all of the original Bay, including the SBSP Restoration Project Area (Atwater and others 1977; Helley and others 1979). Figure 3.5-2 is a contour map of Bay mud thickness in the study area.

Due to movement on the San Andreas and related faults including the Hayward and Calaveras Faults, as well as the previous geologic history, a wide variety of igneous, metamorphic, and sedimentary rocks are present. The north-northwest-trending faults and sediment-filled Southern San Francisco Bay and Santa Clara Valley basin are clearly visible.

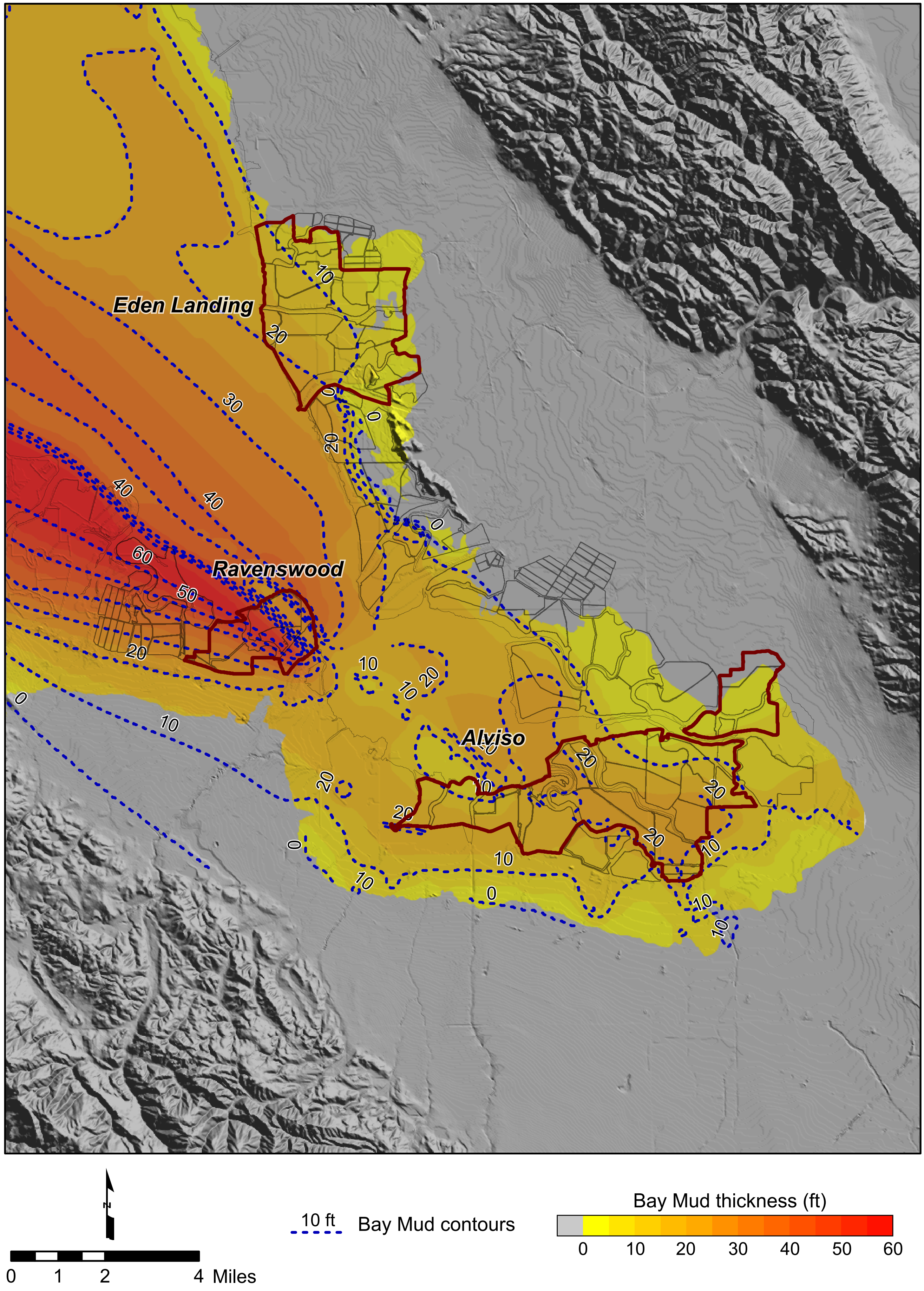

Figure 3.5.2 - Bay Mud thickness within the SBSP Restoration Project area

Geologic units are classified according to geologic time periods. The most recent time period is the Quaternary Period which covers from 1.8 million years ago to present. The Quaternary Period is subdivided into the Pleistocene Epoch (1.8 million years ago to 11,000 years ago) and the Holocene Epoch (11,000 years ago to present). The Pleistocene includes a number of world-wide glacial periods of low sea level stands. Estuarine (bay) muds were deposited in San Francisco Bay during high sea level periods of the Sangamon (70,000 to 130,000 years ago) and the Holocene (less than 11,000 years ago) (Atwater and others 1977).

Minerals present at some locations in the watershed that may be of particular interest to the SBSP Restoration Project are cinnabar and chrysotile. Cinnabar is a mercury sulfide mineral (HgS) and mercury ore that occurs naturally in the Bay Area, and has historically been mined for the production of mercury. One of the primary mining areas was the New Almaden Mining District in the Santa Cruz Mountains southwest of San Jose, which was the largest producer of mercury in North America (Stoffer 2002). Mercury mining in this area occurred from the late 1820s to 1976, although the majority of the production occurred prior to 1900. The majority of the mercury produced was subsequently used to separate gold from ore during gold mining activities in the Sierra Nevada region (Stoffer 2002). This and other smaller mercury deposits are a potential source of natural and anthropogenic mercury in sediments. Chrysotile, a fibrous mineral commonly known as asbestos, is found within the metamorphic rock serpentinite frequently occurring with the Franciscan unit.

Soils

According to soil surveys published by the US Department of Agriculture Soil Conservation Service, soils along the Bay on the San Francisco peninsula generally consist of those typically found on bottom lands, and can vary from very poorly drained to well drained (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1991). Soils along the east side of the Bay, from the vicinity of the Eden Landing pond complex to just north of the Alviso pond complex, are primarily very poorly drained clays (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1980). Soils in the South Bay consist primarily of clays, clay loams, and loams (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1958), which are generally expected to be poorly drained.

Faults

The San Francisco Bay Region is located within a very broad zone of right-lateral transpression (strike-slip faulting and compression) marking a tectonic boundary zone dominated by strike-slip faulting associated with the San Andreas Fault system. The major active[1] components of the San Andreas Fault system that occur in the South San Francisco Bay Region include the proper or main trace of the San Andreas Hayward, and Calaveras, and Greenville Faults. Locations of the San Andreas, Hayward, and

[1] According to California Geological Survey definitions, *active* faults have a documented history of slip within the past 11,000 years of geologic time (the Holocene epoch), and *potentially active* faults have slipped within the past 1.8 million years (the Quaternary period).

Calaveras Faults are shown on Figure 3.5-1. The Greenville Fault is approximately 20.5 miles (33 km) northeast of the SBSP Restoration Project Area.

Seismicity

Tectonic disturbances create seismic waves which travel through the Earth generating ground shaking or earthquakes. The size of an earthquake can be described by its magnitude or intensity. Magnitude is a measure of the amount of energy released by an earthquake and commonly expressed as local Richter magnitude (M_L) or Moment Magnitude (M_W). The Richter magnitude scale, developed by Charles Richter in 1935, is a logarithmic measure of the amplitude of ground shaking recorded by a seismometer. Moment Magnitude (M_W) is the accepted estimate of magnitude for large earthquakes based on the total energy release of the event from the measured rupture area and slip.

Earthquake Intensity is a way of measuring or rating the effects of an earthquake at different sites on a scale. The Modified Mercalli Intensity Scale (Table 3.5-1) is commonly used in the United States to express the severity of earthquake effects. Intensity ratings are expressed as Roman numerals between I at the low end and XII at the high end. Because of different geologic conditions and the attenuation of seismic waves, intensities vary across a region for a given earthquake.

The San Francisco Bay region is considered to be one of the more seismically active regions in the world, based on its record of historic earthquakes and its position astride the San Andreas Fault system. The San Andreas Fault system consists of several major right-lateral strike-slip faults in the region that define the boundary zone between the Pacific and North American tectonic plates. Numerous damaging earthquakes have occurred along the San Andreas Fault, as well as other regional faults, in historical time. Some of the significant pre-instrumental earthquakes that have occurred in the region are briefly described below.

A large earthquake occurred in June 1838 on the Peninsula segment of the San Andreas Fault (Ellsworth 1990). Toppozada and Borchardt (1998), Hall and others (1999), and Bakun (1999) reevaluated the data for this earthquake and estimated (local) magnitudes (M_L) of 7.5, 7.0 to 7.4, and 6.8, respectively. Severe shaking of Modified Mercalli Intensity (MMI) VIII to IX (Table 3.5-1) occurred in the vicinity of San Jose during this event, with houses shaken down and damage to walls of adobe structures (Toppozada and Borchardt 1998).

An earthquake having an estimated M_L of 6.1 (Bakun 1999) occurred in the San Jose region on November 26, 1858. This earthquake resulted in cracking of almost every brick, adobe, or concrete building in San Jose (Townley and Allen 1939), corresponding to MMI VII to VIII (Toppozada and others 1981). The discrete fault source of this event has not been determined.

A strong earthquake occurred on October 8, 1865, and apparently was centered in the Santa Cruz Mountains south of San Jose 10 km north of Loma Prieta. This earthquake had an estimated M_L of 6.5 (Bakun 1999), and caused damage to buildings in San Francisco, Santa Clara, San Jose, and other areas (Townley and Allen 1939). The reported damage from the 1865 earthquake corresponds to MMI VII to IX in Santa Clara, New Almaden, and San Jose (Toppozada and others 1981).

Table 3.5-1 Modified Mercalli Intensity (MMI) Scale

MMI VALUE	DAMAGE DESCRIPTION	
I		Not felt. Marginal and long period effects of large earthquakes.
II		Felt by persons at rest, on upper floors, or favorably placed.
III		Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV		Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frame creak.
V	Pictures Move	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	Objects Fall	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture move or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or hear to rustle).
VII	Non – Structural Damage	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	Moderate Damage	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	Heavy Damage	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.
X	Extreme Damage	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI		Rails bent greatly. Underground pipelines completely out of service.
XII		Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

The 1868 Hayward earthquake occurred north of San Jose along the southern segment of the Hayward Fault and had an estimated M_L of 6.9 (WG99). Surface rupture apparently extended from Oakland southward to the Warm Springs area of Fremont. The event reportedly resulted in damage and/or the complete destruction of every building in Hayward, as well as damage to buildings as far south as Gilroy (Townley and Allen 1939). The reported damage in Santa Clara County corresponds to MMI VII to VIII.

During the M_W 7.8 1906 San Francisco earthquake, the San Andreas Fault ruptured from Shelter Cove near Cape Mendocino southward to near San Juan Bautista. Maximum lateral displacements of 15 to 20 ft occurred north of the Golden Gate at Olema in Marin County (Lawson 1908). Landslides, liquefaction, and ground settlement occurred throughout the San Francisco Bay Region and in the vicinity of the surface rupture as a result of this earthquake. Extensive damage occurred to many buildings in San Jose, corresponding to MMI VIII to IX (Toppozada and Parke 1982). Youd and Hoose (1978) also report that ground failures resulting from the 1906 earthquake were locally observed in the coarse gravelly bottom of Coyote Creek.

More recent earthquakes in the region include the 1957 Daly City earthquake on the San Andreas Fault (M_L 5.3); the Coyote Lake and Morgan Hill earthquakes of 1979 and 1984 on the Calaveras Fault (M_L 5.9 and 6.1, respectively); the 1980 Livermore earthquake on the Greenville Fault (M_L 5.8); and the 1989 M_L 7.1 Loma Prieta earthquake on the San Andreas Fault or a parallel subsidiary fault. Of these earthquakes, the strongest shaking and most damage resulted from the October 17, 1989, M_L 7.1 Loma Prieta earthquake. The 1989 earthquake ruptured on or southwest of the Santa Cruz Mountains segment of the San Andreas Fault and produced MMI VII effects in San Jose.

Subsidence

Local land elevations, particularly in the South Bay, have subsided from the original elevations prior to historical development, primarily due to the extraction of significant amounts of groundwater. Land subsidence due to the over-extraction of groundwater in the South Bay is well documented (Freeze and Cherry 1979) and is primarily due to agricultural pumping in the early part of the 1900s. Land adjacent to the Bay in Santa Clara Valley was reported to have subsided two to eight ft from 1912 to 1967 (Helley and others 1979). This inelastic consolidation of clays is not reversible. Subsidence was virtually halted by 1971 when groundwater pumping decreased with surface water importation from the San Francisco Regional Water System and State Water Project. Groundwater recharge efforts also helped to reduce subsidence. As a result, groundwater levels in the region have since recovered (Helley and others 1979). Due to current awareness and management of this problem, further land subsidence is not expected in the future.

Landsliding

Landsliding is a general term used to describe the gravity-driven downslope movement of weathered earth materials. Landsliding is frequently used to describe rapid forms of flow, slide, or fall, where a mass of rock or weathered debris moves downhill along discrete shear surfaces. Landslides are commonly complex features that may consist of both rotational and translational movements transforming to flows. Water generally plays an important role in landsliding by oversteepening slopes through surface erosion, by generating seepage pressures through groundwater flow, and by adding weight to a soil mass when it is saturated. Other factors that influence landsliding are: (1) strength of the rock/soil material; (2) degree/depth of weathering; (3) slope angle; (4) the orientation and density of rock structures, such as bedding, joint, and fault planes; and (5) grading activities. Inertial forces from earthquake ground shaking can also reduce the stability of a slope and cause sliding or falling of soil or rock.

Landslides include rock slides and mud flows that have the potential to cause serious damage to life and property. While landslides do occur in the region, the relatively gentle surface gradients in the vicinity of the SBSP Restoration Project Area suggest that landslide hazards are minimal.

Seismic Hazards

Seismic or earthquake hazards are generated by the release of underground stress along a fault line causing ground shaking, surface fault rupture, tsunami/seiche generation, liquefaction and earthquake induced landsliding.

Surface Fault Rupture

Earthquakes generally are caused by a shift or displacement along a discrete zone of weakness, termed a fault, in the Earth's crust. Surface fault rupture, which is a manifestation of the fault displacement at the ground surface, usually is associated with moderate- to large-magnitude earthquakes (magnitudes of about 6 or larger). Generally, primary surface fault rupture occurs on active faults having mappable traces or zones at the ground surface. In other words, major faults tend to rupture on pre-existing planes of weakness. The amount of surface fault displacement can be as much as 20 ft, depending on the earthquake magnitude and other factors. Large earthquakes also can "trigger" slip on adjacent faults, which may or may not be mapped at the surface, causing coseismic ground deformation (*e.g.,* Lawson 1908; Schmidt and others 1995).

Potential surface fault rupture hazards exist along the known active faults in the greater San Francisco Bay Region. The faults which have been identified as potential surface rupture hazards by the California Geologic Survey in close proximity to the SBSP Restoration Project Area include the San Andreas and Hayward Faults, which are approximately 7.5 miles (12km) and 1.5 miles (2.6km) from the Alviso pond complex, respectively (Figure 3.5-1). These faults show historic (last 200 years) displacement associated with mapped surface rupture or surface creep.

Other faults in the South Bay include concealed potentially active Quaternary faults with evidence of displacement sometime during the past 1.8 million years. The San Jose and Palo Alto Faults are mapped on the western boundary of the Bay and extend through the Alviso and Ravenswood pond complexes. The Silver Creek Fault, which is mapped on the eastern margin of the Bay, intersects the Alviso pond complex and truncates within a mile of the Eden Landing pond complex. (Jennings 1994) (Figure 3.5-1).

Ground Shaking

A potential earthquake hazard that exists throughout the San Francisco Bay Region is strong ground shaking. Ground shaking takes the form of complex vibratory motion in both the horizontal and vertical directions. The amplitude, duration, and frequency content of ground shaking experienced at a specific site in an individual earthquake are highly dependent on several factors, including: the magnitude of the earthquake, the fault rupture characteristics, the distance of the fault rupture from the site, and the types and distributions of soils beneath the site.

Large-magnitude earthquakes produce stronger ground shaking than small-magnitude events. Sites close to the zone of fault rupture typically experience stronger motion than similar sites located farther away. Site soils have the capability to amplify ground motion in certain frequency ranges and to dampen ground motion within other frequency ranges. Soft soils sites amplify ground motions in the long period range compared to stiff or firm soils sites. This would affect structures having long natural periods of vibration such as bridges and tall buildings.

Tsunami and Seiche

Tsunamis are long-period, low-amplitude ocean waves that pose an inundation hazard to many coastal areas around the world. Tsunami waves are generated when the floor of an ocean, sea, bay or large lake is rapidly displaced on a massive scale. The amplitude[2] of the waves in the open ocean generally is low, typically less than a meter (m), and the period[3] of the waves may be from five minutes to well over an hour, with corresponding wave lengths of tens to hundreds of kilometers. The tsunami waves change shape as the seafloor ramps up near coastlines and water depth becomes shallow, trapping wave energy and potentially causing the wave height to increase dramatically. Tsunami waves at coastlines can range in size from barely perceptible on tide gauge recordings to heights upwards of 30 meters. Some historical occurrences of mega-tsunamis have reported wave heights reaching over 100 meters. Upon reaching the coastline, the momentum of the tsunami waves may carry them inland for some distance, and they may run up on land to elevations greater than the wave height at the coast. Subduction zone mega-thrusting, sea-floor surface faulting, explosive volcanic eruptions, and subaerial and subaqueous landslide movement all have the potential to displace the seafloor and generate a tsunami.

A seiche is a wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours as a result of seismic or atmospheric disturbances. The geometry of the basin and frequency of oscillation have the potential to amplify the waves. Tsunami waves often create seiches when they enter embayments.

Within San Francisco Bay there is a potential for tsunami. The tsunamagenic source may be from a local event within the Bay or a distant event outside of the Bay where waves travel into the Bay through the Golden Gate. Local sources would be generated from local fault rupture or intense ground shaking. The potential for a large tsunami wave generated from a local source is considered to be low based on the absence of large thrust (reverse) fault mechanisms within the Bay’s tectonic setting. Distance sources are

[2] Wave amplitude refers to the height of the wave from the crest to the trough.

[3] The period of the waves refers to the length of time between one wave crest and the next at a given reference point.

offshore faulting from large thrust faults (reverse), for example the Cascadian or Aleutian subduction zone or from a sub-marine landslide at the break in the coast shelf. The 1964 Alaskan earthquake and subsequent tsunami registered a run-up height of approximately one m within San Francisco Bay.

The relatively closed geometry of San Francisco Bay makes it susceptible to a seiche.

Liquefaction and Related Ground Failure Phenomenon

Liquefaction is a soil behavior phenomenon in which a soil located below the groundwater surface loses a substantial amount of strength due to high excess pore-water pressure generated and accumulated during strong earthquake ground shaking. During earthquake ground shaking, induced cyclic shear creates a tendency in most soils to change volume by rearrangement of the soil-particle structure. The potential for excess pore-water pressure generation and strength loss associated with this volume change tendency is highly dependent on the density of the soil, with greater potential in looser soils. Youd and Perkins (1978) addressed the liquefaction susceptibility of various types of soil deposits, assigning a qualitative susceptibility rating based upon general depositional environment and geologic age of the deposit. Recently deposited, relatively normally consolidated soils, such as Holocene-age river channel, floodplain, and deltaic deposits and uncompacted or poorly compacted artificial fills located below the groundwater table, have high liquefaction susceptibility. Loose sands and silty sands are particularly susceptible. Silty and clayey soils tend to be less susceptible than sandy soils to liquefaction-type behaviors. Even within sandy soils, the presence of finer-grained materials affects susceptibility. Some sensitive clays have exhibited liquefaction-type strength losses (Updike and others 1988). Dense natural soils and well-compacted fills have low susceptibility to liquefaction.

Permanent ground displacements due to lateral spreads or flow slides and differential settlement are commonly considered significant potential hazards associated with liquefaction. These displacement hazards are direct products of the soil behavior phenomena (*i.e.*, high pore water pressure and significant strength reduction) produced by the liquefaction process. Lateral spreads are ground failure phenomena that occur near abrupt topographic features (*i.e.*, free-faces such as creek banks) and on gently sloping ground underlain by liquefied soil. Lateral spreading movements may be on the order of inches to several ft or more and are typically accompanied by surface fissures and slumping. Flow slides generally occur in liquefied materials found on steeper slopes and may involve ground movements of hundreds of ft. As a result, flow slides can be the most catastrophic of the liquefaction-related ground-failure phenomena. Fortunately, flow slides are much less common occurrences than lateral spreads.

Earthquake-induced settlement is a result of the dissipation of excess pore pressure generated by ground shaking that, as described above, is associated with the tendency for loose, saturated soils to rearrange into a denser configuration during shaking. Such dissipation produces volume decreases (termed consolidation or compaction) within the soil that are manifested at the ground surface as settlement.

Figure 3.5-3 is a liquefaction susceptibility map for the SBSP Restoration Project Area (Knudsen and others 2006) based on sub-surface conditions including soil type, soil thickness and depth to groundwater. Locations of observed ground effects (lateral spreading, sand boil or settlement) from historic earthquakes (1989 Loma Prieta, 1906 San Francisco and others) are also shown.

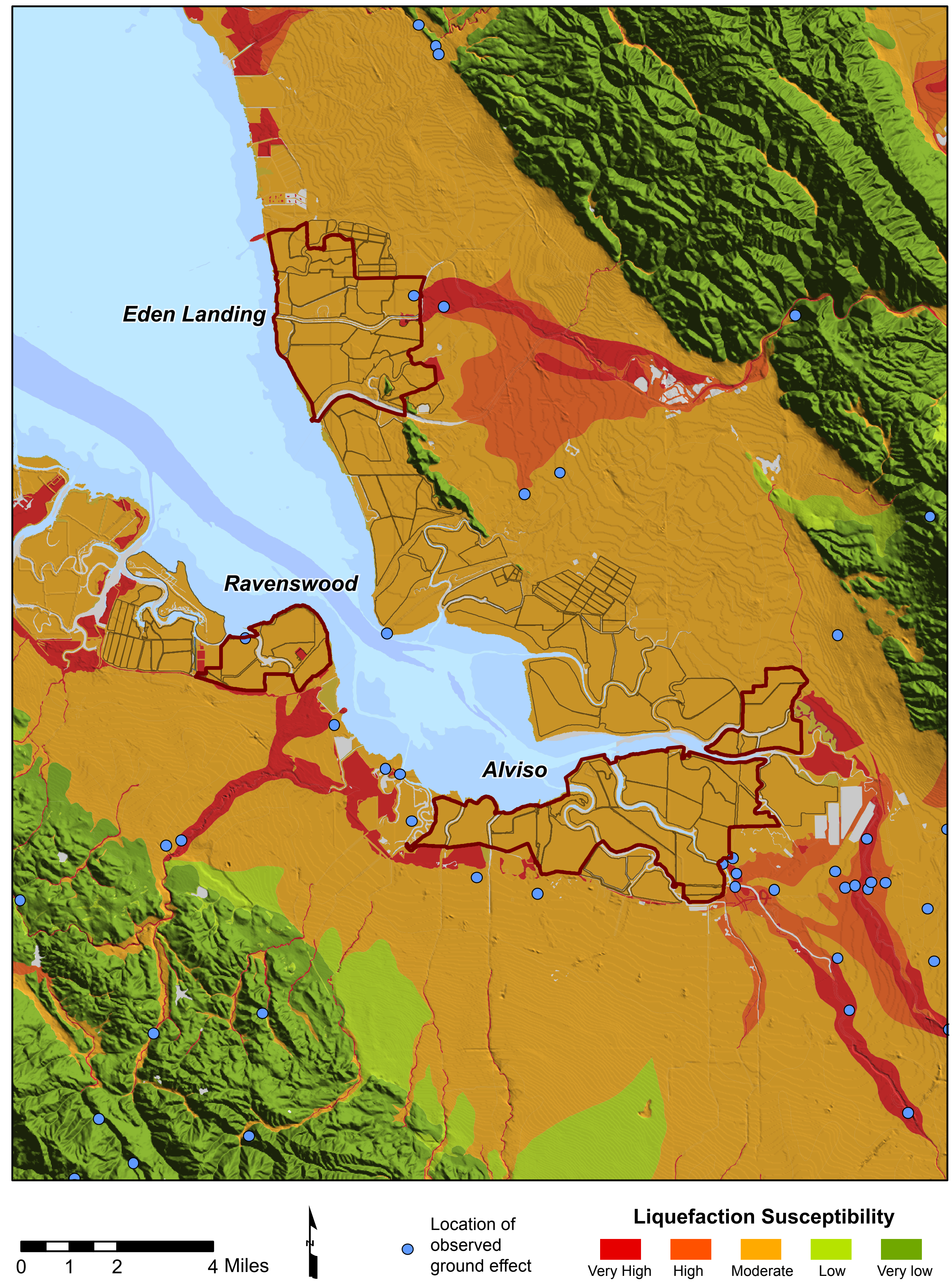

Figure 3.5.3 - Liquefaction susceptibility map, SBSP Restoration Project area

Earthquake-Triggered Landslides

While earthquake-triggered landslides are known to occur in the South Bay, the relatively gentle surface gradients in the vicinity of the SBSP Restoration Project Area suggest that such landslide hazards are minimal under existing conditions. Landslide hazards are discussed in detail above.

Project Setting

The primary unit of importance underlying the SBSP Restoration Project Area is the Holocene Bay mud. Other units anticipated within the Project Area include Quaternary alluvium, eolian deposits, and older Pleistocene Bay mud (Figure 3.5-2).

Due to the nature of the salt ponds and the site conditions that were there prior to their existence, most if not all of the SBSP Restoration Project Area is underlain by Holocene Bay mud. The Holocene Bay mud is relatively impermeable to both infiltration and groundwater flow. The Bay muds are generally underlain by and in some cases overlain by alluvial deposits.

Eden Landing

Soils in the Eden Landing pond complex are primarily Reyes-Urban Land soils (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1980). These soils consist of very poorly drained clays located on tidal flats or urban land, and are otherwise known as Bay muds.

Within the Eden Landing pond complex the thickness of Bay mud varies from about zero to twenty eight ft. Potential for settlement within the pond complex is strongly correlated to Bay mud thickness. An outcropping of Franciscan Unit rock type exists within the pond complex.

Eden Landing is approximately 3.3 miles (5.3 km) from the trace of the Hayward Fault and 11.7 miles (18.7 km) from the San Andreas Fault. The northern terminus of the potentially active Silver Creek Fault is mapped less than a mile from the eastern boundary of the pond complex.

Most of the Eden Landing pond complex is in an area of moderate liquefaction susceptibility (Knudsen and others 2006). However, one localized area within the pond complex is considered to have very high liquefaction susceptibility.

Ponds E8A, E8X, and E9. As described above, these ponds consist of Bay muds with the potential for settlement. The area has moderate liquefaction susceptibility.

Ponds E12 and E13. As described above, these ponds consist of Bay muds with the potential for settlement. The area has moderate liquefaction susceptibility.

Ponds E6A and E6. These ponds are adjacent to an area of very high liquefaction susceptibility.

Ponds E1C and E2C. These ponds are within or adjacent to outcroppings of undifferentiated Franciscan Unit rock and are expected to have negligible liquefaction susceptibility or settlement.

Alviso

Soils in the Alviso pond complex are generally not categorized, but labeled as tidal marsh or salt concentration ponds. Some soils are categorized Alviso Clays and Mocho fine sandy loam over basin clays (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1958), which generally would be expected to be poorly drained.

The thickness of Holocene Bay mud within the Alviso pond complex varies from zero to approximately 25 ft. Some Holocene levee fill and alluvium overlie parts of these areas. The thickness of Bay mud along Coyote Creek ranges between approximately two and 22 ft. Young alluvium overlies the Bay mud in the upper reaches of Coyote Creek. In some areas within the Alviso pond complex, young alluvium overlies these Bay muds. The extent of the Bay muds ends close to the outboard edge of the Alviso pond complex, and in some areas Holocene alluvium underlies the ponds (Woodward-Lundgren & Associates 1971) (see Figure 3.5-2). The potential for settlement within the pond complex is strongly correlated to Bay mud thickness.

The Alviso pond complex is approximately 1.8 miles (2.9 km) from the Hayward Fault and eight miles (12.9 km) from the San Andreas Fault. The concealed Quaternary San Jose Fault extends through the western end of the pond complex and the concealed Quaternary Silver Creek Fault extends through the eastern end of the pond complex.

The Alviso pond complex has moderate liquefaction susceptibility, although most of the ponds along the southern boundary border areas of high to very high liquefaction susceptibility (Knudsen and others 2006).

Pond A6. As described above, this pond consists of Bay muds with the potential for settlement. The area has moderate liquefaction susceptibility. No fault traces cross this pond.

Pond A8. This pond consists of Bay muds with the potential for settlement. The area has moderate liquefaction susceptibility. No fault traces cross this pond.

Ponds A1 and A2W. The potentially active concealed trace of the Quaternary San Jose Fault crosses these ponds.

Ponds A16, A17, and A21. The potentially active concealed trace of the Quaternary Silver Creek Fault extends through these ponds.

Ravenswood

Soils in the Ravenswood pond complex are primarily categorized as Novato-Reyes and Reclaimed Urban land-Orthents (US Department of Agriculture Soil Conservation Service and University of California Agricultural Experiment Station 1991). Novato-Reyes soils are poorly drained soils located on tidal flats. Reclaimed Urban land-Orthents soils are found on urban land and reclaimed tidal flats, and are poorly drained.

Within the Ravenswood pond complex the thickness of Bay mud varies from 15 to 60 ft (Figure 3.5-2). This relatively variable package of Bay mud thickness is attributed to the close proximity of the pond complex to the axis of the Bay and the main paleo-drainage. The potential for settlement within the pond complex is strongly correlated to this thickness of the Bay mud.

Ravenswood is 9.4 miles (15.1 km) miles from the Hayward Fault and 6.8 miles (10.9 km) miles from the San Andreas Fault. The trace of the concealed Quaternary San Jose Fault cuts through the eastern half of the pond complex.

Ponds SF2, R1 and R2. The potentially active concealed Quaternary San Jose Fault trace extends through these ponds. These ponds are also adjacent to an area of very high liquefaction susceptibility (Knudsen and others 2006).

3.5.2 Regulatory Setting

Federal

FEMA regulations govern design and construction of flood control levees. These regulations are discussed in Section 3.3, Hydrology, Flood Management and Infrastructure.

State

State regulations which govern geotechnical and geological aspects of the SBSP Restoration Project include the Alquist-Priolo Earthquake Fault Zoning Act and Seismic Hazards Mapping Act. The California Building Code (CBC) would apply if a significant permanent structure is constructed. The three primary regulations governing soils and geology are discussed below.

Alquist-Priolo Earthquake Fault Zoning Act

This California legislation was originally enacted in 1972 as the Alquist-Priolo Special Studies Zones Act. It was renamed in 1994 and became the Alquist-Priolo Earthquake Fault Zoning Act (the Alquist-Priolo Act) (California Geological Survey 1997). This act primarily addresses surface fault rupture by prohibiting the location of structures designed for human occupancy across active faults and regulating construction in earthquake fault zones. It provides guidance for how active faults should be identified, defines relevant terms, and establishes an approval process for proposed buildings in active earthquake areas.

The Alquist-Priolo Act focuses on faults that are "sufficiently active" and "well-defined", zoning these areas differently and requiring stricter construction regulations. A "sufficiently active" fault is defined as one where one or more of its segments or strands show evidence of surface displacement during the Holocene Epoch (approximately the last 11,000 years). A fault is "well defined" if its trace can be clearly identified by a trained geologist at the ground surface or in the shallow subsurface, using standard professional techniques, criteria, and judgment (Hart and Bryant 1997).

Seismic Hazards Mapping Act

The Seismic Hazards Mapping Act addresses seismic hazards such as strong ground shaking, soil liquefaction, and earthquake-related landslides. This act requires the State of California to identify and map areas that are at risk for these and other related hazards. Cities and counties are also required to regulate development in the mapped seismic hazard zones.

Permit review is the primary method of regulating local development under the Seismic Hazards Mapping Act. Cities and counties cannot issue development permits in these hazard zones until site-specific soils and/or geology investigations are carried out and measures to reduce potential damage are incorporated in the development plans.

The design of all structures (building and non-building structures) is required to comply with the Uniform Building Code (UBC)[4] and the CBC, which are the applicable building codes. Construction activities are overseen by the immediate local jurisdiction and regulated through a multi-stage permitting process. Projects within city limits typically require permit review by the city, while projects in unincorporated areas require a county permit. Grading and building permits require a site-specific geotechnical evaluation by a state-certified engineering geologist and/or geotechnical engineer. The geotechnical evaluation provides a geological basis from which to develop appropriate construction designs. A typical geotechnical evaluation usually includes an assessment of bedrock and quaternary geology, geologic structure, soils, and history of excavation and fill placement. The evaluation may also address the requirements of the Alquist-Priolo Act and the Seismic Hazards Mapping Act when appropriate.

3.5.3 Environmental Impacts and Mitigation Measures

Overview

The geologic factors that are expected to affect the lifespan and performance of existing levees within the SBSP Restoration Project Area include: subsidence from ongoing consolidation of Bay mud; subsidence and slope failure resulting from liquefaction during an earthquake; tsunami; and fault rupture.

Almost all of the levees within the SBSP Restoration Project Area are underlain by very soft, highly compressible, normally consolidated sediments of San Francisco Bay (locally termed Bay mud). Ongoing consolidation of Bay mud under the weight of recently constructed fill for the pond levees would cause continued ground settlement. The amount of future consolidation is expected to vary within a given complex based on: weight of recently added fill, thickness of underlying Bay mud, and the time since recent fill placement.

Almost all of the levees within the SBSP Restoration Project Area are within areas of moderate to very high liquefaction susceptibility. Liquefaction of saturated loose granular soils during an earthquake may cause ground settlement. The amount of liquefaction is expected to vary within a given complex based on

[4] Published by the International Conference of Building Officials, the UBC is a widely adopted model building code in the United States. The CBC incorporates by reference the UBC with necessary California amendments.

density, depth, and thickness of potentially liquefiable soil layers. Liquefaction occurring near the surface of a slope may cause the slope to fail and deform.

Many of the levees within the SBSP Restoration Project Area are subject to the potential for overtopping and accelerated erosion resulting from tsunami and seiches. The size of a tsunami is expected to vary based on earthquake magnitude, earthquake distance, wave direction, atmospheric conditions, and local Bay dimensions.

Many of the levees within the SBSP Restoration Project Area are subject to the potential for fault rupture. The concealed quaternary San Jose Fault extends through the Alviso and Ravenswood pond complexes. The concealed quaternary Silver Creek Fault extends through the Alviso pond complex.

Significance Criteria

For the purposes of this EIS/R, the Project would have a significant effect if it would:

- Be located on a site with geologic features which pose a substantial hazard to property and/or human life (*e.g.,* an active fault, an active landslide); or
- Expose people or property to major geologic hazards that cannot be avoided or reduced through the use of standard engineering design and seismic safety techniques; or
- Cause substantial erosion or siltation.

As explained in Section 3.1.2, while both CEQ Regulations for Implementing NEPA and the CEQA Guidelines were considered during the impact analysis, impacts identified in this EIS/R are characterized using CEQA terminology. Please refer to Section 3.1.2 for a description of the terminology used to explain the severity of the impacts.

Program-Level Evaluation

SBSP Restoration Project Long-Term Alternatives

SBSP Impact 3.5-1**: Potential effects from settlement and subsidence due to consolidation of Bay mud.**

Very soft, highly compressible, normally consolidated sediments of San Francisco Bay (locally termed Bay mud) exist throughout the SBSP Restoration Project Area. Based on existing data, Bay mud deposits are up to 60 ft thick at some locations. The degree of settlement of Bay mud anticipated generally depends on: thickness of the soft Bay mud deposit, consistency and compressibility characteristics of the soil, changes in groundwater elevation(s), and magnitude of new loads (fill or structures) placed above the Bay mud.

Lowering the groundwater elevation in areas that contain significant thicknesses of Bay mud can cause consolidation of Bay mud and ground subsidence. As much as 13 ft of surface subsidence occurred in Santa Clara and San Mateo counties between about 1912 and 1969. This subsidence is mainly attributed to regional groundwater depletion. Lowered groundwater elevations through this period increased effective stresses within local Bay mud deposits, which caused consolidation and ground subsidence. Since 1969, the implementation of groundwater replenishment programs has slowed or stopped the consolidation and ground subsidence. No subsidence from groundwater depletion has been inferred from extensometers readings in San Jose and Sunnyvale since 1973 (Helley and others 1979).

Placing new earthen or structural loads in areas that contain significant thicknesses of Bay mud can cause consolidation of Bay mud and ground settlement resulting in lower ground surface elevations. Generally, higher new loads result in larger settlements, and thicker layers of Bay mud consolidate more than thinner layers. Depending on the thickness and engineering characteristics of Bay mud that underlies a particular area within the SBSP Restoration Project Area, long-term settlements of up to four inches may result from placing one foot of new fill at the ground surface.

Consolidation of Bay mud occurs over time. Typically, a large portion of settlement, say 50 percent, occurs over a period of weeks or months, with the remainder occurring over a period of years, sometimes decades. The thickness of the Bay mud layer strongly affects the time of consolidation. Thin layers consolidate more rapidly than thicker layers.

Ongoing consolidation of Bay mud under the weight of recently constructed fill for the pond levees causes continued ground settlement resulting in lower ground surface elevations. The amount of future consolidation is expected to vary within a given pond complex based on: weight of recently added fill, thickness and consistency of underlying Bay mud, and the time since recent fill placement. The amount of future consolidation may cause portions of certain levees to settle to, or below, minimum elevations required for flood protection.

Refer to similar discussion for Impact 3.3-1 in Section 3.3, Hydrology, Flood Management, and Infrastructure.

Alternative A No Action. The salt pond levees are subject to degradation under normal conditions. Under Alternative A, the landowners would coordinate with the local flood management agencies to focus their limited maintenance and improvement funds on pond levees with high priority to be maintained. At Eden Landing, CDFG would focus their levee maintenance on the levees along the east side of Ponds E4, E5, E6, and E6C, to reduce the potential for periodic overtopping into areas that currently provide flood detention for low-lying areas of Alameda County. They would also coordinate levee maintenance and land management activities with the proposed Alameda Creek Flood Control Channel project. At Alviso, the No Action Alternative assumes that the levees along Ponds A5, A6, and A7 are the least likely to be maintained and that the levee along the west side of Pond A8 would be raised to prevent frequent tidal overtopping. This approach maintains the existing flood detention storage in Pond A8, but not in Ponds A5, A6, and A7.

Levees within the SBSP Restoration Project Area that are not a priority to maintain would be increasingly prone to failure over the next 50 years due to continued levee settlement. Unintentional breaching and periodic levee overtopping would be expected.

Alternative A Level of Significance: Potentially Significant

Alternative B Managed Pond Emphasis. Under Alternative B, the Managed Pond Emphasis Alternative, 50 percent of the SBSP Restoration Project Area would remain as managed ponds, and the remaining 50 percent of the Project Area would be restored to tidal habitat. In tidal areas, there would be no maintenance to repair and raise portions of levees that have settled to, or below, minimum elevations required for flood protection. However, in managed ponds, some levees would be maintained and raised as necessary to ensure minimum elevations. The lifespan of, and the degree of ongoing flood protection from, existing levees is higher for Alternative B then for Alternative A, and new features (inboard levees that provide flood protection and habitat islands and berms) would be designed and constructed to account for ongoing and future settlement. New and/or improved flood control levees would be designed and constructed to protect inland areas from the effects of a breach in outboard levees. Because new inboard levees would be designed to account for ongoing and future settlement, potential effects on people and property from settlement and subsequent flooding would be less than significant under CEQA. In addition, the impact would be beneficial under NEPA because levees would be maintained and raised to ensure flood protection.

Alternative B Level of Significance: Less than Significant (CEQA), Beneficial (NEPA)

Alternative C Tidal Habitat Emphasis. Under Alternative C, the Tidal Habitat Emphasis Alternative, 90 percent of the SBSP Restoration Project Area would be restored to tidal habitat, and the remaining 10 percent of the Project Area would remain as managed ponds. In tidal areas, there would be no maintenance to repair and raise portions of levees that have settled to, or below, minimum elevations required for flood protection. However, in managed ponds, some levees would be maintained and raised as necessary to ensure minimum elevations. The lifespan of, and the degree of ongoing flood protection from, existing levees is higher for Alternative C than for Alternative A, and new features (inboard levees that provide flood protection and habitat islands and berms) would be designed and constructed to account for ongoing and future settlement of soft soils below the levees. New and/or improved flood control levees would be designed and constructed to protect inland areas from the effects of a breach in outboard levees.. Because new inboard levees would be designed to account for ongoing and future settlement, potential effects on people and property from settlement and subsequent flooding would be less than significant under CEQA. In addition, the impact would be beneficial under NEPA because levees would be maintained and raised to ensure flood protection.

Alternative C Level of Significance: Less than Significant (CEQA), Beneficial (NEPA)

SBSP Impact 3.5-2: **Potential effects from liquefaction of soils and lateral spreading.**

Saturated loose granular soils exist within, and below, sediments of San Francisco Bay throughout the SBSP Restoration Project Area. These soils are potentially liquefiable. During and immediately after ground shaking from a moderate to strong earthquake, saturated loose granular soils may lose strength, and may experience relatively rapid volumetric change. The expression of liquefaction and the corresponding volumetric change is often ground subsidence. When liquefaction occurs within an embankment or near the surface of a slope (*e.g.,* cut slope, fill slope, existing shoreline, existing river channel) strength loss within saturated granular soils during liquefaction may result in slope failure and lateral deformation (lateral spreading).

The severity of the liquefaction hazard depends on: density of the saturated granular soils, depth and thickness of potentially liquefiable layers, magnitude and duration of the ground shaking, and distance to the nearby free face or ground slope. Generally, looser deposits have the potential to densify more as a result of ground shaking and are subject to larger volumetric changes. Generally thicker deposits will accumulate more volumetric change than thinner deposits.

Liquefaction of saturated loose granular soils during an earthquake may cause ground settlement resulting in lower ground surface elevations within the SBSP Restoration Project Area. The amount of liquefaction is expected to vary within a given pond complex based on density, depth, and thickness of potentially liquefiable soil layers. The amount of liquefaction may cause portions of certain levees to settle to, or below, minimum elevations required for flood protection. Liquefaction occurring near the surface of a slope may cause the slope to fail and deform.

Alternative A No Action. Under Alternative A, the No Action Alternative, there would be limited maintenance to repair or improve portions of levees that have experienced settlement or lateral deformation from liquefaction of saturated loose granular soils during a significant ground shaking event. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded.

Alternative A Level of Significance: Potentially Significant

Alternative B Managed Pond Emphasis. Under Alternative B, the Managed Pond Emphasis Alternative, 50 percent of the SBSP Restoration Project Area would remain as managed ponds, and the remaining 50 percent of the Project Area would be restored to tidal habitat. In tidal areas, there would be no maintenance to repair or improve portions of levees that have experienced settlement or lateral deformation from liquefaction of saturated loose granular soils during a significant ground shaking event. Liquefaction may cause portions of outboard pond levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded.

In managed ponds, some levees would be maintained and improved as necessary to ensure minimum elevations for flood protection, and minimum factors of safety against slope failure. The lifespan of, and the degree of ongoing flood protection from, existing levees is higher for Alternative B then for Alternative A, and new inboard levees that provide flood protection would be designed and constructed to avoid, reduce or otherwise account for future settlement from liquefaction. New and/or improved flood control levees would be designed and constructed to protect inland areas from the effects of a breach in outboard levees. Because levees would be designed to account for liquefaction and lateral spreading, potential effects on people and property from liquefaction and lateral spreading (and subsequent flooding) would be less than significant under CEQA. In addition, the impact would be beneficial under NEPA because levees would be maintained and raised to ensure flood protection.

Alternative B Level of Significance: Less than Significant (CEQA), Beneficial (NEPA)

Alternative C Tidal Habitat Emphasis. Under Alternative C, the Tidal Habitat Emphasis Alternative, 90 percent of the SBSP Restoration Project Area would be restored to tidal habitat, and the remaining 10 percent of the Project Area would remain as managed ponds. In tidal areas, there would be no maintenance to repair or improve portions of levees that have experienced settlement or lateral deformation from liquefaction of saturated loose granular soils during a significant ground shaking event. Areas where liquefaction causes the levee crest to settle below minimum elevations required for flood protection may be overtopped, ponds may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached, ponds may be flooded.

In managed ponds, some levees would be maintained and improved as necessary to ensure minimum elevations for flood protection, and minimum factors of safety against slope failure. The lifespan of, and the degree of ongoing flood protection from, existing levees is higher for Alternative C then for Alternative A, and new inboard levees that provide flood protection would be designed and constructed to avoid, reduce, or otherwise account for future settlement from liquefaction. New and/or improved flood control levees would be designed and constructed to protect inland areas from the effects of a breach in outboard levees. Because levees would be designed to account for liquefaction and lateral spreading, potential effects on people and property from liquefaction and lateral spreading (and subsequent flooding) would be less than significant under CEQA. In addition, the impact would be beneficial under NEPA because levees would be maintained and raised to ensure flood protection.

Alternative C Level of Significance: Less than Significant (CEQA), Beneficial (NEPA)

SBSP Impact 3.5-3: **Potential effects from tsunami and/or seiche.**

A tsunami, which is a series of ocean waves generated by sudden displacements in the sea floor (*e.g.*, from earthquakes) was recorded near Fort Point (west of the Golden Gate Bridge) during the 1906 San Francisco Earthquake (USGS 2005). A tsunami wave of 10 centimeters resulted from the magnitude 7.8 earthquake. However, there has been no recorded evidence of tsunamis inside San Francisco Bay and there is no geologic evidence to suggest that any has occurred (Adelson 2005). National warning systems are in place to provide warning in the event tsunamis occur. These warnings would provide sufficient time for evacuation if necessary.

Alternative A No Action. Under Alternative A, the No Action Alternative, there would be no maintenance to repair or improve portions of levees for increased performance during tsunami. In areas where a tsunami overtops levees, ponds may be flooded, and erosion of levee slopes may be accelerated. Because the proposed Project would not include habitable structures, and warning systems would allow for evacuation of the shoreline in such an event, inundation by tsunamis would not expose people to potential injury or death.

Alternative A Level of Significance: Less than Significant

Alternative B Managed Pond Emphasis. Under Alternative B, the Managed Pond Emphasis Alternative, 50 percent of the SBSP Restoration Project Area would remain as managed ponds, and the remaining 50 percent of the Project Area would be restored to tidal habitat. In tidal areas, there would be no maintenance to repair or improve portions of levees for increased performance during tsunami. In areas where a tsunami overtops levees, ponds may be flooded, and erosion of levee slopes may be accelerated. In managed pond areas, some levees may be improved and provide better protection against tsunamis. Other levees may be repaired after a tsunami occurrence.

Because the proposed Project would not include habitable structures, and warning systems would allow for evacuation of the shoreline in such an event, inundation by tsunamis would not expose people to potential injury or death. Due to the limited facilities adjacent to the shoreline (*e.g.,* trails), and the higher level of protection offered by new inboard levees that provide flood protection, potential damages would be less than significant under CEQA and beneficial under NEPA.

Alternative B Level of Significance: Less than Significant (CEQA), Beneficial (NEPA)

Alternative C Tidal Habitat Emphasis. Under Alternative C, the Tidal Habitat Emphasis Alternative, 90 percent of the SBSP Restoration Project Area would be restored to tidal habitat, and the remaining 10 percent of the Project Area would remain as managed ponds. In tidal areas, there would be no maintenance to repair or improve portions of levees for increased performance during tsunami. In areas where a tsunami overtops levees, ponds may be flooded, and erosion of levee slopes may be accelerated. In managed pond areas, some levees may be improved and provide better protection against tsunamis. Other levees may be repaired after a tsunami occurrence.

Because the proposed Project would not include habitable structures, and warning systems would allow for evacuation of the shoreline in such an event, inundation by tsunamis would not expose people to potential injury or death. Due to the limited facilities adjacent to the shoreline (*e.g.,* trails), and the higher level of protection offered by new inboard levees that provide flood protection, potential damages would be less than significant under CEQA and beneficial under NEPA.

Alternative C Level of Significance: Less than Significant (CEQA), Beneficial (NEPA)

SBSP Impact 3.5-4: **Potential for ground and levee failure from fault rupture.**

Fault rupture hazards exist along known active faults in the greater San Francisco Bay Area. Potential surface rupture hazards identified in close proximity to the SBSP Restoration Project Area by the CGS include the San Andreas and Hayward Fault zones which are approximately 7.5 miles (12km) and 1.5

miles (2.6km) from the Alviso pond complex, respectively. These faults show historic (last 200 years) displacement associated with mapped surface rupture or surface creep.

Other faults in the SBSP Restoration Project Area include concealed potentially active Quaternary faults with evidence of displacement sometime during the past 1.8 million years. The San Jose and Palo Alto Fault zones are mapped on the western boundary of the Bay and cut through the Alviso (Ponds A1, A2W) and Ravenswood (Ponds R1, R2, and SF2) pond complexes. The Silver Creek Fault is mapped on the eastern margin of the Bay and intersects the Alviso pond complex (Ponds A16, A17) and truncates within a mile of the Eden Landing pond complex. (Jennings 1994).

Fault rupture during an earthquake may cause failure of levees, including separation, settlement, and vertical and horizontal dislocation between the ground surface and levees.

Alternative A No Action. An earthquake fault rupture may cause a breach in existing levees at Alviso ponds A1, A2W, A16, A17 and/or Ravenswood ponds R1, R2, and SF2. Under Alternative A, the No Action Alternative, in the event of a levee breach caused by surface fault rupture during an earthquake however, there is a potential for flooding in nearby areas (see also Impact 3.3-1 in Section 3.3.3, Hydrology Flood Management, and Infrastructure for a discussion of flooding effects).

Alternative A Level of Significance: Potentially Significant

Alternative B Managed Pond Emphasis. Under Alternative B, the Managed Pond Emphasis Alternative, 50 percent of the SBSP Restoration Project Area would remain as managed ponds, and the remaining 50 percent of the Project Area would be restored to tidal habitat. Within the portion of the Project Area that would be restored to tidal habitat, there would be no maintenance to repair pond levees damaged as a result of fault rupture. An earthquake fault rupture may breach existing pond levees within this area; however, the pond levees are not intended to provide flood protection.

The San Jose and Palo Alto Fault zones are mapped on the western boundary of the Bay and cut through proposed new inboard flood protection levees along the southern boundary of Alviso Pond A2, the western boundary of Alviso Pond A1, and along the northern boundary of Ravenswood Pond SF2. The Silver Creek Fault is mapped on the eastern margin of the Bay and cuts through proposed new inboard flood protection levees along the southern boundary of Alviso Pond A16. New flood protection levees would be designed and managed to maintain or improve levels of flood protection landward of the SBSP Restoration Project Area and would be designed to withstand failure from fault rupture. Therefore, potential effects on people and property from fault rupture would be less than significant.

Alternative B Level of Significance: Less than Significant

Alternative C Tidal Habitat Emphasis. Under Alternative C, the Tidal Habitat Emphasis Alternative, 90 percent of the SBSP Restoration Project Area would be restored to tidal habitat, and 10 percent of the Project Area would remain as managed ponds. Within the portion of the Project Area that would be restored to tidal habitat, there would be no maintenance to repair pond levees damaged as a result of fault rupture. An earthquake fault rupture may breach existing levees.

While Alternative C would restore a larger portion of the Project Area to tidal habitat, the proposed flood protection levees would be designed and managed to maintain or improve levels of flood protection landward of the SBSP Restoration Project Area. These flood protection levees would be designed to withstand failure from fault rupture. Therefore, potential effects on people and property from fault rupture would be similar to those effects described for Alternative B, and would be less than significant.

Alternative C Level of Significance: Less than Significant

SBSP Impact 3.5-5: **Potential effects from consolidation of Bay mud on existing subsurface utility crossings and surface rail crossings.**

Bay mud exists throughout the SBSP Restoration Project Area. Based on existing data, Bay mud deposits are up to 60 ft thick at some locations. Placing new earthen or structural loads in areas that contain significant thicknesses of Bay mud can cause consolidation of Bay mud and ground settlement resulting in lower ground surface elevations. Generally, higher new loads result in larger settlements, and thicker layers of Bay mud consolidate more than thinner layers. Depending on the thickness and engineering characteristics of Bay mud that underlies a particular area within the SBSP Restoration Project Area, long-term settlement of up to four inches may result from placing one foot of new fill at the ground surface.

Existing improvements, such as subsurface utilities and railways, that pass through or adjacent to areas that are expected to receive new earthen or structural loads (*i.e.,* new flood protection levees, new habitat berms, new habitat islands) would be subject to additional settlement. Depending on the magnitude, distribution, and rate of the new loads applied, additional settlement may impact performance, and disrupt service, of the existing improvements.

Alternative A No Action. Under Alternative A, the No Action Alternative, there would be limited maintenance to repair and raise portions of levees that have settled to, or below, minimum elevations required for flood protection. There would also be no new earthen or structural loads to increase the rate and magnitude of settlement. Therefore, impacts would be less than significant.

Alternative A Level of Significance: Less than Significant

Alternative B Managed Pond Emphasis. Under Alternative B, the Managed Pond Emphasis Alternative, 50 percent of the SBSP Restoration Project Area would remain as managed ponds, and the remaining 50 percent of the Project Area would be restored to tidal habitat. In tidal areas, there would be no maintenance to repair and raise portions of levees that have settled to, or below, minimum elevations required for flood protection. However, in managed ponds, some levees would be maintained and raised as necessary to ensure minimum elevations. New flood protection levees would be designed to account for ongoing and future settlement, including the potential effects on existing utility and rail crossings. Therefore, impacts would be less than significant.

Alternative B Level of Significance: Less than Significant

Alternative C Tidal Habitat Emphasis. Under Alternative C, the Tidal Habitat Emphasis Alternative, 90 percent of the SBSP Restoration Project Area would be restored to tidal habitat, and the remaining 10 percent of the Project Area would remain as managed ponds. In tidal areas, there would be no maintenance to repair and raise portions of levees that have settled to, or below, minimum elevations required for flood protection. However, in managed ponds, some levees would be maintained and raised as necessary to ensure minimum elevations. New flood protection levees would be designed to account for ongoing and future settlement, including the potential effects on existing utility and rail crossings. Therefore, impacts would be less than significant.

Alternative C Level of Significance: Less than Significant

Project-Level Evaluation

***Phase 1 Impact 3.5-1*: Potential effects from settlement due to consolidation of Bay mud.**

For general discussion of Phase 1 Impact 3.5-1, refer to SBSP Impact 3.5-1 above.

Phase 1 No Action

The following discussion addresses the No Action Alternative (Alternative A) at the project level.

The salt pond levees are subject to degradation under normal conditions. Under Alternative A, the landowners would coordinate with the local flood management agencies to focus their limited maintenance and improvement funds on pond levees with high priority to be maintained. At Eden Landing, CDFG would focus their levee maintenance on the levees along the east side of Ponds E4, E5, E6, and E6C, to reduce the potential for periodic overtopping into areas that currently provide flood detention for low-lying areas of Alameda County. They would also coordinate levee maintenance and land management activities with the proposed Alameda Creek Flood Control Channel project. At Alviso, the No Action Alternative assumes that the levees along Ponds A5, A6, and A7 are the least likely to be maintained and that the levee along the west side of Pond A8 would be raised to prevent frequent tidal overtopping. This approach maintains the existing flood detention storage in Pond A8, but not in Ponds A5, A6, and A7.

Levees within the SBSP Restoration Project Area that are not a priority to maintain would be increasingly prone to failure over the next 50 years due to continued levee settlement. Unintentional breaching and periodic levee overtopping would be expected.

Phase 1 No Action Level of Significance: Potentially Significant

Phase 1 Actions

The following discussion addresses the Phase 1 actions (the first phase of Alternatives B and C) at the project level.

Based on contours of thickness of Bay mud developed from existing data, as much as 30 ft of Bay mud exists below ponds within the Eden Landing and Alviso pond complexes, including Pond A8. As much as 60 ft of Bay mud may exist below ponds within the Ravenswood pond complex. Based on Cargill Inc. (Cargill) maintenance records, ongoing consolidation of Bay mud and settlement would be expected. Portions of levees may eventually settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. However, because levees would be maintained and raised as necessary to ensure minimum elevations, potential effects on people and property from subsidence would be less than significant.

Phase 1 Actions Level of Significance: Less than Significant

Phase 1 Impact 3.5-2: **Potential effects from liquefaction of soils and lateral spreading.**

For general discussion of Phase 1 Impact 3.5-2, refer to SBSP Impact 3.5-2 above.

Phase 1 No Action

The following discussion addresses the No Action Alternative (Alternative A) at the project level.

Eden Landing. Based on existing data, most of the Eden Landing pond complex is in an area of moderate liquefaction susceptibility. Ponds E6 and E6A are adjacent to an area of very high liquefaction susceptibility. Ponds E1C and E2C are located within or adjacent to outcroppings of undifferentiated Franciscan Unit rock and are expected to have negligible liquefaction susceptibility. Under the Phase 1 No Action Alternative, there would be no maintenance to repair and raise portions of levees that have experienced settlement or lateral deformation from liquefaction of saturated loose granular soils during a significant ground shaking event. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded.

Alviso. Based on existing data, the Alviso pond complex is within an area of moderate liquefaction susceptibility. Most of its southern boundary borders areas of high to very high liquefaction susceptibility. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded.

Ravenswood. Based on existing data, the Ravenswood pond complex is within an area of moderate liquefaction susceptibility. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded.

Phase 1 No Action Level of Significance: Potentially Significant

Phase 1 Actions

The following discussion addresses the Phase 1 actions (the first phase of Alternatives B and C) at the project level.

Eden Landing. Based on existing data, most of the Eden Landing pond complex is in an area of moderate liquefaction susceptibility. Ponds E6 and E6A are adjacent to an area of very high liquefaction susceptibility. Ponds E1C and E2C are located within or adjacent to outcroppings of undifferentiated Franciscan Unit rock and are expected to have negligible liquefaction susceptibility. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded. However, because levees within managed pond areas would be repaired after an occurrence of liquefaction or lateral spreading, potential effects on people and property from liquefaction and lateral spreading would be less than significant.

Alviso. Based on existing data, the Alviso pond complex, including Pond A8, is within an area of moderate liquefaction susceptibility. Most of its southern boundary borders areas of high to very high liquefaction susceptibility. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded. However, because levees within managed pond areas would be repaired after an occurrence of liquefaction or lateral spreading, potential effects on people and property from liquefaction and lateral spreading would be less than significant.

Ravenswood. Based on existing data, the Ravenswood pond complex is within an area of moderate liquefaction susceptibility. Liquefaction may cause portions of levees to settle below minimum elevations, allowing them to be overtopped. Corresponding ponds and adjacent areas may be flooded. In areas where liquefaction causes failure and deformation of levee slopes, levees may be breached. Corresponding ponds and adjacent areas may be flooded. However, because levees within managed pond areas would be repaired after an occurrence of liquefaction or lateral spreading, potential effects on people and property from liquefaction and lateral spreading would be less than significant.

Phase 1 Actions Level of Significance: Less than Significant

***Phase 1 Impact 3.5-3*: Potential effects from tsunami and/or seiche.**

For general discussion of Phase 1 Impact 3.5-3, refer to SBSP Impact 3.5-3 above.

Phase 1 No Action

The following discussion addresses the No Action Alternative (Alternative A) at the project level.

Under the No Action Alternative, there would be no maintenance to repair or improve portions of levees for increased performance during tsunami and/or seiche. In areas where a tsunami overtops levees, ponds and adjacent areas may be flooded, and erosion of levee slopes may be accelerated. Because the proposed Project would not include habitable structures, and warning systems would allow for evacuation of the shoreline in such an event, inundation by tsunamis would not expose people to potential injury or death.

Phase 1 No Action Level of Significance: Less than Significant

Phase 1 Actions

The following discussion addresses the Phase 1 actions (the first phase of Alternatives B and C) at the project level.

In areas where a tsunami overtops levees, ponds and adjacent areas may be flooded, and erosion of levee slopes may be accelerated. Because the proposed Project would not include habitable structures, and warning systems would allow for evacuation of the shoreline in such an event, inundation by tsunamis would not expose people to potential injury or death. Due to the limited facilities adjacent to the shoreline (*e.g.,* trails), potential damages would be less than significant.

Phase 1 Actions Level of Significance: Less than Significant

***Phase 1 Impact 3.5-4*: Potential for ground and levee failure from fault rupture.**

For general discussion of Phase 1 Impact 3.5-4, refer to SBSP Impact 3.5-4 above.

Phase 1 No Action

The following discussion addresses the No Action Alternative (Alternative A) at the project level.

Eden Landing. No active or potentially active faults are mapped within the Eden Landing pond complex.

Eden Landing Phase 1 No Action Level of Significance: No Impact

Alviso. The concealed quaternary Silver Creek Fault runs through the eastern end of the Alviso pond complex, including Ponds A16 and A17. The concealed quaternary San Jose Fault runs through the eastern half of the Alviso pond complex, including Ponds A1 and A2W. In the event of a levee breach caused by surface fault rupture during an earthquake, there is a potential for flooding in nearby areas.

Alviso Phase 1 No Action Level of Significance: Potentially Significant

Ravenswood. The concealed quaternary San Jose Fault runs through the eastern half of the Ravenswood pond complex, including Ponds R1, R2, and SF2. In the event of a levee breach caused by surface fault rupture during an earthquake, there is a potential for flooding in nearby areas.

Ravenswood Phase 1 No Action Level of Significance: Potentially Significant

Phase 1 Actions

The following discussion addresses the Phase 1 actions (the first phase of Alternatives B and C) at the project level.

Eden Landing. No active or potentially active faults are mapped within the Eden Landing pond complex.

Eden Landing Phase 1 Actions Level of Significance: No Impact

Alviso. The concealed quaternary Silver Creek Fault runs through the eastern end of the Alviso pond complex, including Ponds A16 and A17. The concealed quaternary San Jose Fault runs through the western half of the Alviso pond complex, including Ponds A1 and A2W. Recreational facilities at Pond A16 (interpretative stations and viewing platform) would be designed to be located away from the Silver Creek Fault. No new recreational facilities would be placed on top of the fault trace. As part of Phase 1, existing levees would be maintained and repaired as needed. As discussed above, Alternatives B and C would provide new inboard flood protection levees that would withstand failure from fault rupture. As such, potential effects on people and property due to a rupture immediately on or adjacent to a fault during an earthquake would be less than significant.

Alviso Phase 1 Actions Level of Significance: Less than Significant

Ravenswood. The concealed quaternary San Jose Fault runs through the eastern half of the Ravenswood pond complex, including ponds R1, R2, and SF2. Recreational facilities (interpretative stations and viewing platforms) would be designed to be located away from the San Jose Fault. No new recreational facilities would be placed on top of the fault trace. As part of Phase 1, existing levees would be maintained and repaired as needed. As discussed above, Alternatives B and C would provide new inboard flood protection levees that would withstand failure from fault rupture. As such, potential effects on people and property due to a rupture immediately on or adjacent to a fault during an earthquake would be less than significant.

Ravenswood Phase 1 Actions Level of Significance: Less than Significant

***Phase 1 Impact 3.5-5*: Potential effects from consolidation of Bay mud on existing subsurface utility crossings and surface rail crossings.**

For general discussion of Phase 1 Impact 3.5-5, refer to SBSP Impact 3.5-5 above.

Phase 1 No Action

The following discussion addresses the No Action Alternative (Alternative A) at the project level.

Eden Landing. An existing subsurface utility (sewer line) crosses Pond E6A. While limited O&M activities would occur, no new earthen or structural loads would be placed within the Phase 1 ponds under the No Action Alternative. Therefore, impacts would be less than significant.

Eden Landing Phase 1 No Action Level of Significance: Less than Significant

Alviso. The existing Union Pacific Railroad (UPRR) runs north-south along the eastern edge of Alviso Ponds A12, A16, and A17. While limited O&M activities would occur, no new earthen or structural loads would be placed within the Phase 1 ponds under the No Action Alternative. Therefore, impacts would be less than significant.

Alviso Phase 1 No Action Level of Significance: Less than Significant

Ravenswood. There are no known existing utility or rail crossings within the Ravenswood pond complex. Therefore, no impact would occur.

Ravenswood Phase 1 No Action Level of Significance: No Impact

Phase 1 Actions

The following discussion addresses the Phase 1 actions (the first phase of Alternatives B and C) at the project level.

Eden Landing. An existing subsurface utility (sewer line) crosses Pond E6A. Placement of new fill for flood protection levees, habitat berms, or habitat islands in these locations would potentially induce consolidation of Bay mud, cause additional subsidence, and affect the performance (disrupt service) of the utility. Placement of new fill for flood protection levees, habitat berms, or habitat islands in these locations would be designed to account for ongoing and future subsidence, including the potential effects on the existing utility crossings. Therefore, impacts would be less than significant.

Eden Landing Phase 1 Actions Level of Significance: Less than Significant

Alviso. The existing UPRR runs north-south along the eastern edge of Alviso Ponds A12, A16, and A17. New fill for flood protection levees are planned along the eastern edge of Alviso Pond A12 and along the southern edge of Alviso Pond A16. Placement of new fill for flood protection levees, habitat berms, or habitat islands in these locations would potentially induce consolidation of Bay mud, cause additional subsidence, and affect the performance (disrupt service) of the railway. Placement of new earthen or structural loads in this location would be designed to account for ongoing and future subsidence, including the potential effects on the existing railway crossings. Construction of improvements adjacent to the existing railway, at the crossing, would be planned and staged to minimize temporary disruptions. Therefore, impacts would be less than significant.

Alviso Phase 1 Actions Level of Significance: Less than Significant

Ravenswood. There are no known existing utility or rail crossings within the Ravenswood pond complex. Therefore, no impact would occur.

Ravenswood Phase 1 Actions Level of Significance: No Impact