Chapter 8
Geology and Soils

8.1 Environmental Setting

8.1.1 Introduction and Sources of Information

This chapter describes the geology, soils, and seismicity in the project area. It includes regulatory, regional, and project settings to provide a context for analyzing the effects of the project. Sources of information used in preparation of this chapter, in addition to regulations, include various maps, articles, tables, and reports from USGS. Information about the regional and project settings obtained from USGS includes data pertaining to slides and earthflows, soil types, fault lines, Quaternary deposits, and liquefaction susceptibility. Additionally, information was obtained from reports published by scientists/geologists working in the San Francisco Bay area and conversations with engineers familiar with the project area.

8.1.2 Regulatory Setting

Various state and local regulations apply to geologic hazards and geotechnical practice in the Bay Area. These include the California Alquist-Priolo Earthquake Fault Zoning Act, the Seismic Hazards Mapping Act, and the uniform building code (UBC), as well as county and city regulations that address geologic hazards as they relate to grading and construction activities. The following sections provide additional information on the three primary geologic/geotechnical regulations.

8.1.2.1 Alquist-Priolo Earthquake Fault Zoning Act

California's Alquist-Priolo Earthquake Fault Zoning Act (California Public Resources Code Section 2621 *et seq.)* was originally enacted in 1972 as the Alquist-Priolo Special Studies Zones Act and was renamed in 1994. The Alquist-Priolo Act prohibits the location across the traces of active faults of most types of structures intended for human occupancy and strictly regulates construction in the corridors along active faults (earthquake fault zones). The act is intended to reduce the hazard to life and property from surface fault ruptures during earthquakes. It also defines criteria for identifying active faults, giving legal definition to terms such as *active*, and establishes a process for reviewing building proposals in and adjacent to earthquake fault zones.

Under the Alquist-Priolo Act, if faults are “sufficiently active” and “well-defined,” they are zoned differently, and construction along them is regulated more stringently. A fault is thought of as *sufficiently active* if one or more of its segments or strands show evidence of surface displacement during Holocene time (approximately the last 11,000 years). A fault is considered *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).

8.1.2.2 Seismic Hazards Mapping Act

Intended to reduce damage resulting from earthquakes, the Seismic Hazards Mapping Act of 1990 (California Public Resource Code Sections 2690–2699.6) is similar to the Alquist-Priolo Act. While the Alquist-Priolo Act addresses surface fault rupture, the Seismic Hazards Mapping Act addresses other earthquake-related hazards, including strong ground shaking, liquefaction, and seismically induced landslides. Its provisions are conceptually similar to those of the Alquist-Priolo Act. The state is charged with identifying and mapping areas at risk of strong ground shaking, liquefaction, landslides, and other corollary hazards, and cities and counties are required to regulate development in mapped seismic hazard zones.

Permit review is the primary method for local regulation of development under the Seismic Hazards Mapping Act. More specifically, cities and counties are prohibited from issuing development permits for sites in seismic hazard zones until appropriate site-specific geologic and/or soils investigations have been carried out and measures to reduce potential damage have been incorporated into the development plans.

8.1.2.3 Construction Permitting and Site-Specific Geotechnical Investigations

Construction activities are regulated by local jurisdictions through a multistage permitting process. Construction permitting is overseen by the immediate local jurisdiction. Projects proposed for unincorporated lands require county permits; projects in incorporated areas (within city limits) usually require only city permit review. Grading and building permit applications both require completion of a site-specific geotechnical evaluation overseen by a state-certified engineering geologist and/or geotechnical engineer.

In order to provide appropriate construction design, the site-specific geotechnical investigation provides a geologic basis for development. Geotechnical investigations typically assess the following parameters:

- bedrock and Quaternary geology,
- geologic structure,
- soils, and
- previous history of excavation and fill placement.

As appropriate, they may also address the requirements of the Alquist-Priolo Act and the Seismic Hazards Mapping Act.

8.1.3 Regional Setting

The region is located in California's geologically active Coast Ranges Geomorphic Province. The province is characterized by a series of northwest-trending mountain ranges, valleys, and faults. The dominant geologic processes that have shaped the San Francisco Bay region are active faulting along the San Andreas, Hayward, and other faults; uplift and erosion of the east bay and peninsular hills; and subsidence of the San Francisco Bay basin.

The San Francisco Bay region appears to be a pull-apart basin that has been continuously subsiding since late Quaternary time (the past 700,000 years) in response to local crustal subsidence between the San Andreas and Hayward faults. The stratigraphy beneath the San Francisco Bay region records changes in depositional environments resulting from changes in sea level. The primary geological units that underlie a large part of the San Francisco Bay region are the Alameda Formation, Old Bay Mud, San Antonio Formation, Young Bay Mud, and the Temescal Formation.

Regional geologic features are depicted, within the scope of the area encompassed under the Water Delivery Option, in Figure 8-1.

8.1.3.1 Formations

The Franciscan Formation basement was above sea level and exposed to dissection by rivers and streams. As the basement began to subside between 1,000,000 and 500,000 years ago, the initial unit deposited on its surface was the Alameda Formation. As the basin continued to subside and the sea level abruptly rose at the beginning of the last interglacial episode, about 115,000 years ago, the Pacific Ocean fully entered the region, depositing the Old Bay Mud on top of the Alameda Formation erosional surface. The Old Bay Mud is thicker than 50 feet beneath the central part of the bay, with a maximum thickness of more than 100 feet just east of Yerba Buena Island. During the Wisconsin glacial stage, the sea level fell, exposing the Old Bay Mud to subaerial erosion. The San Antonio

Formation was deposited onto the Old Bay Mud. The San Antonio Sediment, typically 25 feet thick, was deposited in complex, dynamic depositional environments that include alluvial fans, floodplains, lakes, swamps, and beaches. The individual units are discontinuous and difficult to correlate regionally. Young Bay Mud was deposited on top of the San Antonio Formation after another rise in sea level beginning between 11,000 and 8,000 years ago. Young Bay Mud is a series of unconsolidated muds deposited in quiet water characterized by high initial void ratios and low unit densities.

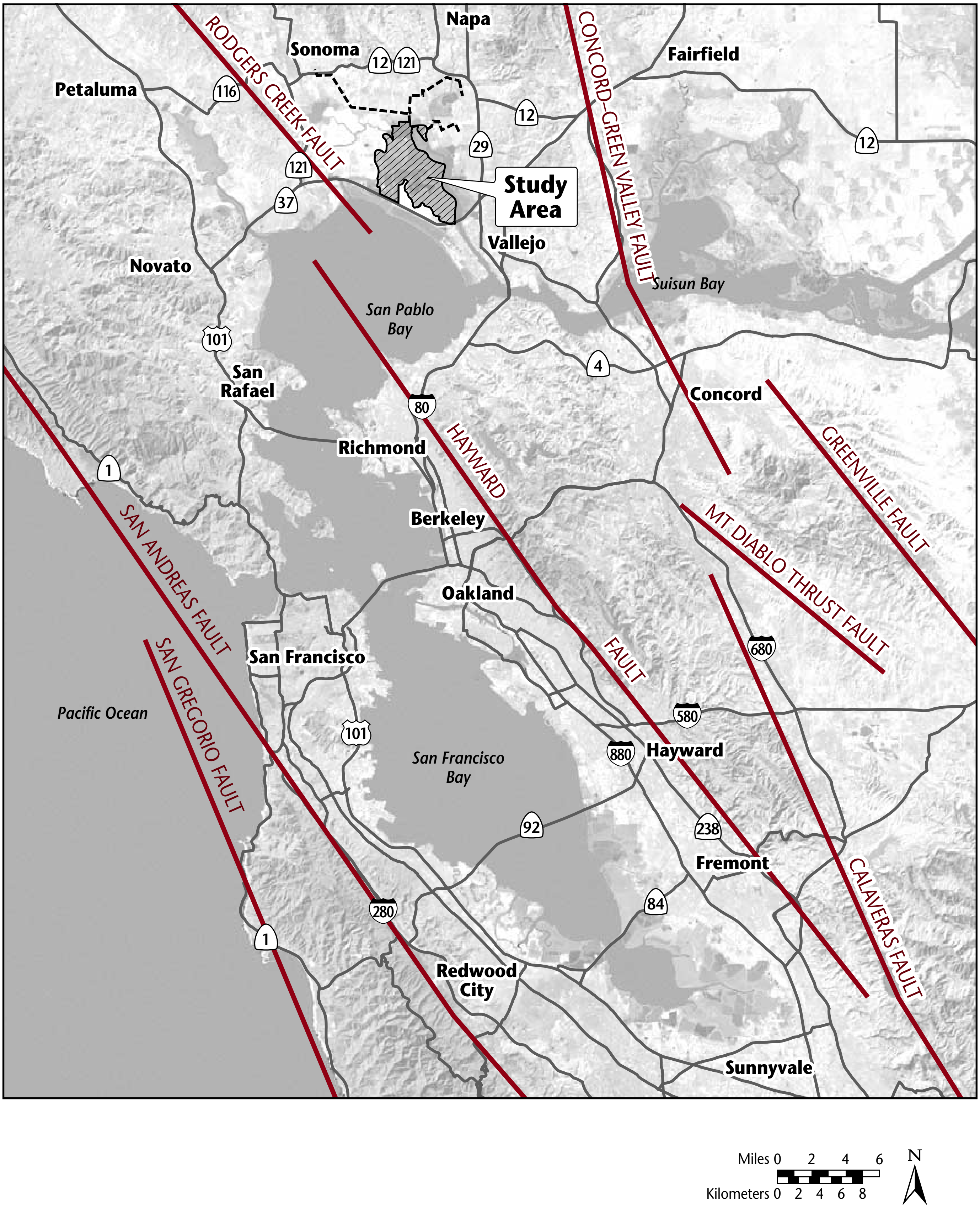
The San Francisco Bay area lies within the active San Andreas fault system. Major faults in the area include the Hayward, San Andreas, Calaveras, and Concord faults (Figure 8-2). The region is therefore subject to potential significant ground shaking from earthquakes along these faults and other faults in the San Andreas system.

During the last 160 years, the San Andreas fault system has produced numerous small-magnitude and a dozen moderate- to large-magnitude earthquakes (magnitude >6) in the Bay Area (SAIC 1997). USGS has estimated a 70% probability that one or more earthquakes with a Richter magnitude of 6.7 or greater will occur in the Bay Area in the 30-year period between 2000 and 2030 (U.S. Geological Survey 1999). The Working Group on California Earthquake Probabilities estimated an approximately 67% probability of one or more large (magnitude >7) earthquakes occurring in the Bay Area between 1990 and 2020.

8.1.3.2 Tsunamis

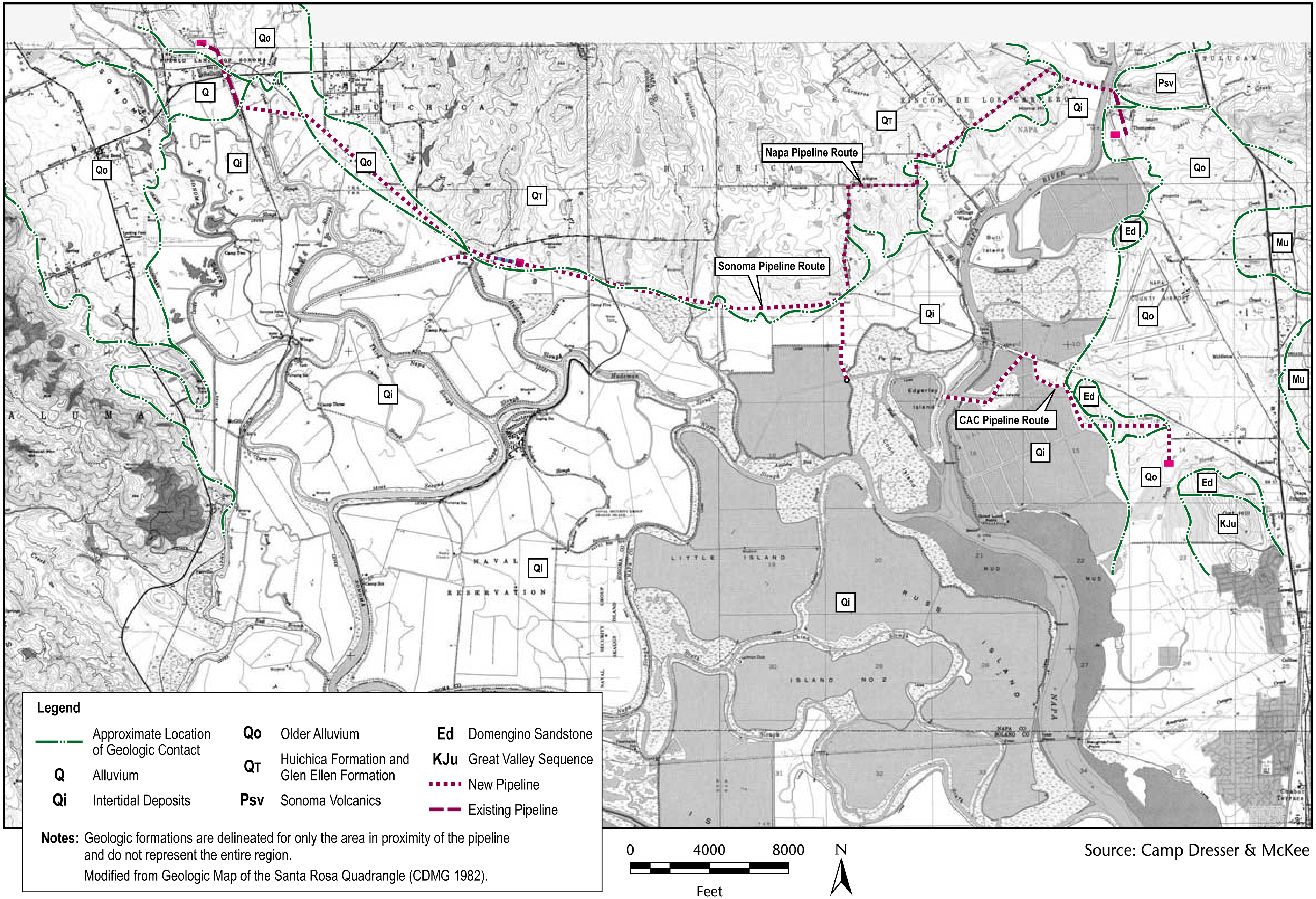
Tsunamis are seismically induced floods caused by the transfer of energy from an earthquake epicenter to coastal areas by ocean waves. Although tsunamis are generated in many areas around the Pacific Rim, only Alaska’s Aleutian Trench could generate tsunamis capable of causing significant runups in northern California. The last noticeable tsunami observed in San Francisco Bay was the result of the Great Alaskan Earthquake of 1964. Significant damage along the west coast from that tsunami was restricted to Crescent City, located on unprotected coastline more than 250 miles northwest of the project area. Also, the project area is located adjacent to the bay. Tsunami heights are greatly reduced once they enter the bay through the Golden Gate Gap.

Tsunamis that enter San Francisco Bay decrease in height within the bay. The Great Alaskan Earthquake produced a maximum recorded runup of 7.5 feet at the Golden Gate Bridge, but no significant damage was reported. Because San Francisco is oblique, not direct, to waves traveling from Alaska, wave magnitudes were significantly weakened.



Jones & Stokes

Figure 8-1
Regional Faults



Notes: Geologic formations are delineated for only the area in proximity of the pipeline and do not represent the entire region.

Modified from Geologic Map of the Santa Rosa Quadrangle (CDMG 1982).

Source: Camp Dresser & McKee

Jones & Stokes

Figure 8-2
Geologic Formations

8.1.4 Project Setting

The following sections provide additional information on the topography, geology, soils, and known geologic hazards of the project site and adjacent areas. Each of the sections below discusses the following:

- the project area for the salinity reduction and habitat restoration options (i.e., the Napa River Unit);
- the area for the Project Component of the Water Delivery Option (i.e., the corridors along the Napa, Sonoma, and CAC Pipelines); and
- the area for the Program Component of the Water Delivery Option (i.e., the connection of effluent pipelines from the LGVSD, Novato SD, and City of Petaluma WWTPs).

8.1.4.1 Topography

Napa River Unit

The Napa River Unit consists primarily of former mudflats and marshlands that have been isolated from tidal action by levees. These levees extend along the banks of the Napa River and surround the individual ponds formerly used in the production of salt. The Napa River levees are owned and maintained by local public agencies and private property owners. The salt pond levees are currently owned by the State of California and are not maintained for flood protection purposes.

Water Delivery Project Component Area

The corridors for the Sonoma, CAC, and Napa- Pipelines share similar flatland topography, except for isolated areas along localized stream channels and drainage culvert locations. Elevations range from approximately 15 feet to less than 3 feet above sea level for the Sonoma Pipeline, approximately 45 feet to less than 5 feet above sea level for the CAC Pipeline, and approximately 0 to 200 feet above sea level for the Napa Pipeline.

A vast majority of the land within both alignments was once mudflats and marshland reclaimed from San Pablo Bay by levees. Slope gradients vary from nearly horizontal to gently sloping (less than 3 feet horizontal to 1 foot vertical [3:1]) over most of the project corridor~~)~~.

Water Delivery Program Component Area

The pipeline corridors proposed under the Program Component of the Water Delivery Alternative would generally follow road, highway, and railroad easements. The corridor "segments" are discussed individually below.

Las Gallinas Valley Sanitation District Wastewater Treatment Plant to U.S. 101–State Route 37 Junction

The LGVSD WWTP is located at near sea level to 20 feet above sea level. The topography of the pipeline corridor ranges from sea-level mudflats to foothills up to several hundred feet above sea level. From the WWTP site to U.S. 101, elevations vary from 3 feet to 30 feet above sea level along Smith Ranch Road. Along U.S. 101 between Smith Ranch Road and SR 37, elevations range from 30 feet to 200 feet above sea level.

Novato Sanitation District Wastewater Treatment Plant to U.S. 101–State Route 37 Junction

The Novato SD WWTP is located at or slightly below sea level along mudflats. Elevations from the WWTP to U.S. 101 along Davidson Street vary from sea level to 40 feet above sea level. From U.S. 101 at Davidson Street to the U.S. 101–SR 37 junction, elevations range from 4 feet to 40 feet above sea level.

U.S. 101–State Route 37 Junction to State Route 37–Lakeville Highway Junction

The pipeline corridor from the point where the LGVSD WWTP and Novato SD WWTP pipelines would converge (at the junction of U.S. 101 and SR 37) to the junction of SR 37 and the Lakeville Highway (from Petaluma) is characterized by largely coastal flatland topography, with elevations ranging from sea level to 40 feet above sea level.

City of Petaluma Wastewater Treatment Plant to Lakeville Highway–State Route 37 Junction

The City of Petaluma WWTP is located on coastal flatland, bordered to the south by mudflats, with elevations ranging from sea level to 10 feet above sea level. From the WWTP to the Lakeville Highway–SR 116 junction (along SR 116), the topography is characterized by rolling hills near coastal flatlands, with elevations ranging from 16 feet to 75 feet above sea level. From the SR 116–Lakeville Highway junction to the SR 37–Lakeville Highway junction (along the Lakeville Highway), elevations range from sea level to 65 feet above sea level.

State Route 37–Lakeville Highway Junction to the State Route 37–State Route 121 Junction

From the SR 37–SR 121 junction, coastal flatland topography at elevations of about 2 feet above sea level increase (traveling east) to foothills at elevations reaching over 165 feet along SR 37. Elevations return to approximately sea level at the intersection with SR 121.

State Route 37–State Route 121 Junction to Southern Pacific Railroad–Ramal Road Intersection

The corridor runs through coastal mudflats (separated by levees) along existing Southern Pacific Railroad tracks at elevations of about 7–11 feet above sea level, surrounded by flatlands at, or below, sea level. At the point where the railroad tracks cross Redding Road, the corridor follows an existing dirt road (after crossing Steamboat Slough) along Steamboat Slough at elevations of 4–9 feet above sea level. From the dirt road, the corridor meets the corridor for the Sonoma Pipeline (proposed under the Project Component of the Water Delivery Alternative) at the intersection of the Southern Pacific Railroad tracks and Ramal Road, at an elevation of 13 feet above sea level.

8.1.4.2 Geology (Stratigraphy)

Napa River Unit

The Napa River Unit lies at the north margin of San Francisco Bay, which occupies a late Pliocene structural depression encompassing the Santa Clara Valley to the south and the Petaluma, Sonoma, and Napa Valleys to the north (Norris and Webb 1990). The project area is situated in a lowland area underlain by sediments deposited in the Bay-Delta estuary over the last 2 million years.

The entire Napa River Unit is underlain by varying thicknesses of Bay Mud, a soft compressible organic-rich marine deposit of silt and clay with peat and local, thin sand and gravel lenses. San Francisco Bay has two units of Bay Mud: Young Bay Mud is nearest the surface, with Old Bay Mud (Yerba Buena Formation) found below. Nonmarine deposits, including alluvial deposits, lie between the Young and Old Bay Mud, underlie the Old Bay Mud, and also irregularly flank the margins of the marsh area. The hills that bound the Napa River Unit and the Napa and Sonoma Valleys are underlain by a variety of rock units, the most important of which are the Franciscan Formation (sandstone, shale, serpentine, and other rocks), the Chico Formation (mostly marine sandstone), the Merced Formation (Tertiary marine sands and sandstone), and the Sonoma volcanic (Tertiary volcanic flows and tuffs).

Water Delivery Project Component Area

The following sections describe the geologic units that underlie the preferred Sonoma, CAC, and Napa Pipeline alignments. The stratigraphic units described here are based on review of geologic maps for the area, except for artificial fill (California Division of Mines and Geology 1982a). Artificial fill was observed along much of the pipeline alignment corridors. Only units that would be encountered during construction are described below.

~~Summary of Earthen Materials~~

~~In summary, earthen materials likely to be encountered along all three pipeline corridors include artificial fill, native soil, Young Bay Mud, and interfluvial basin~~

~~deposits. Table 8-1 presents some of the geotechnical constraints that these materials may present to project construction.~~

Artificial Fill

Artificial fill exists extensively along the Sonoma, CAC, and Napa Pipeline alignments as evidenced by railroad and street improvements. The depth of artificial fill likely varies from a few feet up to approximately 10 feet. While information is limited to the characteristics of this deposit, artificial fill is likely composed of sand, silt, and clay mixtures originating from adjacent nearby surficial deposits. Because of the heterogeneous nature of fill materials placed along the project corridor and unknowns regarding their sources, these materials may have corrosive characteristics.

Alluvium

Young alluvium (Q) underlies a small portion of the Sonoma Pipeline near the WWTP along the NWPRA corridor. This unit is composed of loosely consolidated sand, silt, and clay mixtures with rocks up to boulder size. This unit is susceptible to liquefaction, given its loosely consolidated nature and the relatively shallow depth to groundwater.

Intertidal Deposits

Holocene age intertidal deposits (Qi) underlie or border most of the Sonoma, CAC, and Napa Pipeline corridors. These deposits are composed of soft mud and peat deposits in marshes, swamps, and adjacent waterways (California Division of Mines and Geology 1982a). The deposits interfinger with younger alluvial deposits. This unit is generally less than 20 feet thick along the pipeline alignment (California Division of Mines and Geology 1980). Intertidal deposits have poor engineering characteristics and are subject to failure during severe ground shaking.

Older Alluvium

Older alluvium (Qo) is mapped beneath the northern portion of the Sonoma Pipeline alignment. This Pleistocene unit consists of dissected alluvial deposits composed chiefly of loosely consolidated sand, silt, and clay mixtures with rocks up to boulder size. Older alluvium, as with other local deposits, is highly susceptible to liquefaction, given its loosely consolidated nature and the relatively shallow depth to groundwater.

Domengio Sandstone

The Domengio Sandstone (Ed) is Eocene-age marine quartzose sandstone and has good engineering characteristics.

Huichica Formation and Glen Ellen Formation

The Huichica Formation (Qt) of the Pleistocene age is composed of reworked tuff, weathered volcanic clay, and silt. The Glen Ellen Formation is of Plio-Pleistocene age and is composed of a heterogeneous mixture of pale buff clay, silt, sand, and gravel.

Summary of Earthen Materials

In summary, earthen materials likely to be encountered along all three pipeline corridors include artificial fill, native soil, Young Bay Mud, and interfluvial basin deposits. Table 8-1 presents some of the geotechnical constraints that these materials may present to project construction.

Table 8-1. Geotechnical Constraints of Earthen Materials

	Potential Constraint							
Material Type	Possible damage to concrete because of corrosive characteristics	Cracks in pavement or foundations resulting from high shrink/swell potential	Excessive foundation settlement resulting from high compressibility	Difficulty in excavating because of oversized materials	Instability during earthquakes because of weak or liquefiable nature	Reusability as engineered fill	Low R-value	Unsuitability as subgrade for roadways because of yielding
Fill	✓	✓	✓		✓	✓	✓	
Alluvium (Q)		✓	✓	✓	✓	✓	✓	✓
Intertidal deposits (Qi)	✓	✓	✓		✓		✓	✓
Older alluvium (Qo)	✓	✓	✓	✓	✓	✓	✓	✓
Huichica formation/Glen Ellen formation (Qt)	✓	✓	✓			✓	✓	✓
Domengio sandstone (Ed)						✓		

Water Delivery Program Component Area

The geologic units in the area of the Program Component of the Water Delivery Alternative are similar in composition to those in the Project Component area. The units largely consist of Holocene and Pleistocene alluvial deposits and bedrock. The geologic units (terranes) in the Program Component area are composed almost exclusively of Franciscan Complex and Great Valley Complex rock. The majority of the potential future pipeline alignments would be located on alluvial deposits, which exhibit low shear strength and are susceptible to failure during seismic events.

8.1.4.3 Soils

Napa River Unit

Napa River Unit soils are all of the Reyes series. These soils are silty clays deposited primarily by sediment-laden bay waters, but also by tributary freshwater streams. Slopes in the marsh range from 0 to 2%, but most are less than 1%. The soil is acidic in its undeveloped state; permeability is low; and the erosion hazard of these soils is considered low. Levees in the project area were constructed from native bay muds of varying degrees of compaction/hardness, and were repaired using similar material (Huffman pers. comm.).

Because the levees were constructed with native material, bay muds, they are subject to erosion from wind/wave action and tidal inundation. Preliminary geotechnical surveys of the levees and a report from the on-site manager are depicted in Figure 2-2 in Chapter 2. The available information indicates the following:

- Ponds 1 and 1A have effectively become one large pond because of a breach in the levee between the two ponds. The eastern levee of Pond 1 needs to be reinforced in the next 5 years as it serves as an important staging area for individuals that need to access the pumphouse and caretaker facilities. The levee is also used as a parking lot by members of the Can Duck Club (a duck-hunting club). The northern levee of Pond 1A bordering South Slough needs reinforcement or it may be lost.
- The north and northeast levees from Pond 2 are likely to breach within the next 5 years unless they are repaired. Because of the high wind/wave action and past inability to regulate water levels in this pond, the crest of the levee is only 4–5 feet wide and has been undercut 2–3 feet in some areas.
- Approximately one-third of the eastern portion of the levee along the southern edge of Pond 3 is likely to breach within the next 5–10 years.
- Levees along the outside bends of Ponds 3, 4, and 5 have obvious scour/steep banks and are vulnerable to levee breaching within the next 5–10 years.
- There is substantial erosion of the outboard levee toe along Napa Slough on the west side of Pond 6A, just north of the dividing levee between Ponds 6 and 6A. There is also erosion on the north levee of the canal that runs along the north and east levees of Pond 6A. The eroded area is on the outboard edge (on Napa Slough) on the outer canal levee. This section of levee (approximately 100 feet long) is high and narrow with a steep dropoff into the slough. The majority of the west and north levees of Pond 6A have strips of accreted marsh protecting the existing levees.
- Significant erosion from wind/wave action is apparent at the levee between Ponds 7 and 7A.

Generally, erosion in the sloughs is low as mudflats and lower marshes have formed.

The National Earthquake Hazards Reduction Program has defined five soil types (A–E) based on their shear-wave velocity (Vs). Soils with a low shear-wave velocity experience stronger shaking, whereas soils with a high shear-wave velocity experience weaker shaking. The project site is composed predominantly of type E soil. Soil type E, composed of water-saturated mud and artificial fill, has the lowest shear-wave velocities (less than 200 meters per second) of all of the five soil types. Therefore, the strongest amplification of shaking from earthquakes is expected for this soil type.

Water Delivery Project Component Area

Sonoma Pipeline Alignment

Soils associated with the Sonoma Pipeline are assigned to the Clear Lake-Reyes, Haire-Diablo, and Huichica-Wright-Zamora associations. Soils assigned to the Haire-Diablo association underlie the area surrounding the SVCSD WWTP. The Haire-Diablo association soils are characterized as moderately well drained and well drained, gently sloping to steep fine sandy loams to clays on terraces and uplands. After crossing SR 12/121, the soils transition to the Clear Lake-Reyes association, which are characterized as poorly drained, nearly level to gently sloping clays to clay loams in basins and on tidal flats. Near the *Wye*, the soils transition to the Huichica-Wright-Zamora association, which are characterized as somewhat poorly drained to well drained, nearly level to strongly sloping loams to silty clay loams on low bench terraces and alluvial fans (U.S. Department of Agriculture 1972).

CAC Pipeline Alignment

Soils associated with the CAC Pipeline are assigned to the Reyes-Clear Lake and Haire-Coombs units. Reyes-Clear Lake soils predominate through the portion along Green Island Road and are characterized as poorly drained silty clay loams and clays deposited on tidal flats, in basins, and on basin rims. Haire-Coombs series soils are mapped near the western terminus of the pipeline segment along Green Island Road and extend to the end of the existing pipeline segment under the Napa River. Haire-Coombs series soils are characterized as nearly level to moderately steep, moderately well drained and well drained gravelly loams, loams, and clay loams on terraces.

Napa Pipeline Alignment

Soils associated with the Napa Pipeline are assigned to the Reyes–Clear Lake and Haire-Coombs units. Soils assigned to the Reyes–Clear Lake association underlie the proposed pipeline as it leaves the WWTP and crosses the Napa River. ~~Reyes–Clear Lake soils are characterized as poorly drained silty clay loams and clays deposited on tidal flats, in basins, and on basin rims.~~ As the pipeline heads southeast and then east on Las Amigas, it encounters Haire-Coombs soils. ~~This soil association is characterized as nearly level to moderately steep, moderately well-drained, and well-drained gravelly loams, loams, clay loams on terraces.~~

Water Delivery Program Component Area

The soil composition along the pipeline corridors under the Program Component of the Water Delivery Alternative includes

- Holocene San Francisco Bay Mud (Qhbm),
- Holocene alluvial fan deposits (Qhf),
- artificial fill and artificial fill over Bay Mud (af/afbm),
- undifferentiated Holocene alluvium (Qha),

- late Pleistocene fan deposits (Qpf),
- late Pleistocene to Holocene fan deposits (Qf),
- early to late Pleistocene undifferentiated alluvial deposits (Qoa), and
- pre-Quaternary deposits and bedrock (br).

Almost all of the areas proposed for the Program Component pipeline corridors occur on artificial fill (used for street/highway and railroad bed materials) over alluvial deposits and mud.

8.1.4.4 Seismicity

Napa River Unit

The Napa River Unit is located between the Rodgers Creek fault and the Concord–Green Valley fault and just north of the northern end of the Hayward fault (Figure 8-2). The closest fault is the northwest trending Rodgers Creek fault. The southern tip of this fault lies approximately 2 miles west of the project site. The Concord–Green Valley fault is approximately 15 miles to the east. The northern section of the Hayward fault, about 3 miles south of the project site, has a 32% probability of one or more magnitude 6.7 earthquakes over the next 30 years (U.S. Geological Survey 1999).

Ground shaking is the primary cause of earthquake damage to human-made structures, including levees. Areas with soft soils tend to experience stronger seismic shaking than others. Soft soils amplify ground shaking; the influence of the underlying soil on the local amplification of earthquake shaking is called the *site effect*.

Other factors influence the strength of earthquake shaking at a site as well, including the earthquake’s magnitude and the site’s proximity to the fault. These factors vary from earthquake to earthquake. Soft soil always amplifies shear waves. If an earthquake is strong enough and close enough to cause damage, the damage will usually be more severe on soft soils. As stated previously, the project is located on soft soils, with low shear-wave velocities that amplify shaking.

Primary Seismic Hazards—Surface Fault Rupture and Ground Shaking

No active faults have been mapped in the Napa River Unit and none of the former salt ponds are in an earthquake fault zone designated by the state under the Alquist-Priolo Act (California Division of Mines and Geology 2000). However, the active Rodgers Creek fault has been mapped as far south as Sonoma Creek (California Division of Mines and Geology 2000) and likely extends farther southeast across Sonoma Creek and south of SR 37. According to USGS and special studies maps, the Rodgers Creek fault lies approximately 2 miles west of the site. The potential for ground rupture during an earthquake is limited to areas within 250 feet of a fault. Thus, the Rodgers Creek fault does not pose a threat of ground rupture at the project site.

Each of the 12 salt ponds has the potential to experience ground shaking as a result of seismic activity on any of the Bay Area's principal active faults. Moreover, the salt ponds are almost exclusively located on unconsolidated sediments, with Bay Mud composing each of the surrounding levees. This type of substrate has been shown to amplify and prolong ground shaking, particularly during large seismic events, and Bay Mud has a high propensity for liquefaction (U.S. Geological Survey 2000c).

Secondary Seismic Hazards—Liquefaction and Ground Failure

The 12 ponds in the Napa River Unit are located almost exclusively in areas where the existing risk of seismically induced liquefaction is high. In addition to liquefaction, corollary risks associated with seismic ground shaking include settlement in unconsolidated or weakly consolidated sediments, and lurching or lurch cracking in soft, saturated materials. Fine-grained sediments (including Bay Mud) and bedrock are unlikely to experience substantial settlement as a result of ground shaking. However, the Bay Mud that underlies much of the project site and composes the levees is considered susceptible to lurching, particularly where deposits are bordered by steep channel banks or adjacent hard grounds (Jones & Stokes 1998).

Landslide Hazards

Landslides are slides and earth flows that can pose serious hazard to property in the hillside terrain of the San Francisco Bay region. The best available predictor of where slides and earth flows might occur is the distribution of past movements (U.S. Geological Survey 2000). These landslides can be recognized from their distinctive topographic shapes, which can persist in the landscape for thousands of years.

Existing landslide hazards are minimal or nonexistent at the ~~project site~~ Napa River Unit because surface gradients are very gentle. A review of slides and earth flows for Napa County revealed that the project site is in an area of gentle slope at low elevation that has little or no potential for the formation of slumps, translational slides, or earth flows except along streambanks and terrace margins (Wentworth et al. 1997). Therefore, landslides pose little threat in the project area.

Water Delivery Project Component Area

The San Francisco Bay region is considered by geologists and seismologists to be seismically very active. Earthquakes generated along active faults may result in very strong ground motion that can cause surface rupture and severe shaking damage to structures and destabilize ground. Table 8-2 summarizes nearby active faults with respect to their closest distance from the specified pipeline corridor, maximum moment magnitude, and expected peak ground acceleration based on the likelihood of earthquake occurrence on any regional fault (probabilistic approach using chance of 10% exceedance in 50 years, alluvium conditions) (California Division of Mines and Geology 1994, 1996, 1999). Figure 8-2~~1~~ shows the location and proximity of identified active faults to the pipeline alignments.

Table 8-2. Significant Regional Faults and Preliminary Seismic Values for Hazard Assessment

Fault	Approximate Distance from Site [a] (kilometers)	Maximum Moment Magnitude [b]
Sonoma Pipeline		
Rogers Creek Fault	5.8	7.0
San Andreas Fault	3.3	7.9
CAC Pipeline		
West Napa Fault	0	6.5
Green Valley Fault	0.8	6.9
Napa Pipeline		
West Napa Fault	1.0	6.5
Green Valley Fault	11.2	6.9
Cordelia Fault	12.8	6.7
Rodgers Creek Fault	16.0	7.0

Note:
[a] Distance from site to closest point on the identified fault
[b] from California Division of Mines and Geology Open-File Report 96-08
Source: California Division of Mines and Geology 1999.

As shown in Figure 8-1, the Sonoma and Napa Pipelines are not currently located within a special studies zone for active faults (California Division of Mines and Geology 1992). No known active or potentially active faults occur along either alignment. However, the CAC Pipeline intersects the southern segment of the active West Napa fault (California Division of Mines and Geology 1994). This fault lies to the east of the CAC Pipeline alignment and is projected to intersect the pipeline alignment west of Napa Junction.

Fault Rupture

Sonoma Pipeline. No known active faults or fault segments are mapped within the Sonoma Pipeline corridor; therefore, the potential for surface rupture because of faulting is considered low.

CAC Pipeline. As previously described, the CAC Pipeline runs to the east of the southern segment of the West Napa fault near Napa Junction. Therefore, the potential for surface rupture because of faulting is considered high during its designated maximum moment magnitude event of M_m=6.5.

Napa Pipeline. No known active faults or fault segments are mapped within the Napa Pipeline corridor; therefore, the potential for surface rupture because of faulting is considered low.

Ground Shaking

Collapsed structures, cracked walls or foundations, broken utility lines, cracked pavement, and ground failure may occur as a result of strong ground shaking during a major seismic event. Most earthquake damage is the result of ground shaking and its secondary effects (liquefaction, lurching, lateral spreading, and settlement).

USGS estimates the rates of occurrence of earthquakes and 30-year earthquake probabilities (U.S. Geological Survey 1999). The USGS study considers a range of magnitudes for earthquakes on the major faults in the region. The California Division of Mines and Geology (CDMG) also has an estimate of the range of peak ground accelerations (g) (a measure of the intensity of ground shaking during an earthquake) expected in the vicinity of the project corridor. This range may exceed 0.70 g during a major earthquake (California Division of Mines and Geology 1999). This estimate is based on probabilistic criteria of 10% chance of exceedance in 50 years and considers underlying alluvium conditions.

In addition, the majority of ~~both~~ the three pipeline alignments are underlain by shallow groundwater and soils that are conducive to liquefaction. This condition, coupled with the proximity of the pipelines to faults capable of high ground acceleration makes the underlying soils highly prone to ground failure, including liquefaction and settlement (California Division of Mines and Geology 1982b). As a result, most of the project is susceptible to the effects of ground shaking.

Unconsolidated alluvial deposits, including Bay Mud, have a lower shear velocity, which dampens ground motion and decreases peak ground accelerations. However, depending on the direction of wave propagation of the ground motion and the underlying geologic conditions, localized ground amplification effects may cause an increase in peak ground acceleration, particularly in the more damaging vertical direction. This amplification effect was experienced during the Loma Prieta earthquake that occurred on October 17, 1989, where the I-880 Cypress Freeway structure located in Oakland (62 miles from the earthquake's epicenter on the San Andreas fault, and more than 10~~7~~ miles from the project corridor) collapsed as a result of strong ground motions that were greater than in many areas closer to the causative fault.

Liquefaction

Soil liquefaction is the sudden and total loss of soil strength during earthquake-induced ground motion. Liquefaction occurs in loose, saturated, clean sand where ground shaking increases effective pore pressure resulting in the displacement of individual sand grains and groundwater. During liquefaction, the soil transforms into a fluid-like state, allowing displacement of water and the potential mobilization of sand if not confined. Soil liquefaction potential is governed by the physical properties of the soil, such as sediment grain size distribution, compaction, cementation, saturation, layer thickness, and depth. Liquefaction is also governed by the degree and duration of ground motion.

Based on review of the Association of Bay Area Governments' (ABAG's) Regional Liquefaction Map and other supporting documents, the entire project corridor is susceptible to liquefaction (California Division of Mines and Geology

1980, 1982a). Loose, poorly consolidated, saturated sand deposits that are expected to experience strong ground motion during a major seismic event underlie the area. Induced settlement, sand boils at the surface, foundation failures, and abrupt ground loss can be caused by liquefaction.

Ground Lurching

Ground lurching is the horizontal movement of ground located adjacent to slope faces during strong, earthquake-induced ground motion. The results of ground lurching include longitudinal cracking parallel to the slope face at some distance setback from the top of the slope. Areas along the pipeline ~~project~~ corridors particularly susceptible to ground lurching as a result of fill placement over soft Bay Mud and slope exposures include the section of the NWPRA rail corridor approaching the Wye and continuing east past Buchli Station Road and northeast toward the Stanly Ranch property (Figure 8-2). Other fill embankments located within the project corridor may be susceptible to ground lurching.

Lateral Spreading

Lateral spreading is the horizontal displacement of soil during strong, earthquake-induced ground motion. It occurs in loose, unconfined sedimentary and fill deposits but can also occur in consolidated fills over loose sand or soft mud deposits.

Some potential exists for lateral spreading to occur along pond levees and a portion of the Sonoma Pipeline along the section of the Northwestern Pacific Railroad corridor approaching the Wye and continuing east past Buchli Station Road and northeast toward the Stanly Ranch property (Figure 8-2).

Tsunamis and Earthquake-Induced Flooding

A review of existing data on regional tsunami potential and magnitude, predictions of rates of sea-level rises, and potential settlement rates from similar sites indicates that the pipeline surface grade is unlikely to~~may~~ experience earthquake-induced flooding.~~ However, considering that the pipeline would be below grade and that inundation would occur in low-elevation areas that are marginal to estuary waters or tidal sloughs, the resultant risk potential to the project is low.~~

~~A tsunami with a wave height of 20 feet at the Golden Gate Bridge that is predicted to occur approximately once every 200 years would result in a wave height above 10 feet south of the project corridor along South Airport Drive (Ritter and Dupre 1972). However, i~~Inundation hazards from tsunamis, wave run-up, sea level rise, or settlement are minimal because the lower project area is located in existing marshland and much of the potential wave energy would be attenuated before reaching the project areas.

Other Geotechnical Considerations

Other geotechnical considerations include settlement, erosion, landslides, and shallow groundwater.

Settlement. Earthen materials underlying the pipeline corridors are prone to settlement from increased vertical loads resulting from fill placement. If additional loads are placed as a result of construction of the pipelines, increases in the rate and amount of settlement can be expected. In addition, as previously discussed under seismic hazards, settlement resulting from loss of soil strength during a major earthquake (i.e., liquefaction) may occur. High potential for settlement exists along the new segments of pipeline for the Sonoma, CAC, and Napa Pipelines.

Erosion. In general, soil underlying the project corridor is characterized as having low to moderate erosion potential. Erosion would be expected at unlined drainage channels and culverts that intersect the pipeline alignment.

Landslides. Because the general ~~flatland~~ topography encompassing the project corridors is flat, the risk of landslides is low, except for one location on the Sonoma Pipeline. An isolated area near Merazo along the Sonoma Pipeline is characterized as an area of “relatively low slope stability” (California Division of Mines and Geology 1980). Other areas along the pipeline corridors have the potential for experiencing relatively small “pop-outs” that could be considered a form of landslide.

Shallow Groundwater. Groundwater beneath the pipeline corridors is considered shallow, less than 10–15 feet below the ground surface. Geotechnical consequences of shallow groundwater conditions include, but are not limited to, special dewatering requirements during excavation/construction, ground instability affecting earthwork activities, and excessive water pressure and infiltration acting upon belowgrade facilities and structures.

Water Delivery Program Component Area

Because of the regional effects of seismic events, the seismic conditions for the area of the Program Component of the Water Delivery Alternative are nearly the same as those of the Project Component area.

Fault Rupture

The corridors for the potential future pipelines are located around the western edge of San Pablo Bay, between the San Andreas and Rodgers Creek faults. The corridors are in the vicinity of, and could be affected by, the San Andreas fault and the northern Hayward fault; however, the Program Component area is not located within an Alquist-Priolo fault hazard zone for these faults. The Water Delivery Program Component area is located very near, and a potential future pipeline corridor may cross, the Rodgers Creek fault. The pipeline segment affected by this fault would be within an Alquist-Priolo fault hazard zone. The potential for surface rupture from faulting is considered high for this fault during its designated maximum moment magnitude event of M_m=7.0.

Ground Shaking

The potential for ground shaking of the Water Delivery Program Component area would be similar to that for the Project Component area. The probability of ground shaking during seismic events is essentially identical for both components. Like the Project Component area, the potential future pipeline corridors are characterized largely by unstable alluvial soils that have the potential for failure during periods of strong ground shaking, although the loosely consolidated material may dampen ground motion and decrease peak ground accelerations.

Liquefaction

Because of the predominance of alluvial soils along the Water Delivery Program Component corridors, the corridors are susceptible to liquefaction during seismic events. According to ABAG's Regional Liquefaction Map, the majority of the Water Delivery Program Component area is characterized by high to very high susceptibility to liquefaction.

Ground Lurching

The Water Delivery Program Component area has potential for ground lurching similar to that of the Project Component area. The Program Component area is predominantly flat or gently sloping, with some steeper slopes composed mostly of rock, which exhibits little potential for instability and lurching. Areas along Water Delivery Program Component corridors adjacent to slopes with alluvial soils and levees on Bay Mud are more susceptible to ground lurching.

Lateral Spreading

The Water Delivery Program Component would use corridors along existing roadways and railroads built on artificial fill over Bay Mud or other loosely consolidated alluvial soils. As such, the potential for spreading, especially for levees under loads (of cars, trains, or pipelines), is higher than in most parts of the Project Component area.

Tsunamis and Earthquake-Induced Flooding

As with the Project Component area, inundation hazards from tsunamis, wave runup, sea level rise, or settlement in the Water Delivery Program Component area are minimal because the corridors subject to any such impacts are located in existing marshland and much of the potential wave energy would be dissipated.

Other Geotechnical Considerations

Conditions in the Water Delivery Program Component area related to settlement, erosion, landslides, and shallow groundwater are described below.

Settlement. Because of the soil composition along the proposed corridors, the potential for settlement from increased loads is considered high, especially during seismic events.

Erosion. Similar to the Project Component area, soils in the Water Delivery Program Component area have low to moderate erosion potential. As such, erosion would be expected to occur at unlined drainage channels and culverts that intersect the pipeline corridor.

Landslides. Because the topography of most of the Water Delivery Program Component area is flat, the potential for landslides is low. However, in areas adjacent to slopes greater than 25%, the potential for slope failure, particularly during seismic events, is greatly increased. Moderate to high landslide risks occur generally along such slopes, namely along the northeastern side of the Lakeville Highway north of SR 37 and along the western side of SR 121 north of SR 37.

Shallow Groundwater

Subsurface conditions, including groundwater levels, are very similar for the areas of both the Project and Program Components of the Water Delivery Alternative. As such, the Program Component area is anticipated to exhibit groundwater levels at less than 10–15 feet below ground surface in flat lowland areas, and at greater depths in foothill areas.

8.2 Environmental Impacts and Mitigation Measures

8.2.1 Methodology and Significance Criteria

Impacts on geology and soils were analyzed qualitatively based on a review of soils and existing geologic data of the project site. Criteria based on the State CEQA Guidelines were used to determine the significance of geology, soils, and seismicity-related impacts. The project would have a significant impact on geology, soils, and seismicity if it would result in

- exposure of people or structures to potential adverse effects (including the risk of loss, injury, or death) as a result of rupture, ground shaking, or ground failure;
- substantial soil erosion or the loss of topsoil;
- construction of structures on a geologic unit or soil that is unstable or that would become unstable as a result of the project and potentially result in an on- or off-site landslide, lateral spreading, subsidence, liquefaction, or collapse; or
- construction of structures on expansive soils as defined in Table 18-1-B of the UBC (1994), creating substantial risks to life or property.

Furthermore, analysis of impacts related to geology, soils, and seismicity addressed the risk of personal injury, loss of life, and damage to property (including levees, utilities infrastructure, and other structures) with a specific focus on the potential for implementation of the restoration to exacerbate risks associated with known existing geologic hazards, including earthquakes, and tsunamis.

8.2.2 No-Project Alternative

8.2.2.1 Impact Geo-1: Levee Failure as a Result of Strong Seismic Ground Shaking

The project area is likely to undergo strong ground shaking from a major earthquake in the Bay Area within the next 30 years (U.S. Geological Survey 1999). Smaller seismic events are also likely to occur during this timeframe, and seismic hazards will continue to be a factor throughout the lifespan of the project. Moreover, the site is on unconsolidated sediments, which are known to amplify and prolong seismic ground shaking (e.g., Goldman 1969). Levees and utilities are thus at risk from strong seismic ground shaking. Strong seismic activity would cause already deteriorating levees to fail. Levee failure could cause sloughs to plug up. In addition, levee failure could result in a release of highly saline water and bittern into the Napa River, resulting in damage to water quality and aquatic life as described in Chapter 4, “Water Quality.” This impact is considered significant. However, this alternative would result in no project being implemented; therefore, no mitigation is required.

8.2.2.2 Impact Geo-2: Levee Failure as a Result of Erosion

Under the No-Project Alternative, the levees in the project area would continue to deteriorate, primarily through erosion. Erosion may be caused by wind/wave action within the ponds or by scour along the outside of the ponds. In Pond 2 areas, erosion-related levee failure may occur within 5 years; in several other areas, erosion-related levee failure could occur within the next 5–10 years. This impact is considered significant. However, this alternative would result in no project being implemented; therefore, no mitigation is required.

8.2.3 Salinity Reduction Option 1A: Napa River and Napa Slough Discharge

The potential geological impacts associated with the project are similar for all the options. The impacts are generally associated with (1) seismic activity (ground shaking can cause levee rupture and structural damage), (2) levee breaching (potential for soil erosion), and (3) construction of recreational facilities (structures built on expansive soil). The risks of levee failure discussed in this section pertain to the actual potential of the levee to fail and any direct impact on people or structures as a result of that failure.

8.2.3.1 Impact Geo-1: Levee Failure as a Result of Strong Seismic Ground Shaking

As mentioned above under the No-Project Alternative, the project site is likely to undergo strong ground shaking from a major earthquake in the Bay Area within the next 30 years (U.S. Geological Survey 1999). Smaller seismic events are also likely to occur during this timeframe, and seismic hazard will continue to be a factor throughout the lifespan of the project. Moreover, the site is on unconsolidated sediments, which are known to amplify and prolong seismic ground shaking (e.g., Goldman 1969). Levees, water control structures, utilities, and recreational facilities are thus at risk of damage from strong seismic ground shaking.

Under Salinity Reduction Option 1A, repairs and upgrades to existing levees and water conveyance/control structures would be performed. The levees and water control structures would also receive regular maintenance. In addition, new control structures would be engineered to withstand seismic events to the extent practicable. Because of the repairs, proper engineering of new facilities, and ongoing maintenance, this impact is considered less than significant. No mitigation is required.

8.2.3.2 Impact Geo-3: Levee Failure or Structural Damage as a Result of a Rupture of a Known Earthquake Fault

According to USGS and special studies maps, the nearest known and mapped fault is the Rodgers Creek fault, which lies approximately 2 miles west of the project site. Because of the distance to this fault, surface fault rupture is unlikely to pose a substantial risk of personal injury, loss of life, or damage to property in the project site. The potential for ground rupture during an earthquake is limited to areas within 250 feet of a fault. Therefore, this impact is considered less than significant. No mitigation is required.

8.2.3.3 Impact Geo-4: Landslide, Lateral Spreading, Subsidence, Liquefaction, or Collapse as a Result of Construction on Unstable Soils

The project site is underlain almost exclusively by unconsolidated sediments, including Bay Mud. Bay Mud exhibits high compressibility and low shear strength. However, the site levees have been in place since the 1850s, and the site has not experienced landslides, lateral spreading, subsidence, liquefaction, or collapse. The implementation of the project would not increase the risk of any of these hazards.

Repair and maintenance of existing levees would include fill placement and construction on the levees. These activities may impose excess loads on the unstable substrate, potentially leading to subsidence and/or differential settlement. Localized loading (e.g., as a result of levee construction) would likely increase substrate shear stresses and has the potential to result in levee failure if design or construction is inadequate or inappropriate. However, structures would be engineered to withstand seismic events to the extent practicable, and these structures would not be located in an area that would result in the increased exposure of people to adverse effects. Therefore, this impact is considered less than significant. No mitigation is required.

8.2.3.4 Impact Geo-5: Risk to Life or Property as a Result of Construction of Structures on Expansive Soils

Soils at the project site are expansive soils (Reyes clay, Reyes silty clay, and Bay Mud). These soils exhibit shrink-swell behavior (Soil Conservation Service 1972, 1985). Although these soils are expansive, structures would be constructed in accordance with applicable engineering standards and building codes. Thus, shrink-swell behavior would not pose a risk of personal injury, loss of life, or damage to property in the restored tidal marshlands. Although the expansive soils have the potential to affect levees, the levees at the site are not used for flood control; therefore, this impact is considered less than significant. No mitigation is required.

8.2.3.5 Impact Geo-6: Flooding of the Project Area as a Result of Tsunamis

Based on modeling by Garcia and Houston (1975), performed for sites near the project site that are also connected to the bay, both the 100-year tsunami and the 500-year tsunami would have the potential to inundate the project site. The 100-year tsunami would likely produce runups in San Pablo Bay ranging from 3.3 feet along the shore of Tubbs Island (Sonoma Creek and south of SR 37) to 4.1 feet in portions of Novato Creek. Likely runups for the 500-year tsunami range from 3.7 feet at Tubbs Island to 6.3 feet on Novato Creek. Similar runup ranges could be expected at the project site.

Because the final elevation of the marsh and associated levees is undetermined at this time, the effect of a tsunami is uncertain. However, it is known that the gradients at the site would be very gentle, thus increasing the effect of any tsunami that can exceed the height of the outer levees, resulting in inundation of the project site. Because the site consists of tidal marsh and managed ponds, inundation of the project area is not of concern. Under Salinity Reduction Option 1A, no existing levees would be removed; thus there would be no change in the potential for tidal inundation.

The salt ponds themselves would continue to be open space during the salinity reduction phase. Consequently, risk of personal injury or loss of life as a result of tsunami inundation would not be exacerbated by the project and would not represent an increase compared with existing conditions. Recreational users and operations and maintenance staff would be protected from all but proximally generated events by the NOAA’s tsunami warning system. This impact is considered less than significant. No mitigation is required.

8.2.3.6 Impact Geo-7: Potential Erosion as a Result of Excess Pond Water Height

The potential for levee erosion increases as the pond water level increases. Higher water levels in managed ponds (i.e., Pond 1, 1A, 2, 6, 6A, 7, 7A, and 8) would result in windblown waves and potential overtopping during significant storm events. Both of these factors would increase the rate of levee erosion. This impact is considered significant. Implementation of Mitigation Measure Geo-1 would reduce this impact to a less-than-significant level.

Mitigation Measure Geo-1: Maintain Water Level 2 Feet below Levee Crest

The project sponsors will control pond water height through active management of unbreached ponds, reducing the potential for pond erosion.

8.2.4 Salinity Reduction Option 1B: Napa River and Napa Slough Discharge and Breach of Pond 3

Impacts under Salinity Reduction Option 1B are nearly the same as those under Salinity Reduction Option 1A for Impacts Geo-3, Geo-4, Geo-6, and Geo-7. Impacts Geo-1, Geo-5, and Geo-7 are slightly different and are described below. Additional impacts are also described below.

8.2.4.1 Impact Geo-1: Levee Failure as a Result of Strong Seismic Ground Shaking

Because the levee for Pond 3 would be breached intentionally under this option, potential levee failures are of less concern for this pond than under Salinity Reduction Option 1A. This impact is considered less than significant. No mitigation is required.

8.2.4.2 Impact Geo-5: Risk to Life or Property as a Result of Construction of Structures on Expansive Soils

Again, the levee for Pond 3 would be breached intentionally under this option; potential levee failures are of less concern for this pond than under Salinity Reduction Option 1A. While the expansive soils have the potential to affect levees, the levees at the site are not used for flood control; therefore, this impact is considered less than significant. No mitigation is required.

8.2.4.3 Impact Geo-7: Potential Erosion as a Result of Excess Pond Water Height

The potential for levee erosion increases as the pond water level increases. Higher water levels in managed ponds (i.e., Pond 1, 1A, 2, 6, 6A, 7, 7A, and 8) would result in windblown waves and potential overtopping during significant storm events. Both of these factors would increase the rate of levee erosion. However, ~~I~~in Pond 3, a breached pond, water levels are expected to be lower than historical levels because water in the ponds will equilibrate with the tides. This impact is considered significant. Implementation of Mitigation Measure Geo-1, “Maintain Water Level 2 Feet Below Levee Crest,” would reduce this impact to a less-than-significant level. This measure is described under Salinity Reduction Option 1A.

8.2.4.4 Impact Geo-8: Potential Erosion as a Result of Increased Tidal Prism

Breaching of the existing Pond 3 levee under this option would result in an increase in the tidal prism (water volume and potentially velocity) entering and exiting Pond 3, potentially resulting in increased erosion adjacent to the breach. This erosion is intentional and consistent with the habitat restoration effort that would follow shortly after the salinity in Pond 3 is reduced to ambient conditions. If the~~is erosion~~ increased tidal prism leads to unintentional breaches, there is the potential for substantial erosion. This issue is addressed in Impact H-3, “Increased Risk of Property Damage, Injury, or Death as a Result of Flooding,” in Chapter 3, “Hydrology.”

This impact is considered significant. Implementation of Mitigation Measure H-1, “Repair Unintended Levee Breaches,” would reduce this impact to a less-than-significant level. This measure is described in Chapter 3, “Hydrology.”

8.2.5 Salinity Reduction Option 1C: Napa River and Napa Slough Discharge with Breaches of Ponds 3 and 4/5

Impacts under Salinity Reduction Option 1C (Impacts Geo-1, Geo-3, Geo-4, Geo-5, Geo-6, Geo-7, and Geo-8) are nearly the same as those under Salinity Reduction Option 1B. Salinity Reduction Option 1C would also include the breaching of Pond 4/5, resulting in the potential for additional erosion. However, the impact conclusions and mitigation for this option are the same as for Salinity Reduction Option 1B.

8.2.6 Salinity Reduction Option 2: Napa River and San Pablo Bay Discharge

Impacts under Salinity Reduction Option 2 (Impacts Geo-1, Geo-3, Geo-4, Geo-5, Geo-6, and Geo-7) are nearly the same as those under Salinity Reduction Option 1A, except that construction associated with the water control structures would be more extensive. Because all such construction would be completed in accordance with applicable codes, no additional impacts are anticipated. All impacts remain less than significant, and no mitigation is required.

8.2.7 Water Delivery Option

Potential impacts associated with the construction of the Water Delivery Option differ from those associated with the salinity reduction options. Impacts Geo-1, Geo-2, Geo-3, Geo-7, and Geo-8 are not applicable to the Water Delivery Option because they are specific to levees and conditions in the ponds. Potential impacts Geo-4, Geo-5, and Geo-6 are similar to the impacts associated with the salinity reduction options; the differences are described below. In addition, the Water Delivery Option potentially results in two other impacts (Geo-9 and Geo-10), as described below.

8.2.7.1 Impact Geo-4: Landslide, Lateral Spreading, Subsidence, Liquefaction, or Collapse as a Result of Construction on Unstable Soils

Water Delivery Project Component (Sonoma Pipeline)

As discussed above in “Project Setting,” the soils along sections of the Sonoma Pipeline corridor are susceptible to liquefaction or failure during a seismic event. However, no structures other than the pipeline would be constructed on such soils. Operation of the pipeline would not affect ground stability. This impact is considered significant. Implementation of Mitigation Measure Geo-2 would reduce this impact to a less-than-significant level.

Mitigation Measure Geo-2: Remove Unstable or Expansive Soils and Backfill with Engineered Fill

In the event that unstable geologic units or soils are encountered during pipeline construction, the contractor will remove such materials and will backfill the pipeline section with engineered fill meeting the required specifications for compaction and shear strength.

Water Delivery Project Component (Napa Pipeline)

Similar to the Sonoma Pipeline, segments of the Napa Pipeline have soils that are susceptible to liquefaction or failure during a seismic event. This impact is considered significant. Implementation of Mitigation Measure Geo-2, “Remove Unstable or Expansive Soils and Backfill with Engineered Fill,” would reduce this impact to a less-than-significant level. This measure is described above.

Water Delivery Project Component (CAC Pipeline)

Similar to the Sonoma and Napa Pipeline, segments of the CAC Pipeline have soils that are susceptible to liquefaction or failure during a seismic event. This impact is considered significant. Implementation of Mitigation Measure Geo-2, “Remove Unstable or Expansive Soils and Backfill with Engineered Fill,” would reduce this impact to a less-than-significant level. This measure is described above.

Water Delivery Program Component

The exact alignments and construction methods for the Program Component pipelines have not yet been determined; however, impacts relative to unstable geologic units and soils for the potential future pipelines could be generally similar in nature and scope to those described above for the currently proposed pipelines. This impact is considered significant. Implementation of Mitigation Measure Geo-2, “Remove Unstable or Expansive Soils and Backfill with Engineered Fill,” would reduce this impact to a less-than-significant level. This measure is described above.

8.2.7.2 Impact Geo-5: Risk to Life or Property as a Result of Construction of Structures on Expansive Soils

Water Delivery Project Component

Expansive soils could be encountered during trenching and construction of the Sonoma Pipeline. This impact is considered significant. Implementation of Mitigation Measure Geo-2, “Remove Unstable or Expansive Soils and Backfill with Engineered Fill,” would reduce this impact to a less-than-significant level. This measure is described under Impact Geo-4 above.

Water Delivery Program Component

Impacts relative to expansive soils for the potential future pipelines would be similar in nature and scope to those described above for the currently proposed pipelines. This impact is considered significant. Implementation of Mitigation Measure Geo-2, “Remove Unstable or Expansive Soils and Backfill with Engineered Fill,” would reduce this impact to less-than-significant level. This measure is described under Impact Geo-4 above.

8.2.7.3 Impact Geo-9: Exposure of People or Structures to Potential Adverse Effects as a Result of Fault Rupture, Ground Shaking, or Ground Failure

Water Delivery Project Component (Sonoma Pipeline)

Because of the passive nature of operation of the Sonoma Pipeline, the short-term nature of construction activities along the corridor, and the lack of people or structures in proximity to the project, construction and operation of the Sonoma Pipeline would not expose people or structures to potential adverse impacts (including the risk of loss, injury, or death). In the event that a seismic event were to damage the pipeline, shutoff valves would prevent flooding from reclaimed water, and no potential significant impacts on people or structures are expected relative to exposure to reclaimed water. This impact is considered less than significant. No mitigation is required.

Water Delivery Project Component (Napa Pipeline)

The Napa Pipeline would have similar construction and operation impacts as those described above for the Sonoma Pipeline. This impact is considered less than significant. No mitigation is required.

Water Delivery Project Component (CAC Pipeline)

The CAC Pipeline would have construction and operational impacts similar to those described above for the Sonoma Pipeline. This impact is considered less than significant. No mitigation is required.

Water Delivery Program Component

The exact alignments and construction methods for the Program Component pipelines have not yet been determined. Impacts related to fault rupture, ground shaking, and ground failure for the potential future pipelines would be comparable to those for the Project Component, except that they would be experienced over a larger area. Construction and operation of the pipelines would be similar to that of the Project Component, and recycled water pipeline breakage would not be expected to threaten people or structures over the larger program area. This impact is considered less than significant. No mitigation is required.

8.2.7.4 Impact Geo-10: Substantial Soil Erosion or Loss of Topsoil

Water Delivery Project Component (Sonoma Pipeline)

Trenching and construction activities for the Sonoma Pipeline could cause some loss of topsoil on and near the pipeline corridors. However, such activities would be carried out in compliance with applicable regulations and standards related to erosion control during construction projects. Implementation of standard on-site BMPs (e.g., sandbags, silt screens, watering of dry exposed soils) would minimize soil erosion or loss of topsoil. Operation of the Sonoma Pipeline would not contribute to significant erosion or loss of topsoil because the pipeline would be buried below grade, and water delivered under this option would be applied to the salt ponds in a manner that would not cause or contribute to soil erosion at the project site. This impact is considered less than significant. No mitigation is required.

Water Delivery Project Component (Napa Pipeline)

The Napa Pipeline would be constructed in a similar fashion to the Sonoma Pipeline, and would have similar soil erosion impacts. This impact is considered less than significant. No mitigation is required.

Water Delivery Project Component (CAC Pipeline)

The CAC Pipeline would be constructed in a similar fashion to the Sonoma Pipeline, and would have similar soil erosion impacts. This impact is considered less than significant. No mitigation is required.

Water Delivery Program Component

The exact alignments and construction methods for the Program Component pipelines have not yet been determined; however, the construction and operation of each of the potential future pipelines could have erosion impacts similar in scale to those for the currently proposed pipelines. The potential future pipelines from the surrounding WWTPs would not be expected to cause or contribute to substantial soil erosion with implementation of standard construction practices, similar to those of the Sonoma, CAC, and Napa Pipelines. This impact is considered less than significant. No mitigation is required.

8.2.8 Habitat Restoration Option 1: Mixture of Tidal Marsh and Managed Ponds

Impacts under Habitat Restoration Option 1 (Geo-1, Geo-4, Geo-5, Geo-6, Geo-7, and Geo-8) are similar to impacts under Salinity Reduction Option 1C because exterior levees would be breached in both cases. However, more levees would be breached, and the breaches would be wider under Habitat Restoration Option 1 than under Salinity Reduction Option 1B or 1C. The key differences between the impacts under the two options are described below.

8.2.8.1 Impact Geo-1: Levee Failure as a Result of Strong Seismic Ground Shaking

As discussed previously, the project site is likely to undergo strong ground shaking from a major earthquake within the next 30 years. Smaller seismic events are also likely to occur during this timeframe, and the site is located on unconsolidated sediments, which are known to amplify and prolong seismic ground shaking. Levees, water control structures, utilities, and recreational facilities are thus at risk of damage from strong seismic ground shaking.

Under this option, repairs and maintenance of existing levees and water conveyance/control structures would be performed as required to maintain the integrity of these structures. In addition, new recreational facilities would be engineered to withstand seismic events to the extent practicable. Because of the repairs, proper engineering of new facilities, and ongoing maintenance, this impact is considered less than significant. No mitigation is required.

8.2.8.2 Impact Geo-4: Landslide, Lateral Spreading, Subsidence, Liquefaction, or Collapse as a Result of Construction on Unstable Soils

The project site is underlain almost exclusively by unconsolidated sediments, including Bay Mud. Bay Mud exhibits high compressibility and low shear strength. However, the site levees have been in place since the 1850s, and the site has not experienced landslides, lateral spreading, subsidence, liquefaction, or collapse. The implementation of Habitat Restoration Option 1 would not increase the risk of any of these hazards.

Repair and maintenance of existing levees would include fill placement and construction on the levees. These activities may impose excess loads on the unstable substrate, potentially leading to subsidence and/or differential settlement. Localized loading (e.g., as a result of levee construction) would likely increase substrate shear stresses and has the potential to result in levee failure if design or construction is inadequate or inappropriate. However, these structures would be engineered to withstand seismic events to the extent practicable. New recreational facilities would also be designed in accordance with applicable codes. These structures would be engineered to be seismically resistant. Therefore, this impact is considered less than significant. No mitigation is required.

8.2.8.3 Impact Geo-5: Risk to Life or Property as a Result of Construction of Structures on Expansive Soils

Soils at the project site are expansive, exhibiting shrink-swell behavior. Although these soils are expansive, any new structures such as recreational facilities would be constructed in accordance with applicable engineering standards and building codes. Thus, shrink-swell behavior would not pose a risk of personal injury, loss of life, or damage to property in the restored tidal marshlands. Although the expansive soils have the potential to affect levees, the levees at the site are not used for flood control. Therefore, this impact is considered less than significant. No mitigation is required.

8.2.8.4 Impact Geo-6: Flooding of the Project Area as a Result of Tsunamis

As described earlier, based on modeling by Garcia and Houston (1975), the study area could potentially be inundated by tsunamis. Because the final elevation of the marsh and associated levees is undetermined at this time, the effect of a tsunami is uncertain. However, it is known that the gradients at the site would be very gentle, thus increasing the effect of any tsunami. Because the site consists of tidal marsh and managed ponds, inundation of the project area is not of concern for the environment.

The existing levees are not designed as flood protection levees; thus, removal or breaching of any of the levees would not affect the risk of flooding of the project area by a tsunami. The project site would remain a recreational use area during habitat restoration. Consequently, risk of personal injury or loss of life as a result of tsunami inundation would not be increased by Habitat Restoration Option 1. Recreational users and operations and maintenance staff would be protected from all but proximally generated events by the NOAA's tsunami warning system. This impact is considered less than significant. No mitigation is required.

8.2.8.5 Impact Geo-7: Potential Erosion as a Result of Excess Pond Water Height

The potential for levee erosion increases as the water level in the ponds increases. Higher water levels in the ponds retained as ponds either in the interim or in the long term would result in larger, more powerful waves, as well as the potential for overtopping during significant storm events. Both of these factors would increase the rate of levee erosion. This impact is considered significant. Implementation of Mitigation Measure Geo-1, "Maintain Water Level 2 Feet below Levee Crest," would reduce this impact to a less-than-significant level. This measure is described under Salinity Reduction Option 1B.

8.2.8.6 Impact Geo-8: Potential Erosion as a Result of Increased Tidal Prism

Under Habitat Restoration Option 1, three ponds (Ponds 3 and 4/5) would be opened to substantial tidal action through levee breaches. Levee breaches for habitat restoration would be more extensive than levee breaches required during desalination. Some of these levee breaches would be located along the Napa River, and others would be located along the sloughs. As the river and sloughs widen to historical widths, both accreted marsh and existing levees may be subject to erosion.

Breaching of the existing levees would result in an increase in the tidal prism, potentially resulting in increased erosion in the nearby sloughs and along the Napa River. Depending on the increase in tidal volume, the existing sloughs could both deepen and widen. As the tidal prism increases, erosion of the sides and substrates of the interior and exterior sides of levees, including existing marsh slough margins, would increase. Finally, with breached levees, pond bottoms could also be subject to erosion.

This impact is considered significant. Implementation of Mitigation Measures H-1, "Repair Unintended Levee Breaches," H-3, "Refine Project Design to Limit Adverse Effects of Increased Tidal Discharge," and H-4, "Evaluate Susceptibility of Levees to Wind-Driven Wave Erosion and Conduct Repairs as Needed," would reduce this impact to a less-than-significant level. These measures are described in Chapter 3, "Hydrology."

8.2.9 Habitat Restoration Option 2: Tidal Marsh Emphasis

More levees would be breached under Habitat Restoration Option 2 than under Habitat Restoration Option 1. The number of ponds opened to substantial tidal prism is greatest in Habitat Restoration Option 2. Impacts under this option are nearly the same as those under Habitat Restoration Option 1 for Impacts Geo-1, Geo-3, Geo-4, Geo-5, and Geo-6. Impacts Geo-7 and Geo-8 are slightly different and are described below.

8.2.9.1 Impact Geo-7: Potential Erosion as a Result of Excess Pond Water Height

The potential for levee erosion from excess water height in the ponds retained as ponds is also significant for Habitat Restoration Option 2, although fewer ponds would be retained as ponds under this option. This impact is considered significant. Implementation of Mitigation Measure Geo-1, "Maintain Water Level 2 Feet below Levee Crest," would reduce this impact to a less-than-significant level. This measure is described under Salinity Reduction Option 1B.

8.2.9.2 Impact Geo-8: Potential Erosion as a Result of Increased Tidal Prism

Under Habitat Restoration Option 2, five ponds and part of one pond (Ponds 3, 4/5, and 6/6A, and the eastern half of Pond 2) would be opened to substantial tidal action through levee breaches. Breaching of the existing levees would result in an increase in the tidal prism. The resulting tidal prism is the largest encountered in any of the options.

The increase in tidal prism could result in increased erosion in the nearby sloughs and along the Napa River. The existing sloughs would likely both deepen and widen. As the tidal prism increases, erosion of the sides and substrates of the interior and exterior sides of levees, including existing marsh slough margins, could also increase. Finally, with breached levees, pond bottoms could also be subject to erosion.

This impact is considered significant. Implementation of Mitigation Measures H-1, "Repair Unintended Levee Breaches," H-3, "Refine Project Design to Limit Adverse Effects of Increased Tidal Discharge," and H-4, "Evaluate Susceptibility of Levees to Wind-Driven Wave Erosion and Conduct Repairs as Needed," would reduce this impact to a less-than-significant level. These measures are described in Chapter 3, “Hydrology.”

8.2.10 Habitat Restoration Option 3: Pond Emphasis

Fewer ponds would be opened to substantial tidal action, and therefore fewer levee breaches would be required under Habitat Restoration Option 3 than under Habitat Restoration Option 1. Impacts under this option are nearly the same as those under Habitat Restoration Option 1 for Impacts Geo-1, Geo-3, Geo-4, Geo-5, and Geo-6. Impacts Geo-7 and Geo-8 are slightly different and are described below.

8.2.10.1 Impact Geo-7: Potential Erosion as a Result of Excess Pond Water Height

The potential for levee erosion from excess water height in the ponds retained as ponds is potentially significant for Habitat Restoration Option 3, because all but two ponds would be retained as ponds under this option. This impact is considered significant. Implementation of Mitigation Measure Geo-1, “Maintain Water Level 2 Feet below Levee Crest,” would reduce this impact to a less-than-significant level. This measure is described under Salinity Reduction Option 1B.

8.2.10.2 Impact Geo-8: Potential Erosion as a Result of Increased Tidal Prism

Under Habitat Restoration Option 3, only two ponds (Ponds 3 and 4) would be opened to substantial tidal action through levee breaches. Breaching of the existing levees would result in an increase in the tidal prism. The resulting tidal prism would be the smallest encountered in any of the habitat restoration options.

The increase in tidal prism could result in increased erosion in the nearby sloughs and along the Napa River. The existing sloughs could both deepen and widen, although the degree of erosion would likely be less than for any of the other habitat restoration options. As the tidal prism increases, erosion of the sides and substrates of the interior and exterior sides of levees, including existing marsh slough margins, could also increase. Finally, with breached levees, pond bottoms could also be subject to erosion.

This impact is considered significant. Implementation of Mitigation Measures H-1, “Repair Unintended Levee Breaches,” H-3, “Refine Project Design to Limit Adverse Effects of Increased Tidal Discharge,” and H-4, “Evaluate Susceptibility of Levees to Wind-Driven Wave Erosion and Conduct Repairs as Needed,” would reduce this impact to a less-than-significant level. These measures are described in Chapter 3, “Hydrology.”

8.2.11 Habitat Restoration Option 4: Accelerated Restoration

Under Habitat Restoration Option 4, various design features have been added that would accelerate marsh evolution compared with Habitat Restoration Option 1. Impacts under this option are nearly the same as those under Habitat Restoration Option 1 for Impacts Geo-1, Geo-3, Geo-5, and Geo-6. Impacts Geo-4, Geo-7, and Geo-8 are slightly different and are described below.

8.2.11.1 Impact Geo-4: Landslide, Lateral Spreading, Subsidence, Liquefaction, or Collapse as a Result of Construction on Unstable Soils

Repair and maintenance of existing levees as well as construction of interior berms and peninsulas would include fill placement and construction on and adjacent to the levees. These activities may impose excess loads on the unstable soil substrate, potentially leading to subsidence and/or differential settlement. Localized loading (e.g., as a result of levee construction) would likely increase substrate shear stresses and has the potential to result in levee failure if design or construction is inadequate or inappropriate. However, the levees and interior berms would be engineered to withstand seismic events to the extent practicable. New recreational facilities would also be designed in accordance with applicable codes. These structures would be engineered to be seismically resistant. Therefore, this impact is considered less than significant. No mitigation is required.

8.2.11.2 Impact Geo-7: Potential Erosion as a Result of Excess Pond Water Height

The potential for levee erosion from excess water height in the ponds retained as ponds is also significant for Habitat Restoration Option 4, because Ponds 6, 6A, 7, 7A, and 8 would be retained as ponds under this option. This impact is considered significant. Implementation of Mitigation Measure Geo-1, “Maintain Water Level 2 Feet below Levee Crest,” would reduce this impact to a less-than-significant level. This measure is described under Salinity Reduction Option 1B.

8.2.11.3 Impact Geo-8: Potential Erosion as a Result of Increased Tidal Prism

Under Habitat Restoration Option 4, three ponds (Ponds 3 and 4/5) would be opened to substantial tidal action through levee breaches. Breaching of the existing levees would result in an increase in the tidal prism. However, the increase in tidal prism would be reduced by importing sediment to create a 100-

acre fill area and increasing the number of starter channels and berms. The duration of the increased tidal prism would be reduced because the added design features included in this option would accelerate the formation of new marsh.

The increase in tidal prism could result in increased erosion in the nearby sloughs and along the Napa River. The existing sloughs could both deepen and widen, although the degree of lateral erosion may be lessened by pre-dredging the slough channels. As the tidal prism increases, erosion of the sides and substrates of the interior and exterior sides of levees, including existing marsh slough margins, could also increase. Finally, with breached levees, pond bottoms could also be subject to erosion.

This impact is considered significant. Implementation of Mitigation Measures H-1, “Repair Unintended Levee Breaches,” H-3, “Refine Project Design to Limit Adverse Effects of Increased Tidal Discharge,” and H-4, “Evaluate Susceptibility of Levees to Wind-Driven Wave Erosion and Conduct Repairs as Needed,” would reduce this impact to a less-than-significant level. These measures are described in Chapter 3, “Hydrology.”